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# Conditions for Resilient Operations of Complex Systems Undergoing Technological Alterations

Thesis for the degree of Philosophiae Doctor

Trondheim, May 2014

Norwegian University of Science and Technology
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Camilla Knudsen Tveiten

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## Abstract

Technological alterations are ongoing in many areas, also in high-risk industries. The petroleum production industry in Norway is going through a technologically-driven transition period named "Integrated Operations" (IO). The transition includes changes in sensor technology that increase the amount of data provided for important decisions, information and communication technology that enable the remote operation of offshore fields and distributed organizations, and possibilities for operations in marginal fields where oil and gas production was not previously possible. Transitions have been a part of petroleum operations for as long as the industry has existed in Norway – companies merge and new fields are developed. Whereas technological development has followed a continuous path, in other ways IO represents a change due to the dramatic impact it has on its dependence on the geographical location of the actors.

Outside IO there is a quite a dramatic change in the industry as we move towards the end of the petroleum age. Changing public opinion following accidents such as that in the Gulf of Mexico in 2010 as well as climate challenges represents a threat to expanding production.

The dissertation explores 1) the establishing of risk images in an early phase of the development of IO and how risks are differently comprehended in different groups of people, 2) how system risk models can be used to understand how risks may emerge in complex systems as IO, and 3) how emergency handling can benefit from a resilience perspective with IO. The results indicate that altered risk images are formed at an early stage of a (technological) development. Participation in different communities of knowing determines the comprehension of risks. Risk comprehension is influenced by technology optimism as well as one's position in groups such as being part of the management or being responsible for implementation of new concepts or technology. I found that the industry still relied on traditional risk assessment, and that areas where the technological development will have great impact, such as in emergency management did not enter a significant transition period during the period of this study.

I have argued that IO is representative of the time in which it exists – not only something restricted to the oil and gas industry. The trends are not unique. Neither are some of the challenges identified for IO, especially when it comes to the comprehension and handling of risks. By that I find that the results from my work matter for the world outside IO – in healthcare, transport, energy, transport infrastructure, finance and telecommunications.

## Foreword

The dissertation is submitted as a fulfillment of the requirement for the degree Philosophiae Doctor (PhD) at the faculty of Sociology and Political Science, Norwegian University of Science and Technology (NTNU), Trondheim, Norway.

The work has been mainly funded by the Center for Integrated Operations in the Petroleum Industry which is a center for research based innovation at NTNU together with SINTEF and the Institute for Energy Technology (Ife). In addition, the faculty of Sociology and Political Science at NTNU has partly funded the work.

The dissertation consists of four papers and an additional introductory part that presents the background for the work including the research questions, theoretical background, review of existing work within the field of this dissertation, a summary of the papers and main results.

# Table of contents

List of tables and figures

## Tables



## Figures

**Papers**

| | | |
|---|---|---|
| Paper 1: | Risk images in a changing high risk industry | Published in Risk Management (Palgrave), (16:1)February 2014, Pages 44-61 |
| Paper 2: | Safety perception and comprehension among offshore installation managers on the Norwegian Continental Shelf | Invited for submission to special issue in Safety Science after Working on Safety conference at Røros, 2010. Still under review by Safety Science. |
| Paper 3: | Resilient planning of modification projects in high-risk systems: The Implications of Using FRAM for Risk Assessments | Chapter in **Albrechtsen, E and Besnard, D** (eds.) (2013): Oil and Gas, Technology and Humans. Assessing the Human Factors of Technological Change |
| Paper 4: | Building resilience into emergency management | Published in Safety Science, (50: 10) December 2012, Pages 1960-1966 |

# 1 Introduction

## 1.1 Technology in organizational and safety research – an area that needs more attention

In general, organizational research studies do not address technology as a premise for change or as an actor in alterations on the safety level. However, some researchers address this gap (see a good overview by Orlikowski & Barley, 2001) and claim that socio-technical system theorists have increasingly framed technology as a process that requires input and output. Hence, the technology has become more like a "black box." Principally, safety research regards technology both as a contributor to risk scenarios and as a mitigator working as a barrier, but still treats technology as a "black box," an artifact that humans must comprehend and handle (Perrow, 1986; B. A. Turner, 1978; Turner & Pidgeon, 1997; Weick & Sutcliffe, 2001, 2007).

In this introduction I will argue that technology must be taken much more into account in safety studies. I claim that we have to give more attention to the technology that surrounds workers in high-risk environments and the understanding that technology works as an actor in the socio- technical system, realizing that technology may not only alter our individual and interactive behavior, but also our work processes. This is not only something we must handle; technology alters our perspectives and limits of comprehension. It can most certainly be claimed that our perception of risk is influenced by the introductiuon of new technology.

Today it has become quite normal for technology to be introduced, and this implies reforms and changes in high-risk organizations and systems (the term "high-risk organizations" refers to the HRO concept first introduced in LaPorte & Consolini, 1991). Technology that is introduced sometimes has a strong influence on how workers and experts in organizations communicate and relate to each other and on how work time is spent. The development of technology seems to be self-preservative – a process that is faster, better and sometimes cheaper. Devices are sometimes introduced in the early phases of technology development, and updates and new models are introduced before the previous one has become a part of normal life. This may be particularly true for information and communication technology (ICT). It is a characteristic of our modern society that technology is tested in real life, sometimes also in working life, with positive as well as negative implications. Good or bad, this implies that the development of technology is inherently connected to social life and we can argue that technology developed today for use by society and work at large is part of a socio-technical system, in which it may be difficult to see the technological and societal aspects as significantly distinct.

Organizations that operate high-risk systems such as those involved in oil and gas production experience changes, just like other organizations. Normally, changes in high-risk organizations are evaluated in terms of how they impact safety issues. The goal should be that the changes will not result in the impairment of safety issues – the state of the HSE[1] should remain the same or the safety level should be increased (R. Flin, Slaven, & Carnegie, 1996). However, occasionally we experience changes that are not recognized as being relevant to safety, or safety studies are performed in a very early phase when the changes are still not experienced and the changes are unpredictable. Hence, the descriptions of the changes are underspecified, and therefore different studies are required in order to obtain a valid picture of the changes to the risks.

Modern technology differs from much of the earlier technology when it comes to how much latitude people have when interacting with it. Conventional technology such as a production line does not leave much room for variable action, whereas modern information ICT often demands interaction and adaptive behavior. Modern technology is also more like a "black box" for the user: we know that it works, but not how it works. Thus, it is difficult to understand how people and technology interact – the socio-technical system has become more complex and intractable.

## 1.2 Different leeway for action – revitalization of the socio-technical perspective

Whereas different organizational models have been introduced as a means for obtaining behavioral patterns (workflow, information and communication lines, etc.), technology – especially communication and information technology as well as data-providing technology – may have a greater influence on the way people work and relate to each other. Tasks that are to be completed are always within an environment. However, technology and organization are two major elements in this environment, and these two constitute the room for action or leeway provided for people. The performance of tasks will be adjusted to technology and organization. Thus, the leeway for actors in changing environments varies depending on how systems are set up, i.e. regarding rules, sanctions, and choices of actions. Modern technology in organizations seems to open a large leeway for actors in the system and rules seem to be set up ad hoc (e.g. the use of social networks, rules for e-mails, data access, etc.).

[1] HSE means Health, Safety and Environment – in Norwegian Helse, Sikkerhet og miljø (HMS).

Technology has had an impact on work and practice since the early days. I will not focus on the early developments in technology, but on the development of modern ICT and technology for information processing and visualization that has influenced working life over the past three decades. Technology as a premise of change, and how the technology influences organizational changes, has been studied and presented in several interesting publications (e.g. Heath & Luff, 2000). However, risk and safety is not an issue in these studies. Most research on IT and organizational change has focused on adaptation and change within single organizations. Macro-social and cultural elements are assumed to be unproblematic constants (Yates & Maanen, 2001). However, this observation implies that there may be a need to develop a new risk perspective on technology and transitions in high-risk organizations.

Since the start of the twentieth century, several perspectives on organizational safety have been presented – regarding how organizational aspects may influence safety and risk. Apparently, reference texts have been published since the mid to late part of the twentieth century (see, for example, Haddon, 1980; LaPorte & Consolini, 1991; Pidgeon & O'Leary, 2000; Rasmussen, 1997; Reason, 1990, 1997; Vaughan, 1996; Weick & Sutcliffe, 2001, 2007). In reality, technological aspects and factors are sparingly addressed in these perspectives. However, technology will be an issue of concern as well as people's use of the technology (usually referred to as competence and skills). Safety, technology and organization will depend on each other and the dependency and the coupling between safety, organization and technology will become especially important when alterations occur, in either component. Hence, I will claim that it is an imperative to revitalize the socio-technical perspective in safety studies, in order to introduce a more comprehensive and complete theoretical approach to safety studies.

### *Risk images of technological alterations and social construction*

Risk perceptions of new technology and technology-related changes have been studied as individual risk perceptions (e.g. Jaafar et al., 2007; Sjøberg, 1999; Tichy, 2004). In general, differences are found in risk perception, but as I see it, how this influences the forming of risk images in a society or in an organization has not been thoroughly dealt with. From my understanding of former studies of the introduction of new technology in high-risk surroundings, I argue that technology introduced in organizations or societies cannot be understood by itself, but only through our own understanding of how it is used and how it influences our reality. This means that the interpretation of technology and how this influences our reality in relation to possible changes in risks are constructs. Risk images of new technology are formed as social constructs as the individual risk perceptions of the changed realty are negotiated in dialog with and in social interaction between stakeholders, appliers and consumers of the technology.

## 1.3 Integrated operations – an interaction with considerable leeway for action

As a general framework for my study on safety in relation to technological changes, I have focused on the introduction of new technology in the oil and gas industry that has introduced a "step change" in how oil and gas operations are/can be carried out. This is an area where the action span for the actors of high-risk operations is wide due to the fact that the technology influences large parts of their work while giving considerable leeway to making the most of it in an efficient and safe manner.

The technological change Integrated Operations (IO) was initially introduced as a technological development that would improve existing production and expand the possibility of new fields of production of oil and gas on the Norwegian continental shelf (referred to as NCS), linked to the oil and gas companies' desire for lower costs, more efficient reservoir management and fewer mistakes during well drilling that will eventually raise profits and make more oil fields economically viable. The change in operation made by new technology has had different names such as "Smart fields" (SHELL), "Smart wells" (Schlumberger), "eOperation" (Hydro), "Field of the future" (BP), "eField" (Norwegian Petroleum Directorate), "i-field" (Chevron), "Real-time operations" (Halliburton), "Digital oilfield of the future/DOFF" (CERA), and "Intelligent field optimization and remote management/INFORM" (Cap Gemini) (a description of the different concepts can be found in OLF, 2006a). Since 2005, the term Integrated Operations (IO) has been used, mainly influenced by OLF and the major petroleum operating company in Norway, Statoil.

Integrated Operations (IO) was developed as a description of the development of new ways of operating in oil and gas drilling and production on the Norwegian continental shelf as the general trend is towards the development of smaller and a greater number of deep-water fields where incomes and expenditure, as well as practical obtainable solutions, demand remote and cost-efficient operations ("tail production"). From the viewpoint of most researchers, IO is a technologically driven development, or, from the viewpoint of representatives of companies, a business-driven development with a technological enabler. Hence, the main changes can be categorized by technology, distributed work, and business opportunities:

**Technology:** IO includes the use of integrated real-time data technology and increased use of automation and remotely controlled operations.

**Distributed work:** Improved information and communication technology enables the comprehensive use of distributed work, across organization borders or geographically located at different sites. "Around the clock" or 24/7 (24 hours a day, 7 days a week) work onshore offers possibilities for global network organizations with "follow the sun" principles, where distributed work includes work across national and cultural borders.

**Business opportunities:** IO is seen as an opportunity to expand the life expectancy of existing installations with more extensive use of onshore planning, support and operation, and correspondingly a reduction in offshore staff. Also, new fields ("tail production" or "brown fields") that were not considered as good business cases can be developed due to more efficient operations and improved technology.

The implementation of IO has been presented in the literature as a development that would be implemented in two stages, referred to as *Generation 1* and *Generation 2*. Figure 1 below was originally developed for the 2005 OLF report on "Integrated work processes: Future work processes on the Norwegian continental shelf." The description of the concept of two generations has attracted much attention and will therefore be thoroughly presented here.

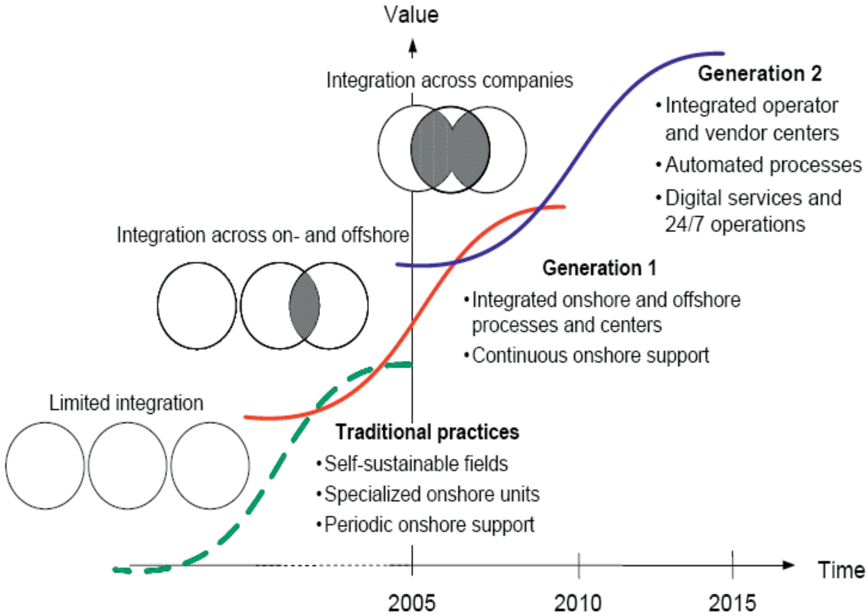


**Figure 1 "Integrated work processes will most likely be implemented in two steps."**

*From the report "Integrated work processes: Future work processes on the Norwegian continental shelf" (OLF, 2005)*

The development of IO as described in Figure 1 goes through two stages in addition to the so-called "traditional practices." The traditional practice is described as operations with limited integration between on- and offshore units. Changes to traditional practices are already seen in 2005 within well planning and well execution, where processes are more integrated. Though limited by organizational borders, production optimization is executed by offshore operators with some support from onshore experts and maintenance management that has evolved from preventive maintenance to condition-based maintenance, along with some integrated work between disciplines. In the second stage, named "IO Generation 1," decisions are jointly made by onshore and offshore teams, working in integrated on- and offshore centers and collaborating in real time. Personnel onshore monitor the operations, identify operational and safety-related problems, and discuss actions with and support offshore personnel in the implementation phase. Off-the-shelf technologies, like high-quality audio and video systems, are used extensively. In the third stage, "IO Generation 2," installations and subsea fields are operated from integrated onshore centers that are manned 24 hours a day, seven days a week. There can be several locations involved, and vendors can be given responsibility for handling processes that were previously managed by the operators themselves. There is extensive use of digital services and changes in responsibility within the offshore control rooms. Information overload should be limited by "automatic filtering" and the automation of processes and decisions. Parties cooperate over the Internet on a 24/7 basis, and tasks are carried out according to "follow the sun or around the clock" principles. The second generation of IO is expected to become evident in the period 2010–2015. In the report it is stated that development towards second-generation IO requires several adaptations. Some of them are technological: digital infrastructure, information security framework and data standards. The technologies for instrumentation, real-time gathering of data and real-time optimization were, in 2005, still expensive and immature. Thus, further development of these technologies was required for the successful implementation of IO.

### 1.3.1 Technological alterations within IO

The foreseen development is illustrated by the S-curve shapes. The S-curve model in Figure 1 shows the development towards an alternative way of operating, as a process that will follow predetermined steps or phases. It indicates that it is possible to predict the stage of development in the close or more distant future. S-curves are normally used to describe how technologies evolve. It is common belief that most new technologies follow a similar technology maturity life cycle describing the technological maturity of a product. The theory is that innovations spread through society in an S-curve (Rogers, 1962). S-curves have also been used in research and development strategy planning to evaluate the maturity of technology or products (Mann, 1999). The use of S-curves in the OLF figure is an indication that IO is seen as a technological development. The paradox is that the stages described in Figure 1 are mainly of an organizational nature. The model seen in relation to present observed reality is also interesting. Still by the end of 2013, parts of the oil and gas industry in Norway may be at stage 1; others are at, or on their way to, stage 2, whereas some fields may be characterized as having reached this level of offshore-onshore integration. Typically, more newly developed fields and subsea installations are operated closer to stage 2 of IO with more control and operation from onshore and integrated contracts with contractors that are more interwoven in what resembles distributed organizations. Older fields with more traditional installations, however, have adapted to IO by developing onshore support and leaner organizations offshore that rely on communication with onshore support and expertise in their operations. The industry as a whole exists in all stages, in parallel, at any time. Some new fields are planned for the full implementation of these kinds of technical and operational solutions, but even in these instances there seem to be blurred boundaries between traditional and "new" ways of operating in both the technological and the organizational arenas.

### 1.3.2 Stakeholders/actors in the development of IO

There have been several stakeholders in the development of IO, and their risk images of the technological alterations were of interest to me at the beginning of my work with this thesis:

*The Norwegian Oil and Gas Association (Norsk olje og gass), formerly known as the Norwegian Oil Industry Association (OLF[2]),* is a professional body and employers' association for oil and supplier companies engaged in the field of exploration and production of oil and gas on the NCS. In 2004, the OLF established a "Steering Group for Digital Services," later becoming OLF's priority area in IO. The steering group represented the offshore industry. In a presentation from their first meeting, the steering group stated that they would work for the acquisition of real-time data, the availability of a digital infrastructure offshore, information security, a data integration platform to provide quality information, integrated work processes (drilling, reservoir/production and operation/maintenance), new products and services based on real-time data, and the establishment of forums for dialog about IO with all the stakeholders (N. O. I. A. OLF, 2004). The OLF's work on IO lasted until 2010 and has resulted in many reports in the field, most of which are referred to in this thesis.

The center for IO in the petroleum industry (IO Center) is hosted by the Norwegian University of Science and Technology, where research, innovation and education within the IO field to promote accelerated production, increased oil recovery, reduced operating costs and enhanced safety and environmental standards are carried out. It receives funding from the Norwegian Research Council as well as from partners (oil and gas operating companies and contractors). During the first five years the IO Center established four cornerstones or research fields ("drilling and well construction," "reservoir management and production optimization," "operation and maintenance" and "integration across disciplines"), hence, the IO Center includes research within all fields related to the operation of oil and gas production facilities. The IO Center conducts research, innovation and education within the field of IO, to promote increased oil recovery, accelerated production, reduced operating costs, and enhanced safety and environmental standards. In the first research period (2007–2011) these four topics were addressed through four different programs: (1) drilling and well construction, (2) reservoir management and production optimization, (3) operation and maintenance, and (4) new work

[2] I will use the abbreviation OLF in this thesis as this was the name of the organization during my main work with this thesis.

processes and enabling technology. The IO Center is governed by representatives from both the industry and the center's many research partners.

*The Petroleum Safety Authority (PSA)* is the regulatory authority for technical and operational safety, including emergency preparedness, and for the working environment. Their regulatory role covers all phases of the industry, from planning and design, through to construction and operation, to possible ultimate removal. The PSA has held its focus on IO from the beginning of 2005, by financing research within the field, and has arranged for workshops where HSE and ICT security aspects of IO have been debated. They have especially focused on HSE. On their web page they state that the PSA will help reduce the risk of introducing IO, partly by investigating the possible significance of ICT developments for HSE, and that the PSA will be a prime mover in ensuring that the new technology contributes to HSE improvements, not least by encouraging the use of IO when the industry further develops HSE management.

*Operators, contractors and smaller service companies:* All operating companies as well as contractors and vendors that operate on the NCS are to some extent involved in the development of IO. Some are more prominent than others and different companies have played special roles in some areas of development. Drilling contractors have been the driving force in developing ICT solutions for well operations. The companies generally speak of life extension and the more efficient production of oil and gas fields due to IO. In relation to IO, HSE is addressed, although it is not as much a priority as the development of IO.

# 2 Existing research

In order to illustrate the relevant research for the topic of this thesis, I have identified four areas of existing research; (1) Risk and safety within IO, (2) Risk images and risk construction in different groups, (3) Emergency handling in distributed surroundings, focusing on technology-supported emergency handling, and (4) Use of system-based models in risk assessments with a special focus on the Functional Risk Analysis Method (FRAM).

## 2.1 Risk and safety within IO

HSE in general and especially safety aspects related to the IO development have been a focus of research in Norway since the beginning of IO, and several reports and papers have been published, (e.g. Apneseth 2010; OLF, 2007; Apneseth, 2010; OLF, 2007; Ringstad & Andersen, 2006; Tveiten, Lunde-Hanssen, Grøtan, & Pehrsen, 2008; Tveiten, Albrechtsen, & Skjerve, 2009; Tveiten & Schiefloe, 2009). Internationally it is difficult to find publications on IO and safety, or related developments, though Norwegian researchers have published their work in international media. The empirical-based research is sparser, as most publications focus on potential risks or the necessity for new safety perspectives.

The rationality for new safety perspectives has been based on IO as a complex system rather than a system that is possible to divide into defined parts. In two papers presented at the Working on Safety Conference in Crete in 2008, and in the proceedings from the European Safety and Reliability Conference in 2010, Grøtan et al. argue for diversity in perspective-taking when assessing risk in a system as complex as IO (Grøtan, Albrechtsen, Rosness, & Bjerkebæk, 2008; Grøtan, Størseth, & Albrechtsen, 2010). The Cynefin model (Kurtz & Snowden, 2003)[3] is proposed as a promising framework for addressing risk in IO because it can *…"capture the mixed ontological and epistemological dimensions of the sense making situation"* (Grøtan et al., 2010, p. 440). The Cynefin framework is used to describe problems, situations and systems. The evolutionary nature of complex systems, including their inherent uncertainty, is emphasized. The Cynefin framework provides a typology of contexts that guides the user as to what sort of explanations and/or solutions may apply. The model distinguishes between the

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[3] **Cynefin** is a Welsh word chosen for the model by Dave Snowden. Cynefin is commonly translated into "habitat" or "place", though a more complete translation of the word would be that it conveys the sense that we all have multiple pasts of which we can only be partly aware: Our experiences, both through the direct influence of personal experience, and through collective experience.

directed order of the knowable and known and the undirected order of complex and chaos, making it possible to maintain control by responding categorically, by responding to system analysis, by responding according to interference to the system (probing), and by making sense of the system's reactions.

A central theme in research on potential risk in IO has been the introduction of ICT-based collaboration and monitoring. The role of ICT and security aspects is elaborated in a chapter on reducing risk in oil and gas production operations, concentrating on ICT (Johnsen, Ask, & Roisli, 2007). It is concluded that a holistic approach that addresses technical ICT-based risks, organizational risks, and risks related to human factors should be introduced in the petroleum industry (Johnsen, Ask and Roisli, 2007, p. 94).

Looking at IO from a broader angle, it is seen that the introduction of ICT-based collaboration and monitoring influence both work processes and crisis handling (Tveiten et al., 2009). Within empirical studies on the safety aspects of IO, a need has been identified for updating the defined scenarios for hazards and accidents (DSHAs) which are used for emergency management planning, training, risk analysis and investment in risk-reducing barriers. The three possible future operational scenarios "Well control and lean staff levels; Integrated operations support from the onshore operations center", "Onshore CCR (central control room)" and "Integrated supplier of crucial safety equipment" were described and explored in a study among identified significant actors in IO development (C. Tveiten et al., 2008). It was found that all these scenarios introduced unknown or little-known hazard and accident scenarios. Later, the possible hazard and accident scenario of "lost communication through the ICT system" was singled out as a scenario that should gain attention with the introduction of IO. In a study involving a literature review as well as interviews of key individuals within risk assessment and emergency management in the offshore petroleum industry in Norway, the loss of functionality in ICT systems was identified as a possible IO-related DSHA (Skjerve, Albrechtsen, & Tveiten, 2008; Tveiten et al., 2009). In the report from the study it is further stated that

*"...this DSHA may include that expert evaluation/analysis for operation/well is not available in situation of deviance or in normal operation (that gets out of hand), and/or that there is limited contact between first and second line emergency team in an emergency situation (if first line emergency is still offshore) or that there is no local emergency expertise on installation if first line emergency has been moved onshore"* (Skjerve et al., 2008, p. 30).

In the empirical study where the three operational scenarios of "Well control and lean staff levels; "Integrated operations support from the onshore operations center", "Onshore CCR (central control room)" and "Integrated supplier of crucial safety equipment" were assessed, it was explicitly suggested that an IO-related DSHA should be related to failure in ICT systems:

*"It is perceived as a serious risk that ICT systems failure is not part of standard analyses of /defined situations for hazard and accidents (DSHA's)/ (...) In integrated operations-situations involving loss of communication or other ICT-related scenarios are relevant in relation to the definition of factors which can cause dangerous or emergency situations (...) They should be included in the definition in order to ensure that they become part of risk analyses, education, training and so on"* (Tveiten et al., 2008, p. 18).

## 2.2 Risk images and risk construction in different groups

The research area on risk images is mostly covered in studies of risk perception. Such studies often involve looking at differences in risk perception between groups. Of special interest for this thesis are studies on the risk perception of new technology and technology-related changes in high-risk industries. In a study of technology-readiness among managers in a Malaysian construction company, Jaafar, Aziz, Ramayah and Saad (2007) used the Technology Readiness Index (TRI) to identify technology readiness differences between companies. The TRI measures optimism, innovativeness, discomfort, insecurity and a general measurement of all items. As a result of the study the authors stated that risk perception is dependent on an individual's perception of his or her own knowledge about the risky matter. According to this view, those that claim themselves experts or have great knowledge on, for example, a technology, demonstrate a lower perception of risk associated to the implementation of that technology. The basic thought is that optimism, innovativeness, discomfort and insecurity vary within groups of people in terms of their attitudes (skeptic, pioneer, paranoid) towards technology (Jaafar et al., 2007). "Explorer" and "pioneer" were generally found characteristics between managers and technology experts in the companies studied, and respondents with high scores on these characteristics also have significantly higher scores on technology optimism. The differences between groups in terms of risk images of new technology are found to be similar in other studies. It is generally found that the differences between experts and lay people is related to the fact that the experts are normally attributed the highest degree of optimism when judging risks with new technology. A study of risk perception in different groups using a new questionnaire, called the Austrian Technology Delphi (Tichy, 2004) lists several reasons for this difference. He refers to the literature where it is suggested that unrealistic optimism may result from the overestimation of one's own capabilities and the underestimation of risks inherent in one's own work. Perceived controllability, commitment, and emotional investment may be seen as typical constellations influencing an insider's points of view. Also it must be taken into consideration that experts pushing ahead development in their specific field must believe in its significance and in its future. There is a strong influence by the desirability of the outcome. Insiders overestimate their knowledge and their competitiveness relative to their competitors (Tichy, 2004). In his study using the Austrian Technology Delphi inventory, Tichy (ibid) found that in both the Austrian and the equal questionnaire, – the German Technology Delphi – experts self-rated as more knowledgeable gave more positive answers than those experts who rated themselves as less knowledgeable. In different studies, Lennart Sjöberg (1999) found that experts and the public disagree in risk assessments, and that there is some sort of lack of trust among the public whereas the expert's rate risk lower (Sjöberg, 1999). In later studies it has been found that the level of education does not have a significant effect on the perceived need for precaution (Sjöberg, 2009).

A similar finding is common when studying risk perception among "managers", though the occupational category "management" has been used ambiguously within many research studies, describing various levels of management from chief executive officer (CEO) to first-line supervisor. Apart from an earlier survey among offshore installation managers (OIM) in 1991 (Rhona Flin & Slaven, 1993, 1994), which concentrated on the emergency command function of OIMs, the management group in the offshore petroleum industry has been largely ignored by researchers. Management as a feature to risk perception is however found in many safety climate questionnaires. Flin et al. (2000) examined 18 safety climate instruments used in industry and extracted the following dimensions: "Management/Supervision" (especially in relation to perceived commitment to safety), "Safety System" (procedures, practices, and equipment), "Risk" (attitudes to risk-taking), "Work Pressure" (work pace – production versus safety), and "Competence" (knowledge, skills, training). "Procedures/Rules" was also a factor found in a number of studies. Guldenmund (2000) identified similar factors from the 16 articles he reviewed. In both reviews, management appears as a dominant variable for lower risk perception. This includes first line supervisors, site managers and senior managers. The level of management is not however always well specified. Using a self-administered survey on 915 (the response rate was 92%) offshore petroleum personnel, Rundmo (1994) analyzed the association between organizational factors and safety in the Norwegian offshore environment, and found that employee perceptions of greater management commitment to safety and a priority of safety over production goals were important predictors of employee satisfaction with regard to safety and contingency measures (Rundmo, 1994). This finding was replicated in a subsequent survey in the UK sector using a similar set of measures (R. Flin et al., 1996)

Later research within the field of how risks are perceived and comprehended has focused on new perspectives of the duality in risk perception; risk as feelings and risk as analysis. The importance of affect and the lack of rationality in risk decision-making have long been known, based on the works of Kahneman and Tversky on heuristics and biases in judgments (Kahneman et al., 1982). Slovic et al. underline the importance of affect in decision-making (Slovic, Peters, Finucane, & MacGregor, 2005), but emphasize the importance of looking at the two aspects of risk comprehension as a *"dance of affect and reason"* (Slovic, Finucane, Peters, & MacGregor, 2004 (p. 4)). Partly based on findings from neuroscience (Damasio, 1994) they claim that there is also a strong element of rationality in the affective or experimental mode of thinking. According to Slovic et al., "*the rational system is a deliberative, analytical system that functions by way of established rules of logic and evidence, and the experimental system encodes reality in images, metaphors and narratives to which affective feelings have become attached"* (Slovic et al., 2004, page 6). They conclude that the experimental system with its affect heuristics enables people to be rational actors when our experience enables us to anticipate the future and the consequences precisely, but that it fails when the consequences turn out to be different than what was anticipated. Slovic et al. (2004) emphasize the need for understanding the affect heuristic and how it may benefit risk analysis.

### 2.2.1 Construction of risk images

A social arena is a metaphor to describe the symbolic (not geographical or organizational systems) location of political actions that influence collective decisions or policies (Hilgartner & Bosk, 1988; Kitschelt & Offe, 1980). The focus is the political issue at the meso level of society rather than the individual/micro level) or societal behavior as a whole (macro level). The arena idea only incorporates those actions by individuals or social groups that intend to influence collective decisions or policies. The center stage of an arena is occupied by the principal actors – that is those groups in society that seek to influence policies. Theories on social arenas focus on influencing in decision-making (Renn, 1992).

In association with theories and research on communities of practice that originate from the work of Wenger (Wenger, 2004), knowledge-creating groups have been named *communities of knowing*, described as inter-organizational or inter-institutional communities of specialized knowledge workers where dynamic interactions facilitate the emergence of new meaning and knowledge (Boland & Tenkasi, 1995). The term "perspective making" is explained as a process whereby a community of knowing develops and strengthens its own knowledge domains and practices, whereas "perspective-taking" denotes the process of taking account of the knowledge and expertise of others. Boland and Tenkasi claim that communities of knowledge workers who deal with parts of an overall organizational problem through perspective making and taking will interact to “create the patterns of sense making and behavior displayed by the organization as a whole” (ibid, p. 351). One can also say that such communities “develop unique social and cognitive repertoires which guide their interpretations of the world” (ibid, p. 351). Another important point made by Boland and Tenkasi (1995) is that communities of knowing can operate within specific forums, which serve as a kind of “container” for dialogue on certain topics, issues, concerns or tasks. Different kinds of forum reflect the way work on knowledge is being focused, as well as pointing to the kinds of knowledge structures that are emerging. Boland and Tenkasi are especially preoccupied with forums based on electronic communication media, but the reasoning may also be relevant for knowledge work and sense making processes taking place in other kinds of communication setting. Five classifications of forums are presented: *task narrative forums* where stories and other oral communication including videos enables information for all that attend; *knowledge representation forums* where communication is not only narrative in an auditory or visual way, but involves written material that is discussed and reformulated; *interpretive reading forums* that involve an intended criticism or search for tacit information about the knowledge; *theory building forums* where communication on the theories that underlie the decisions is the focus; and finally *intelligent agent forums* where agents outside the organization or system are involved, such as libraries, databases or other information sources.

The forming of risk images among people in general and groups like mass media and authorities in particular have been studied in social settings by researchers like Paul Slovic, Ortwin Renn, and Roger E. Kasperson. Social amplification theory (Renn, 1991; Slovic, Pidgeon, & Kasperson, 2003) and arena theories Renn (1992) recognize political issues in the formation of risk images, as well as the fact that risk images are the result of negotiations and other processes between groups and individuals. In theories of risk approach and assessment where political aspects of the actors involved are important, the actors are seen as involved in role playing, in games and negotiations. Social amplification theory (Kasperson, 1992; Kasperson et al., 1988; Renn, 1991) focuses on social interactions during events or perceptions of risk. Social interactions can heighten or attenuate perceptions of risk. By thus shaping perceptions of risk, risk behaviors are also shaped. Behavioral patterns, in turn, generate secondary consequences that extend far beyond direct harm to humans or the environment. According to Kasperson (1992), liability, insurance loss, loss of trust in institutions, and alienation from community affairs, are a few such examples. Field studies using the social amplification theory as a basis show that the forming of risk images in society is rather complex and depends on a number of attributes, and the role of e.g. mass media is important but not the same in all cases (Kasperson, 1992, p. 173).

Risk and safety within IO, Risk images and risk construction in different groups and cConstruction of risk images are further explored in the studies presented in paper 1 on risk images and 2 on safety comprehension among different groups.

## 2.3 Emergency handling in distributed (technologically-supported) surroundings

In their study of recent crisis managements in the UK, French and Niculae (2005) found that science (or scientific models) formed the basis for coping with crises (French & Niculae, 2005). In their study, they intended to explore a more balanced perspective on the role of scientific input in emergency management, and to reflect on the use of models in the context of decision support systems. Reflecting that socio-economic and cultural issues are left out in studies of emergency management they argue that authorities need to take a socio-technical, rather than purely technical i.e. "science-based", approach at the outset when planning their response to an emergency. The reason for this approach is partly due to the uncertainty that will arise from information in emergency management that does not fit the scientific model. They argue that most emergency management models are based on a belief that the system is known or knowable, i.e. that cause and effect are understood and predictable or can be determined with sufficient data. They further conclude that this may be due to overconfidence in emergency preparedness modeling. They claim that most models are poorly calibrated for major accidents since these are by nature infrequent, thus insufficient historic data exist to test the models.

In a later article within the same area of research from the same authors it is argued that serious accidents arise because they are unanticipated, and management teams must think through alternative strategies from the start (Simon French, Carter, & Niculae, 2007). The people involved are drawn from other "day jobs" and have little experience of working in a crisis situation (with and assessing the import of the advice from their experts) (S French & Niculae, 2005), p. 10).

Investigation reports on the successful handling of major accident scenarios often include a description of how people at the sharp end apply a combination of layers of defense that is not only relying on a detailed or more generic predefined handling of the situation. This has been reported in studies on the emergency management of the Snorre A gas blow out incident in 2004. The pre-described models of events (defined scenarios for hazards and accidents) did not fit the Snorre A case, and the crew needed to improvise and apply uncertain procedures in order to bring the well back to a safe state (Brattbakk, Østvold, Zwaag, & Hiim, 2004; Schiefloe et al., 2005).

When introducing (new) technology in emergency management it seems quite common to conclude that information and communication technology (ICT) must be carefully introduced into emergency preparedness training. This is shown by a study of emergency management of breakdown of the Swedish power grid by Woltjer, Lindgren and Smith (2006), and in a study of the introduction of an information management system for the incident management systems in homeland crisis management in Australia (Iannella & Henricksen, 2007). Woltjer et al. (2006) observed a real-time simulation of the emergency management of a devastating storm. The exercise was initially meant to train the crisis communication skills of radio correspondents. As a storm occurred, resulting in a breakdown of telephone and electrical grids in large parts of the country, the training session was therefore of larger interest than the initial purpose. The emergency management team was to collaborate in a new way for this exercise; the team would normally stay at home and collaborate through telephone conferences, but for this training session they used a meeting room where they could collaborate face to face. The team functions and use of artifacts (whiteboard, e-mail, phone, maps radio, face to face, etc.) was studied. The whiteboard and the face to face communication were the most used media for all team functions. Woltjer et al. concluded that the remaining artifacts lacked important characteristics for use in team communication. They further claimed that there should not be a mismatch between the ICT tools used in training and those used in the actual work environment, as this may lead to domain-specific skills not being transferred to real situations. They go on to say that the skills may transfer but that they are inappropriate and a source of confusion and ineffectiveness (Rogier Woltjer et al., 2006) p. 336). Emergency management systems that are not used on a regular basis are unlikely to be of use in actual emergencies.

Ianella and Henricksen (2007) participated in a training session on the emergency management of a simulated cyclone heading towards a large regional city. They observed the training session and identified areas where ICT could play a larger role to improve the effectiveness of communication and information management. Incident information and resource messaging were identified as two areas where ICT may play such a role. They conclude that crisis information management systems help support the information-rich needs for emergency management teams (Iannella & Henricksen, 2007). A key challenge for such systems is the heterogeneous ICT systems in different organizations which for a crisis information management system are required to provide a seamless service across organizational borders. They also identified challenges for sharing information and terminology between cultures in different organizations (ibid, p. 589). Emergency handling in distributed surroundings is further explored in the paper on Building resilience into emergency management (paper 4)

## 2.4 Use of system-based models in risk assessment

In a project memo for the "Interdisciplinary risk assessment of integrated operations addressing human and organizational factors (RIO)" project, it is argued that none of the perspectives within organizational safety that had been identified in a report by Rosness (2004) and in a revised version of the report by Rosness, Forseth et al. (2010) are sufficient to meet the needs for assessing risk in the RIO project (that is to assess risk in IO) (Hollnagel & Besnard, 2009). The five initially identified perspectives in the 2004 report were the energy and barrier perspective (Haddon, 1980), the normal accident perspective (Perrow, 1984, 1999), the HRO perspective (LaPorte & Consolini, 1991; Roberts, 1993; G. I. Rochlin, 1993), the information processing perspective (B. A. Turner, 1978) and the as a framework for the risk assessment of IO. The authors refer to the argument that socio-technical systems have become so complex that they defy linear and causal descriptions. This is an argument that can be traced back to Perrow's theory of normal accidents (1984) and that is further elaborated on in descriptions of the development of safety management methods (Hollnagel & Speziali, 2008). It is concluded in the memo that the traditional approaches to risk assessment should be completed by approaches that are capable of addressing complex socio-technical systems that defy traditional linear descriptions. They assume that IO in the petroleum industry in Norway falls within such a category. They also argue that safety management of such systems should be obtained by principles and methods that address the carrying out of the system without distinctions made between safety and productivity (Hollnagel & Besnard, 2009).

In a paper for the 2009 EUROCONTROL Safety research and development seminar and additionally in his PhD thesis, Luigi Macchi applied a RE approach to risk assessment using FRAM (Luigi Macchi, 2010; L. Macchi et al., 2009). The FRAM method was first presented in the book *Barriers and accident prevention* (Hollnagel, 2004) and has been related to the RE perspective, together with the system theoretic accident model and processes model and method (STAMP) (Leveson, 2004a, 2004b). Macchi applied FRAM to look for risks due to the combination of variability of normal performance rather than system failures in a minimum safety altitude warning system (MSAW) for air traffic management (ATM). Macchi proposed that performance variability in a risk perspective could be assessed by the use of the precision aspects "precise", "acceptable" and "imprecise", and the temporal characteristics "too early", "on-time" and "too late" in a three-by-three matrix that results in an overall performance variability for each function in a system model. The analysis showed that an inappropriate enabling of the alert transmission in combination with a "trivial" anticipation of a clearance could result in a degraded performance of the monitoring function (Macchi et al., 2009, p. 10)

There are few publications on the use of socio-technical and systemic models for risk assessment. The use of such models is also explored in accident investigation. As a result of a comparison between FRAM and the multi-linear model STEP (Hendrick & Benner, 1987) when investigating an accident, Herrera and Woltjer found that FRAM is well suited for system accidents and that it brings forward a better understanding than traditional methods such as STEP (Herrera & Woltjer, 2009). The use of system based models in risk assessment is further explored in my paper on Resilient planning of modification projects in high-risk systems by use of the FRAM methodology (paper 3).

## 2.5 Relevance of existing research for the research questions of this thesis

Existing research on risk images and risk comprehension showed that there risk awareness about IO existed in the studied groups of informants. Still, little was known on how the risk images and comprehension was formed and how groups of people potentially differed in their risk images. I found it important to study these issues to elaborate on the images of risks related to technological changes. I also found it relevant to look for communities of knowledge within the offshore petroleum industry, as little was known about inter-organizational groups of stakeholders' influence on risk image forming.

I found no existing research on risk assessments of complex planning processes, though promising results were shown with system-based models on complex work operations. As incident investigations had shown that social factors are important contributors to hazardous situations and the handling of crises in the offshore petroleum industry as they are elsewhere, I found it relevant to apply system-based risk assessment models to high-risk work processes in the petroleum industry.

As research had shown that emergency handling may be influenced by the introduction of advanced ICT, I found that empirical studies of emergency situations, followed by interviews and workshops, could bring light to whether emergency handling could benefit from IO or if there were any challenges that could be introduced for emergency management.

## 2.6 Findings from existing research and implications for my research

The presented existing research address the fact that IO introduces a change in risks and that risk perception is influenced by participation in groups. Also it seems evident from the existing research that social arenas are important in decision making processes about risks and that new technology influence emergency handling in different situations.

The existing research does not address how risk images are formed on technological alterations in general in high risk systems or managed in crisis handling. Nor is it demonstrated how new risk assessment methodology can intercept changed risks in technology - altered systems. By addressing these issues I hope to contribute to bridging of different research perspectives and provide better insight on risk comprehension and management in a high risk industry undergoing technological alterations.

# 3 Theory

In general, theories and perspectives on organizational changes give little account of how technology changes alter ways of work in organization. There are theories and perspectives on how organizational issues influence risk and safety, though neither of these perspectives address how operating in a safe manner is influenced by technological changes. In this chapter, I present the essential theories and perspectives on technology in high-risk organizations, and how safety in social technical/material systems is addressed. Though these perspectives give valuable insight to organizational issues in technological and high-risk systems, I end this chapter by arguing for an integrated theoretical perspective on technology and transitions in high-risk organizations.

## 3.1 Technology in high-risk organizational research

An organization may be defined as... "*systematically arranged frameworks relating people, things, knowledge and technologies, in a design intended to achieve specific goals*" (from (Clegg, Kornberger, & Pitsis, 2008) p. 8). Based on this definition, technology and people (and knowledge and things) are seen as separate units or elements in the organization. They relate to each other, but do not necessarily co-act.

Most theories on organizational changes focus on the implementation of modifications that through phases of change result in a new situation – a changed organization (e.g. the business re-engineering perspective first presented by Hammer and Champy in 1993). Researchers have also argued that organizational changes are dynamic and that changes are more the normal situation for organizations than any stable state (Senge, 1992, 1994, 1999). Still, technology is often seen as a premise for organizational change – change in an organization is related to adopting the technology; the introduction of (new) technology produces changes in work processes, performance and routines.

Karl Weick has argued from the sense-making perspective and points out that people make sense of situations and continuously change the organization through micro actions that imply a change in macro systems (Weick, 1995, 2001). He has argued that organizations are like a football match but without rules and full of conflicting goals. In this view, organizational change is not the result of planned actions with clear consequences and implications. Weick takes a constructional perspective in which organizational designs are emergent and where organizational changes are ongoing improvisations, with actors trying to make sense of the situation. These ongoing processes are labeled *double interacts;* where an *act is* followed by a *response* that leads to *reaction* change in the initial act followed by a response, in an ongoing loop (Weick, 1979). Weick (2001) claims that previous technology in the industrial era has been described as deterministic, with clear cause-effect relationships, whereas modern technology is described as more unpredictable and abstract. In Weick's terminology, technology is seen as something (an *equivoque*) that admits several plausible interpretations and is therefore "... *subject to misunderstandings, uncertain, complex and recondite*" (Weick, 2001) p. 148). Weick argues for that the equivocal processes in organizations can better be understood by talking about *structuration* rather than structure, *affect* rather than analysis, *dynamic interactive complexity* rather than static interactive complexity and *premise control* rather than behavioral control (ibid, p. 149). Structuration is used to describe the two sides of a structure; structures are both the medium and the outcome of interaction. Technology constrains people, but is also constrained by people. Structuring is an ongoing process that shapes meaning through interaction; tradition, writing and structure are themselves shaped by those meanings (ibid, p. 162). Dynamic interactive complexity is an extension of the concept of interactive complexity (Perrow, 1984). By thinking of how organizations that function as tightly-coupled complex vs. e.g. loosely-coupled systems, linear functioning organizations are able to cope with tighter and more complex situations, Weick argues that organizations disintegrate at different speeds depending on their former experiences with interactive complexity. Less experience means faster deterioration, whereas organizations that have experienced complex interaction deteriorate at a slower pace. That is: experienced, complex interactive functioning organizations may be argued to be highly-reliable organizations (LaPorte & Consolini, 1991; Roberts, 1993). In high-risk environments with modern technology, when a process begins to fail stressful situations occur and decisions are made in *affect* rather than based on analysis. New technology demands more abstract mental work and there is an increase in the demand on the mental system; the worker cannot rely on skills and rules alone, but needs to apply knowledge-based behavior (Reason, 1990). Weick (2001) argues that behavioral control is more difficult with new technologies because modern technology is controlled by cognitive variables and not so much by orders, rules and regulations. Behavioral control requires visible behavior. *Premise controls* are important when work is non-routine (Weick, 2001 p. 170).

### 3.1.1 The role of technology

Lars Groth argues that even though computers run sophisticated programs they cannot be viewed as actors in the same way that humans are actors. He calls live action *living patterns of action,* and computer "action" *programmed patterns of action* (Groth, 1999). In systems where these patterns of action are tightly integrated and intertwined it is difficult to perceive them as separate. The conclusion for Groth is then that organizations are a system of living patterns of action and programmed patterns of action that constitute what we call organizations (ibid, p. 353). Groth argues that technology in organizations has developed from tools for carrying out single tasks, through computer-based coordinating mechanisms that run larger groups of tasks or whole processes, to an emergence of a third level of computer use; where computer-based systems are clear-cut representations of conceptual models of organizations (ibid, p. 355). In this third level, computer-based systems become active and the living patters of action and the programmed patterns of action will be inherently intertwined. These organizations are (active) model-driven organizations. The airline booking systems is an example of a model-based organization according to Groth.

With the introduction of model-based organizations that rely highly on computers, Groth proposes new organizational forms such as *meta-organizations* and the *organized cloud*. In meta-organizations, the participating organizations are bound closely together by comprehensive systems. The common systems for partners in a meta-organization will coordinate the total or a large part of the activities in the member's organization. Each member of the organization may be a member of several meta-organizations. Meta-organizations resemble virtual organizations or network organizations in that they are constituted of actors working together by information and communication technology, but it is argued that meta-organizations are not virtual, but real, and not just networks that one can connect and disconnect to, but the results of long time commitments and efforts in establishing the relationship. In this way a meta-organization is a good description of organizations that operate in an IO perspective and that are involved in the research presented in this thesis. One example of a meta-organization (to be) is the operating company–contractor company relationship described in "Generation 2" in IO and addressed in Paper 3, "Resilient planning of modification projects in high-risk systems The organizational cloud is another new organizational form proposed by Groth. The organizational cloud is an image used to describe actors in different organizations held together by common database such as (ticket-, flight-, hotel-) booking systems or trading systems for stocks, commodities and currencies (ibid, p. 408). These organized clouds normally coordinate a few of the member's activities in their organization as opposed to meta-organizations that involve the majority of activities in the member organization. Groth studied service trade companies, and in particular information management in these companies.

The value of transferring Groth's research to the area of IO is significant, as the work performed in the service trade is similar to that of the process industry, but it can hardly be argued that IO is a purely model-driven organization. For the topic of this dissertation, it is difficult to see where technology ends and where the organization or work processes start. Therefore, in the following, I present theories that argue for a different view of organizations where systems are not purely social, material or technical, but where technology, things and people are intrinsically interwoven.

## 3.2 From socio-technical systems to socio-materiality

The concept "socio-technical" (systems) originates from the work and publications of the Tavistock Institute of Human Relations (founded in 1946) in London, where scholars such as Eric Trist, Fred Emery and Kurt Lewin studied people in organizations. A study on implications on productivity following mechanization of the work concluded that new technological equipment by itself was not sufficient to create an efficient production system. The conclusion was that the key to an efficient production system lies in good interaction between the technology and organization (Trist & Bamforth, 1951). The Tavistock Institute developed the socio-technical perspective in which it was argued that social life cannot be understood without insight into the material framework condition. Any social system was looked at as a socio-technical system even though the degree of technological influence would vary (F.E. Emery, 1959).

The relationship between technology and people in socio-technical systems has been described as *"... so close is their relationship that the social and the psychological can be understood only in terms of the detailed engineering facts and of the way the technological system as a whole behaves in the environment of the underground situation"* (Trist & Bamforth, 1951) cited in Emery and Trist, (1960). Still, technology was treated as something that sets "*certain requirements of its social system..."* (F. E. Emery & Trist, 1960, p. 328) and thus the technology is itself not changed or in transition. In hindsight, the understanding is that socio-technical system theorists increasingly framed technology as a process that requires input and output, and thus the technology became more like "black boxes" (Orlikowski & Barley, 2001). Also, it seems that the socio-technology system theorist mainly looked at work practice developments that would make the use of technology more efficient and raise productivity as well as improving the working conditions for the workers. Variance in performance is by this attributed to social interaction and not to the interaction *between* technology and social life.

The reciprocity between material and social matters forms the basis for understanding human work and activity. The joint optimization of social and technical systems was the main focus for all socio-technical analyses (F.E. Emery, 1959; F. E. Emery & Trist, 1960; Thorsrud & Emery, 1969). The research at the Tavistock Institute influenced the development of action research – a branch within sociological research that influenced Norwegian organizational studies through contact between the Tavistock Institute and the Norwegian psychologist Einar

Thorsrud. This Norwegian branch within studies of socio-technical systems led to the development of psychological requirements for work, that later became part of the Norwegian Health and Safety at Work Act, and the use autonomous work teams or groups in industry (Fred E. Emery, Thorsrud, & Trist, 1969; Thorsrud & Emery, 1969). The thinking also influenced development within Europe, the USA and Japan (Levin, 2008).

## 3.3 Socio-materiality as a perspective on technology in organizations

Wanda Orlikowski argues for a situated change perspective for technology-based organization transformations. Organizational change is not a process with predetermined steps, but rather an organizing discourse (Orlikowski, 2001). With the use of the label "socio-materiality", researchers such as Wanda Orlikowski, Susan W. Scott, Lucy Suchman and Stephen R. Barley build a new perspective on organizations upon a rationale in which current (late 1990s) research on organizations and technology has either treated technology as *absent present* (technology is essentially unacknowledged (in organizational studies), *an exogenous force* (technology having an impact on organizational life) or as an *emerging process* (technology is a product of ongoing human interpretations and interactions) (Orlikowski, 2010; Orlikowski & Barley, 2001; Orlikowski & Scott, 2008). It is more evident in some of the writings than in others that socio-materiality is looked upon as a new or alternative perspective on technology in organizations (Orlikowski, 2010; Orlikowski & Barley, 2001). A thorough rationale for the new perspective on socio-materiality is outlined in a chapter in the 2008 Academy of Management Annals (Orlikowski & Scott, 2008). Orlikowski and Scott refer to two research themes that involve technology within organizational studies; one that treats organizations and technology as discrete entities that have some inherent and stable characteristics and a second research stream where actors and technology are seen to be related through and an emergent process of interaction – leading to interdependent systems. The authors point to existing difficulties in treating technology as causing organizational effects, and that treating technology as a cause of organizational change is only relevant if there is a specific technological event. The research on the use of technology in organizations within the two research streams have shed light on the impacts, implications and unanticipated consequences of technology, but have not questioned the logic that technology and organizations are separate in the first place (ibid, p. 455).

The *s*ocio-materiality heading is referred to as an umbrella for several research areas all focusing on technology as an inherent part of human social life, where neither technology nor action can be separated into entities (Orlikowski, 2001).

The research area that Orlikowski considers most prominent under the socio-materiality umbrella is Actor Network Theory (ANT) (Callon, 1986; Latour, 1987, 2005). Also, the perspective of high reliability organizations (HRO) (LaPorte & Consolini, 1991; Roberts, 1993; Weick & Sutcliffe, 2001, 2007; Weick, Sutcliffe, & Obstfeld, 1999) is seen as a research area that has shed light on the inseparability between technology and society. The research stream within socio-materiality also consists of contributions from research areas such as human-machine reconfigurations (L. Suchman, 1996; L. A. Suchman, 2007) and information technology (Sassen & Latham, 2005). Common to all contributions is the ontology that dissolves analytical boundaries between technology and humans (Orlikowski & Scott, 2008). As expressed by Orlikowski and Scott:

*"...entities (whether humans or technologies) have no inherent properties, but acquire form, attributes, and capabilities through their interpretation. This is a rational ontology that presumes the social and the material as inherently inseparable."* (Orlikowski and Scott, 2008, p. 456).

From the socio-materiality perspective the relationships between technology and social life are not fixed but are brought forward in acting out practices. It is noted that practice studies are not new in sociology, but emphasis should be on studying practices, not the communities behind them, and comprise technology in the practice studies (Orlikowski and Scott, 2008, p. 462). Every day work practices should be studied. The relationship between technology and organizations in a socio-technical or socio-material view may be easier to visualize when studying normal operations and everyday practice. To obtain a better grasp of normal work is also the focus of resilience engineering, a promising perspective within the area of safe operations (Hollnagel, Nemeth, & Dekker, 2008a, 2008b; Hollnagel, Woods, & Leveson, 2006; Nemeth, Hollnagel, & Dekker, 2009) (see also the section on resilience engineering, this chapter).

Though the more general theory on organizations and technology indirectly addresses safety by descriptions of human interaction with sometimes high-risk technology, a special branch of research has focused on organizational perspectives on safety in high-risk organizations, which will be treated in the following section.

## 3.4 Addressing safety in social technical/material systems

### 3.4.1 The information perspective on accidents – Turner's theory of man-made disasters

Though originating in a linear model on major accidents (the model of man-made disasters (Turner, 1978)), the information perspective on accidents bring to light interesting views on how accident scenarios evolve over time and where root causes can be found in the interaction between the human and organizational arrangements of the socio-technical systems. This may be important in a modern informational technology perspective. Thus, the information perspective is treated in this thesis because it may shed light on accident scenarios where information breakdown play a role.

The essence of Turner's information processing framework is that a disaster is almost always associated with the recognition of a disruption or collapse of the existing cultural beliefs and norms about hazards (Rosness, Grøtan, et al., 2010). Turner's theory of disaster is concerned with a large system, which not only includes physical events but also the perception of these events by individuals (Pidgeon & O'Leary, 2000; B. Turner & Pidgeon, 1997; B. A. Turner, 1978).
In developing his theory, Turner studied the reports of 84 accidents. The theory thus reflects recurring findings in the material he studied. He studied three serious accidents in depth in order to elaborate the theory (B. Turner & Pidgeon, 1997). These accidents were: a landslide in Aberfan in 1966, a collision where a large road transporter was hit by a train at a railway crossing in Hixon in 1968, and a fire in a holiday leisure complex on the Isle of Man in 1973. A common feature of these three accidents was that a large and complex safety problem was dealt with by a number of groups operating in separate organizations, and in separate divisions within organizations. They could thus be considered organizational accidents.

The Man-made Disaster model proposes that accidents or disasters develop through a long chain of events, leading back to root causes such as lack of information flow and misperception among individuals and groups. Chains of discrepant events develop and accumulate unnoticed. This, Turner argues, is a result of a culture where information and interpretations of hazard signals fail. Erroneous assumption about the hazards can lead to the acceptance of informal norms that do not comply with existing regulations, and thus to violations of these regulations. Disaster development should be viewed as a process, often over years, developing from an interaction between the human and organizational arrangements of the socio-technical systems (my own emphasis).

Turner emphasizes the breakdown in the flow and interpretation of information, which is linked to the energy of physical events. The critical assumptions in his theory concern the process leading up to disasters. However, the Man-made Disaster model also includes stages after the actual disaster, including rescue and a final stage of full cultural readjustment to the surprise associated with the event. The whole model comprises six stages (Figure 2):

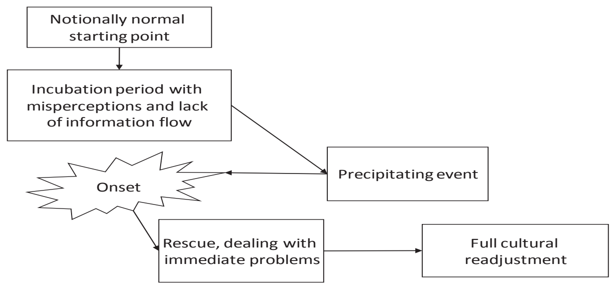


**Figure 2: Main stages in the Man-made Disaster** ***(Turner, 1978; Turner and Pidgeon, 1997).***

The starting point of the model is a situation where matters are reasonably "normal". This implies that the set of culturally held beliefs about the world and its hazards are sufficiently accurate to enable individuals and groups to survive successfully. Individuals and groups adhere to a set of normative prescriptions, ranging from informal norms to laws and regulations, which are culturally accepted as being advisable and necessary precautions to keep risks at an acceptable level.

The second stage, the incubation period, is characterized by the accumulation of an unnoticed set of events that are at odds with the accepted beliefs about the hazards, and the norms for their avoidance. The incubation period starts with rigidities of belief and misperception of danger signals; events happen unnoticed or are misunderstood. Events may also go unnoticed or be misunderstood because of a reluctance to fear the worst outcome. An important factor in this stage is the structure of communication networks, in particular the boundaries where knowledge is not shared or where it is distorted or simplified. If someone takes action to the signals, it often results in what Turner labels "the decoy phenomenon". This is action taken to deal with a perceived problem which, in hindsight, is found to distract the attention from the problems that actually cause the trouble. In many cases the company disregards complaints from outsiders and fails to disseminate and analyze pertinent information. At the same time, the situation is not getting better when individuals often become insecure due to "out of date" regulations and procedures. This makes the situation even more ambiguous, and may cause violations of formal rules and regulations to be accepted as normal. In cases of an actual incident or accident, the incubation period is brought to conclusion by a precipitating event which in a compelling manner reveals the inadequacy of the beliefs about the risks that developed during the incubation period. A dramatic event, such as an explosion or a burning building, creates a large-scale disruption of cultural expectations. The precipitating event is by definition unpredictable for those sharing the culturally-accepted beliefs about the system.

The precipitating event is followed by the onset, the stage in which the direct and unanticipated consequences of the failure occur. The onset is followed by the rescue and salvage stage. This is also the first stage of cultural readjustment to the precipitating event. Involved persons and onlookers make rapid and ad hoc redefinitions of the situation. However, the circumstances during the rescue and salvage stage do not allow for prolonged analyses or comprehensive revision of beliefs. A full cultural readjustment takes place in the last phase of the model. An inquiry or assessment is carried out, and precautionary norms are adjusted to fit the newly-gained understanding of the world. The inquiry may reveal errors and breaches of good practice that did not contribute to the particular accident, but which might contribute to future accidents. The outcome of the final stage is thus the establishment of a new level of precautions and expectations.

### *Prevention of disasters through providing information to those who need it*

Turner stresses the significance of information flow when discussing risk control. The question asked is: *"What stops people acquiring and using appropriate advance warning information, so that large-scale accidents and disasters are prevented*?" (B. Turner & Pidgeon, 1997), p. 162). The answer in general is that relevant information is not available to the right people at the appropriate time in a form that is possible for them to use:

- *Completely unknown prior information*: Where the information which foretells disaster is completely unknown, it is clear that there is little that can be done, except for searching for better procedures for information flow in the relevant arena. This is not a common situation; there is usually someone who knows something relevant.
- *Prior information noted but not fully appreciated*: Where information is potentially available, but not fully appreciated. The situation indicates that the information may not have been understood completely because individuals have a false sense of security when faced with danger signals. Often this emerges from distractions or pressure of work, which can give the subject an impression that the information is irrelevant.

- *Prior information not correctly assembled*: When information about danger signals is carried in the minds of individuals others cannot reach it. A key to preventing disaster is therefore to place information in places where everybody can reach it.
- *Information available, but which could not be appreciated because of conflict with prevailed understanding*: In cases of disaster, Turner saw that relevant information was available, but when it was in conflict with prior information, rules or values, it was neglected and not considered.

The category *prior information not correctly assembled* is again elaborated and divided into (i) *information buried amongst other material,* (ii) *information distributed among several organizations,* (iii) *limited information available to two parties,* and (iv) *prior information willfully withheld.* In subgroup (ii), Turner points to regulations and routines between organizations that establish boundaries and barriers for information flow. This is a point to be emphasized for the growing number of organizations that are undergoing change in terms of out-sourcing and entering into meta-organizations such as those described by Groth (1999).

To control risk, "irrational" events have to be continuously evaluated by the organization. A key factor is to make intensive efforts to collect and analyze information about hazards and find out what we do not know. Experiences from man-made disasters have shown that someone somewhere does actually know something. The outcome of risk control therefore depends on the quality of monitoring risk. Westrum (1993) discusses what can be done to develop organizations with requisite imagination. The organization should provide incentives for thought. The only valid incentive for thinking is to use people's ideas – and to make sure they know that their ideas are being used. The organization also needs to cultivate and reward efforts to bridge the boundaries between organizational layers, departments, subcultures and different sites.

### 3.4.2 High Reliability Organization (HRO)

In addition to being attributed to the socio-materiality perspective, HRO theory/perspective serves as one of the main perspectives of organizational safety, or theories that address the role of organizations in accident and safety management. The HRO perspective was developed by a group of researchers at the University of California, Berkeley, commencing in 1984 (Roberts, 1993). The focus for the researchers was to, from an interdisciplinary point of view, study how organizations with a high degree of complexity could maintain an unusually-high level of safety despite the high-risks and hazards they faced in their operations. Through several publications, the Berkeley researchers established a view of what characterizes HRO organizations (LaPorte & Consolini, 1991; Roberts, 1993). The

HRO perspective states a socio-technical perspective in their research on safety management in stating that:

*"It is impossible to separate physical-technical, social-organizational, and social-external aspects; the technology, the organization, and the social setting are woven together inseparably" (La Porte, 1975; Perrow, 1986).*

It is also argued that:

*"What distinguishes reliability-enhancing organizations is not their absolute error or accident rate, but their effective management of innately risky technologies through organizational control of both hazard and probability...."* (Rochlin, 1993, p. 17).

The earlier publications on the HRO perspective focus on describing the HROs studied (e.g. (LaPorte & Consolini, 1991; Roberts, 1993) and definitions of a HRO. In his definition of HROs, Gene Rochlin points to the following characteristics (G. I. Rochlin, 1993):

- The organization is required to maintain high levels of operational reliability and/or safety if it is to be allowed to continue to carry out its tasks (LaPorte & Consolini, 1991).
- The organization is also required to maintain high levels of capability performance and service to meet public and/or economic expectations and requirements.
- As a result, the organization is reluctant to allow primary-task related learning to precede by the usual modalities of trial-and-error for fear that the last error will be the last trial (LaPorte & Consolini, 1991).
- Because of the consequentiality of error or failure, the organization cannot easily make tradeoffs between capability and safety (Schulman, in Roberts, 1993)
- The organization will be judged to have "failed" – either operationally or socially – if it does not perform at high levels.

The HRO perspective was further developed by researchers outside the Berkeley group. Whereas the earlier research based all finding on the studies of the three organizations that participated in the Berkeley study – the Federal Aviation Administration's Air Traffic Control system, Pacific Gas and Electric Company's nuclear power plant at Diablo Canyon, California, and the U.S. Navy's nuclear powered aircraft carriers – later publications include other high-risk organizations such as hostage negotiation teams, emergency medical teams and wildlife firefighting crews (Weick & Sutcliffe, 2001, 2007). The focus is on thinking, practices and actions in what are labeled HROs.

***Mindfulness and the principles of anticipation and containment***

One concept that has influenced recent HRO theory is the concept of *mindfulness* (Weick & Sutcliffe, 2001, 2007). Mindfulness is defined as "a rich awareness of discriminatory detail" (ibid, p. 42/32). Acting mindfully means being aware of the context of how details differ. Mindful people have an overview of the momentary situation, sometimes referred to as *situation awareness* (Endsely, 1995a; 1995b; 1997). Mindfulness involves the detailed comprehension of emerging threats and of factors that interfere with such comprehensions. Whereas situation awareness as a concept relates to individual cognition, mindfulness may be present in an organization which is subject to certain principles:

Principles of anticipation: The *principle of being preoccupied with failure*, noticing small failures as well as larger ones; the *principle of reluctance to simplify*, noticing the distinctiveness in observations of failure rather than hiding them in categories; and the *principle of sensitivity to operations*, remaining aware of ongoing operations.

Principles of containment: The *principle of commitment to resilience*, locating pathways to recovery rather than only "abandoning ship"; and the *principle of deference to expertise*, knowledge of how to implement the pathways to recovery by trusting expertise rather than experts.

The reluctance to rely on pre-established control systems and risk assessments in complex, high-risk industry is clearly illustrated by the following quote from the publications on managing the unexpected in HRO's:

" *...it is impossible to manage any organization solely by means of mindless control systems that depend on rules, plans, routines stable categories and fixed criteria for correct performance"* (Weick & Sutcliffe, 2001, p. 49; 2007, p. 39).

This reluctance to rely solely on pre-established control systems are shared by a later perspective on organizational safety; resilience engineering.

### 3.4.3 Resilience Engineering

Resilience engineering (RE) (Hollnagel et al., 2008a, 2008b; Hollnagel et al., 2006; Nemeth et al., 2009) partly builds upon HRO theory and Perrow's theory of normal accidents (NAT) (Perrow, 1984, 1986, 1999), as well as relying on other elements of perspectives on system/organizational accidents, such as the energy-barrier perspective (Haddon, 1980), the decision-making perspective involving goal conflicts (Rasmussen, 1997) and the information processing perspective (B. Turner

& Pidgeon, 1997; B. A. Turner, 1978). RE introduces a way of thinking for socio-technical systems where flexibility and adaptation are as important as control and constraint. According to the RE web site,

*"Resilience Engineering looks for ways to enhance the ability of organizations to create processes that are robust yet flexible, to monitor and revise risk models, and to use resources proactively in the face of disruptions or ongoing production and economic pressures. In Resilience Engineering failures do not stand for a breakdown or malfunctioning of normal system functions, but rather represent the converse of the adaptations necessary to cope with the real world complexity. Individuals and organizations must always adjust their performance to the current conditions; and because resources and time are finite it is inevitable that such adjustments are approximate"* (http://www.resilience-engineering.org).

### *Definition and the four cornerstones of resilience engineering*

A general description of resilient organizations and systems is normally presented as:

- A resilient system tries to understand how it functions, not only how it fails. Resilience is the ability to sustain normal functioning, not just to prevent failures.
- A resilient system does not limit descriptions of events to their causes. RE looks for dependencies among functions and for representative variability in functions.
- In a resilient system, learning should be continuous rather than discrete, and driven by planning rather than events. Lessons learned should be treated as interpretation rather than as facts, and should be revised and revised.

There is no formal definition of resilience and RE in the central publications within the RE field, though working definitions do exist. One of these is presented in Volume II of the Ashgate studies on RE:

"A resilient system is able effectively to adjust to functioning prior to, during, or following changes and disturbances, so that it can continue to perform as required after a disruption or major mishap, and in the presence of continuous stresses" *(Hollnagel, 2009a, p. 117)*

The terms "system" and "organization" are interchangeably used in RE publications and this is also underlined in this specific chapter. This working definition is followed by an outline of what is called the four cornerstones of RE;

- The ability to address the **actual** by knowing what to do, or being able to **respond** to regular and irregular disruptions and disturbances by adjusting normal functioning.
- The ability to address the **critical** by knowing what to look for, or being able to **monitor** that which is or could become a threat in the near term. Monitoring must cover the system's own performance as well as changes in the environment.
- The ability to address the **potential** by knowing what to expect, or being able to **anticipate** developments and threats further into the future, such as potential disruptions or changing operating conditions.
- The ability to address the **factual** by knowing what has happened, or being able to **learn** from experience, in particular to learn the right lessons from the right experience.

In order to respond (address the actual) organization must be able to *detect* that something has happened, to *identify* the event and to recognize the event as being serious, the organization must know how to *respond* and be capable of responding. The ability to respond to the actual has been the focus of risk assessment and management, through being prepared to handle identified threats or events by accepting all risks that are lower than a set limit, e.g. by the use of the ALARP (As-Low–As-Reasonably-Practicable) principle, and planning for management of risks that involve regular threats and cost effective risk management.

Irregular threats and events must be managed by monitoring what may become critical and remaining ready to respond if a crisis or disturbance is probable. This sort of monitoring requires the use of *leading indicators* that indicate what may happen before it happens. Because leading indicators rely on a good description of a system, they are difficult to find in intractable systems with complex interactivity, systems that are hard to describe.

Looking for the potential – what may go wrong in the future – requires requisite imagination (Westrum, 1993) or the ability to imagine important aspects of the future. In addressing the difficulty of addressing the potential, Hollnagel (2009a) p. 127) refers to the fact that human thinking has been shown to make use of simplified heuristics such as representativeness, recency, and anchoring (Kahneman, Slovic, & Tversky, 1982) – handy in everyday situations, but restricts the open-minded thinking that is needed in order to look for the possible. Truly resilient organizations, it is argued, realize that there is a need to think about the possible, even though the cost benefits of such thinking are uncertain.

To learn from experience is the fourth cornerstone. Learning from experience is described as the basis for the other cornerstones, though all cornerstones are equally important. If learning from experience is an essential part of resilient systems, it is crucial to form a good basis for learning to know which events or experiences to take into account, have a plan for how to analyze and understand these events, and know who, where and how often learning should take place. Counting incidents and accidents are common in order to show some learning from experience, but learning implies perceiving lessons that are meaningful, small or major.

The four cornerstones are later used in developing the resilience engineering grid (RAG), which is presented in the epilogue of the third volume of the Ashgate studies on RE (Hollnagel, Paries, Woods, & Wreathall, 2011). RAG is intended to assess the organization's resilience via measuring the organization's ability to respond, monitor, learn and anticipate. RAG provides scores for each capability as well as for the combined capabilities. It is strongly emphasized that interdependencies are required between the four capabilities in order to be a resilient organization (Hollnagel, 2011).

### *Variability and the "functional resonance" metaphor*

Both successes and failures result from the adaptations that organizations, groups and individuals perform in order to cope with complexity. Success depends on their ability to anticipate, recognize, and manage risk. Failure is due to the absence of that ability (temporarily or permanently), rather than the inability of a system's component (human or technical) to function normally. Complex socio-technical systems are by necessity underspecified and only partly predictable. Procedures and tools are adapted to the situation, to meet multiple, possibly conflicting, goals, and hence performance variability is both normal and necessary.

The variability of one function in a system is seldom large enough to result in an accident. However, the variability of multiple functions may combine in unexpected ways, leading to disproportionately large consequences. Normal performance and failure are therefore emergent phenomena that cannot be explained by solely looking at the performance of system components.

The performance within a function may be variable, e.g. because time is too short or too long, because resources are missing or controls are inadequate, etc. If the performance of a function is variable, it may be carried out even if e.g. an input is missing or a precondition is not fulfilled. Performance conditions can affect functions. Functions can set and interrogate states.

The term "functional resonance" refers to the possibility that the variability in individual functions may combine and escalate in an unwanted and unexpected way. This is the result of functional couplings in the system. Any part of the system variability can be a "signal", and the "noise" is determined by the variability of the functions in the system. Thus the variations of a number of functions may resonate, i.e. reinforce each other, and thereby cause the variability of one function to exceed its normal limits. This principle captures emergent system properties that only are understandable if the system is not decomposed into isolated components (L. Macchi, Hollnagel, & Leonhard, 2009; Roger Woltjer & Hollnagel, 2007).

Systems with functional resonance may not be captured by the binary logic of many reliability and risk analysis models. A fault tree, for instance, is based on the preconditions that we can define in advance as to what constitutes a failure for each of the components in the fault tree, and that the occurrence of a failure of the system as a whole is determined by the state of the components. The "functional resonance" metaphor suggests that both these preconditions may be invalid for many systems (Rosness, Grøtan, et al., 2010).

### *Underspecification and intractability*

Complex systems or organizations can only be incompletely described (intractability) and are thus underspecified. Within RE it is argued that effective performance can therefore not be prescribed. Since effective performance requires variability, safety must be achieved by controlling variability rather than by constraining it (Hollnagel et al., 2006).

In everyday language, the word "intractable" is used to characterize phenomena, objects, persons or situations that are difficult to deal with or solve, or diseases for which we lack an adequate treatment. In this use of the word "intractable", most socio-technical systems are complex, intractable, interdependent and constantly changing.

Tractable organizations are characterized by simple descriptions with few details. The principles of functioning are known and the system does not change while being described. Intractable systems or organizations are interdependent, descriptions of the system are elaborate with many details, the principles of functioning are partly unknown and the system changes while being described. The notion of an intractable system strongly resembles Perrow's (1999) description of systems with high interactive complexity. Charles Perrow stated that,

*"On the whole, we have complex systems because we don't know how to produce the output through linear systems"* (Perrow, 1999, p. 89).

Complex systems with catastrophic potential in Perrow's writings were judged to be abandoned or demounted. Within RE, as well as within HRO, complexity is seen as manageable, though not through traditional control and linear cause – effect-based thinking. In order to manage a complex system, one must realize that it is intractable and that despite all efforts to describe the system or organization it will remain underspecified, as it is continuously in transition.

Intractability is thus related to events that are the consequence of some unanticipated combination of the normal variability in socio-technical performance. Hence, adverse events and accidents are not necessarily related to collapse of the normal system components and functions, they may also result from intractable combinations of adaptive behavior – such as optimizing system performance or trying to meet requirements of the management or one's self. Intractable events are thus also the flip side of the necessary adaptations to variability. Failures and successes alike are results of adjustments to cope with complexity.

### *Barrier systems to control and dampen unwanted variability*

Within the writings on RE, barriers and barrier systems are greatly emphasized. The barrier conception within the RE perspective includes:

- *Physical barrier systems* that block the movement or transportation of mass, energy or information. Examples include fuel tanks, safety belts and filters.
- *Functional barrier systems* that set up pre-conditions that need to be met before an action (by human and/or machine) can be undertaken. Examples include locks, passwords and sprinklers.
- *Symbolic barrier systems* are indications of constraints on action that are physically present. Examples include signs, checklists, alarms and clearances. Potential functions encompass preventing, regulating, and authorizing actions.
- *Incorporeal barrier systems* are indications of constraints on action that are not physically present. Examples include ethical norms, group pressure, rules and laws.

Barriers are important for resilient organizations as they may hinder unwanted variability or escalation of events in operations. Barriers can help prevent accidents by stopping failures from developing into hazardous situations. Reason hypothesizes that most accidents can be traced to one or more of four levels of failure: organizational influences, unsafe supervision, preconditions for unsafe acts, and the unsafe acts themselves. In the Swiss cheese model, an organization's defenses against failure are modeled as a series of barriers, represented as slices of a Swiss cheese. The holes in the cheese slices represent individual weaknesses in individual parts of the system, and are continually varying in size and position in all slices. The system as a whole produces failures when all of the holes in each of the slices momentarily align, permitting “a trajectory of accident opportunity”, so that a hazard passes through all of the holes in all of the defenses, leading to a failure (Reason, 1997).

## 3.5 Social construction of reality

The introduction of IO in the petroleum industry brings about many elements of change in the reality for operators as well as for management and authorities. These elements appear as partly-known elements or modes of operating, but more than that it appears as something that resembles former ways of operating or totally new elements or ways of operating. This is something that individuals and groups must make sense of in order to plan for, or operate in a safe way. The sensemaking is expressed in concepts, descriptions, ways of working, and formal and informal rules, all developed between individuals in social settings. The situation, as well as all other similar settings in social life is what has been known as the social construction of reality (Berger & Luckmann, 1966), also known as the general constructivist perspective. The term “social” refers to the fact that construction processes are inherently social, i.e. they take place in social settings, where people interact, communicate, discuss and influence each other. Social constructionism as a paradigm claims that the reality for individuals and groups is formed by interpersonal relationships and agreements.

## 3.6 Integrating theoretical perspectives - Technology and transitions in high-risk organizations

Focusing on technological alterations in high-risk industries make socio-technical theories and system-oriented safety perspectives appropriate for studying transitions in risk images, as well as risk assessments and handling. These theories and perspectives make it possible to view technology and social processes as equal entities in an integrated system. The constructivist perspective makes it essential to study risk perception as something that emerges and is constructed between agents in social settings, which are visible in arenas where risks are discussed and in carrying out of work operations The theories and perspectives presented do not directly address technological transitions, though technology is present in the empirical basis for the models or theories presented. For one perspective in particular, the maintenance of balance in systems and resilience is essential for risk management. The following points of relevance from the presented theories and perspectives can be extracted for the study of technological alterations and transitions in high-risk organizations:

1. Risk images are constructed in the interaction between actors in social settings such as arenas for discussions or in workshops or gatherings. Risk images may be possible to extract from observations and participating field studies in such social settings as well as from interviews and surveys.
2. Major accident scenarios may emerge from interactions of actions by humans and technology which by themselves are not necessarily high-risk. Unbalance in systems may stem from failures that are not detected at the time of their occurrence or at the introduction of the technology. Risk influencing elements may be found by studying normal operations and practical work, not necessarily in high-risk situations.
3. Parts of a system may develop informal norms about a transition, or transitions in an element are unattended. Thus systems and organizations may enter an incubation period where danger signals are not detected or are misunderstood. An occurring event may then be unpredictable for the organization. It is essential to look to all parts of a system that undergoes transitions, as well as those that are not directly affected by the changes.

These relevant points are further explored and analyzed in the papers of this thesis. A central point in all the perspectives and theories presented is that changes in risk level of complex socio-technical systems or people's perception of risks cannot be determined through linear, quantitative risk analysis. They must be assessed from a broader angle. In order to assess the overall question on how technological alterations influence risk comprehension and management in a high risk industry such as the offshore petroleum industry I have to look on my research questions through interdisciplinary lenses. The relationship between the theoretical approaches presented in this chapter, the research questions presented in section 0 and the different studies presented in the papers in this thesis is shown in Figure 3 Relationship between theoretical approaches, research questions and papers of this thesis

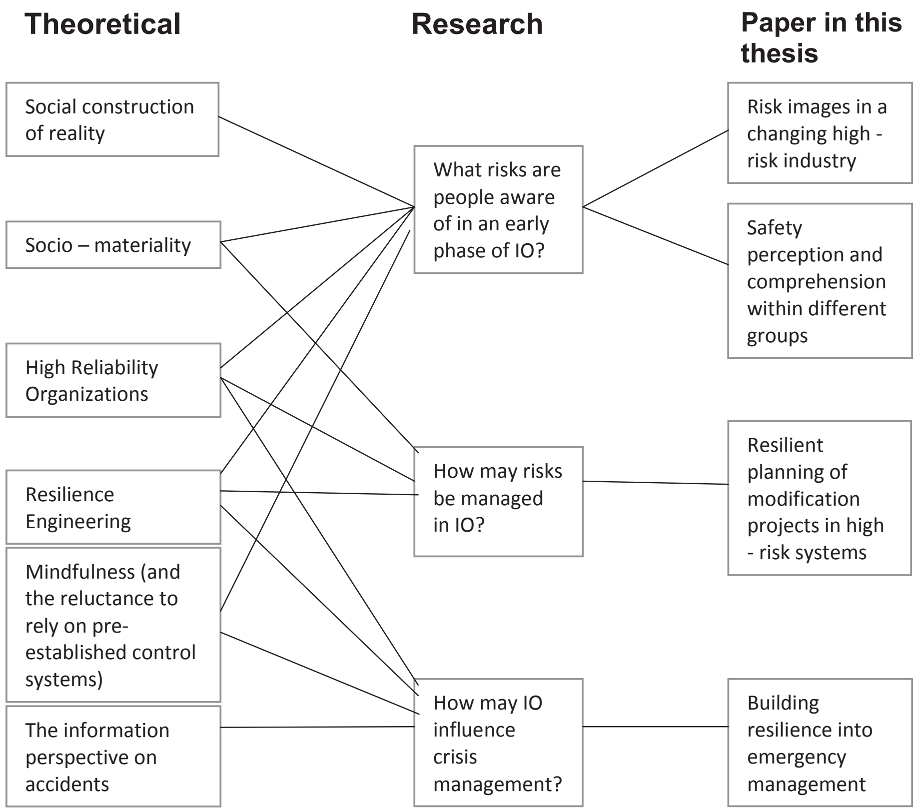


**Figure 3 Relationship between theoretical approaches, research questions and papers of this thesis**

The theoretical approaches social construction of reality, social - materiality, high reliability organizations, resilience engineering and the issue of mindfulness within HRO are the most central theoretical approaches in relation to this thesis. Turner's information perspective on accidents is mostly addressed in the paper on building resilience into emergency management. Before addressing the theoretical approaches in relation to the research question, I will present existing research in the field of the research questions presented in the general problem formulation (section 4).

# 4 General problem formulation

Changing the ways of working in IO introduces a possible change in many of the risks in terms of operations, technology and emergency handling. Changes are mainly due to tighter coupling between technological and human systems, increased complexity in organizations and operations, and possible reduced manning on installations where incidents and accidents may occur. It might well be that IO becomes a successful way of operating in the petroleum industry, and it may be that IO will reduce the risks and improve safety in the industry. It may be stated that the risk images in the offshore petroleum industry prior to IO were characterized by technology optimism. The improvements in safety in the offshore oil and gas production in Norway have mainly been based on technology development such as sensors, emergency shutdown systems, safety valves, etc. Unfortunately, elements that come along with changes in IO can also be a threat to safety, especially when technology and humans, as individuals and as teams within and between organizations (such as between contractors and operators), are seen as separate units in terms of development and learning. Only skilled operators and teams can make good decisions based on the complex information presented in abstract forms with ambiguous information about their uncertainties from remote systems. It is therefore crucial that we have knowledge about what brings out the best from people in strategic, normal and crisis situations – that is, we must understand how people can contribute to their maximum potential in IO. It is also crucial to know how stakeholders in the development of IO (authorities, managers, researchers, etc.) perceive hazards and risks in relation to such a complex change.

Research within this field will enhance information about safety requirements, and about the development of regulations and standards. Viewed against this background, the formulation of my general problem reads:

*How do technological alterations influence risk comprehension and management in a high-risk industry?*

Technology cannot be understood by itself, but only through our understanding of technology. The diversity of elements that constitute IO requires a constructionist approach, both because the reality of IO is a construct but also because risk images, perception and management of risk will be socially constructively formed, affirmed and reaffirmed. The comprehension of IO and what it means in terms of risks may be viewed as an example of secondary socialization for those who are involved. This makes it relevant to study social relationships and arenas where people meet in order to plan management and the operation of systems that contain elements of IO. For this thesis I look into social construction at two levels – the social construction of IO itself, what it is all about, and the social construction of risks related to IO. The social construction of IO influences the social construction of risks. The individual risk image influences, and is influenced by, the socially constructed risk image, which is a representation of the agreement between participants in a social setting.

I have found three areas of interest for studying safety in tasks related to technological alterations by the introduction of IO in the offshore petroleum production industry in Norway. These are as follows:

1. The forming of risk images of the technological and organizational alterations among IO stakeholders in the petroleum industry.
2. The planning process of minor modifications in established installations in order to prepare these for new technology. Maintenance and modification were one of the areas where it was argued by the offshore petroleum industry that IO would have a major impact on work practices (OLF, 2003).
3. Emergency management in organizations that have introduced IO technology and work processes. Emergency management was never mentioned in the early phases of IO as an area where IO would have any impact, but still emergency management faces challenges due to changes in other parts of the organizations.

Technology is introduced and altered without special focus on the consequences regarding organizational issues, both in area of interest two and three above. In area of interest one, the stakeholders are aware of the technological development and possible organizational changes. I argue that research within these areas of interest requires a broad theoretical perspective due to the diversity of research objects. An interdisciplinary angle will help to ensure that the total socio-material/technological system is taken into consideration.

I have focused on the following research questions:

1. From a socio-technical and socio-material point of view,[4] what risks are people aware of in early phases of IO development?
    a. What risk images exist among stakeholders of IO at the blunt end (far from where the operation takes place)?
    b. Relying on existing data from questionnaires, is risk comprehension equally distributed in different groups of offshore

[4] Socio-technical and socio-material points of view refer to viewing social and material issues as being interwoven and impossible to separate in the interpretation of the world. The socio-technical and socio-material perspectives are presented in sections 3.2 and 3.3 of this thesis.

petroleum workers at the sharp end (close to where the operation takes place)?

2. From a system perspective[5] and considering a specific work process, how may risk be managed in an increasingly complex system such as IO?
3. Furthermore, what about emergency handling, which was not an identified area for IO development, but is still an essential part of risk management; how may IO influence the way of working in crisis management?

These research questions were chosen in order to study IO from different perspectives, both in areas that were in focus for the introduction of new technology and work processes, and in areas that existed in the shadows of the introduction of IO. Questions 1a and b were studied in two settings: the forming of risk images among stakeholders of IO and the comprehended risk level among offshore personnel as expressed in the Norwegian Offshore Risk and Safety Climate Inventory (NORSCI, in Norwegian known as the RNNP) in the early phase of IO in 2007. Questions 2 and 3 reflect the two sides of risk management: the prevention of risk scenarios by risk analyses and the handling of risk scenarios as they occur through crisis management to avoid further escalation of hazardous situations and harmful consequences. The second question was studied based on a planning phase of modifications for a mature installation, with an integrated service contract between the operating company and the contractor. The third question was examined through a study of the management of emergency handling in offshore oil and gas production and with a focus on development within IO.

I have addressed how the formed images of risks are manifested in risk perception and the carrying out of new work processes in real life of offshore oil and gas production in an attempt to answer the question on how technological alterations influence risk comprehension and management in a high-risk industry. A constructionist perspective is taken in addressing the forming of risk images in order to start the research process with a wide perspective on what risks in IO are about and what issues to address in the later research.

[5] System perspective here refers to the systemic approach to understanding accidents in complex human-machine systems, e.g. the resilience engineering perspective presented in 3.4.3 of this thesis.

# 5 Research design and methodology

In the following chapter I will give a description of the three cases or areas where I have studied the different research questions outlined in the "General problem formulation" chapter of this thesis. The chapter also includes an outline of the methodology used and limitations of the methods and underlying data.

## 5.1 Case description: technological alterations in the Norwegian offshore petroleum industry (IO)

In the publications from the OLF, four parts of offshore oil and gas production are presented as areas where technology in IO will be implemented. The description from the report that is presented in this text refers to the (then) future description of "Generation 1" and "Generation 2" of IO (between approximately 2010 and 2015 according to the report (OLF, 2005)).

Generation 1 is characterized by the use of onshore centers that facilitate and support offshore operations. The onshore personnel have access to the same information as the personnel offshore. For some areas, like drilling, onshore competence is available 24 hours a day, 7 days a week, but for other operations onshore personnel are only available within normal (onshore) working hours. Vendors and contractors are more involved in the planning of well operations, but also in the planning of maintenance and modifications. The technology will be less mature and not integrated into all work processes. For Generation 2 it is generally claimed that the processes implemented in Generation 1 will lead to closer integration between vendors, contractors, and operating companies due to more mature technology. A typical oil and gas field will be operated by personnel located in operation centers and belonging to both the contractor and operator companies. Contractors will have taken over some of the daily work and decision-making processes. All centers will be operational 24/7. The operation centers will be located across different geographical sites and time zones instead of requiring the personnel to work through the night.

*Well planning and execution:* In Generation 1, onshore drilling centers will be actively used in planning processes, and geologists, geophysicists, reservoir engineers and drillers will develop drilling and completion plans using virtual-reality models. Vendors will be more involved in well planning, and drilling optimization will be more automated and performed onshore. There will be a demand for multifunctional drill teams that can assist in the activity but not the function. Measurements and decisions are to be automated to a greater extent. In Generation 2, drilling contractors and drilling service providers will carry out most of the development of well programs with the operator as a quality assurer. Seismic instruments and sensors will be used while drilling; these provide data for real-time updates on the reservoir – and geological models. Specialists from around the world will participate virtually. Data will flow through the system without manual editing and the data system will provide scenarios, options and estimates for the teams to decide upon. Decision-making processes will be automated. Tools and equipment will be managed in an automated logistics system where all parts are automatically identified, tracked and managed.

*Well completion:* In Generation 1, virtual-reality models will be used when planning and executing work-overs and interventions. Downhole surveillance will develop into measurements based on distributed sensing systems that continuously monitor well performance. The wells will become more advanced in terms of being multilateral, and the limits for what sort of wells can be drilled will be stretched. In Generation 2, well completion will become an integrated part of virtual-reality reservoir models. Wireless intervention tools will be available for interventions in subsea wells without the use of rigs or vessels.

*Production optimization:* In Generation 1, reservoir engineers and topside-oriented engineers will be more integrated by the requirements of closer interdisciplinary interaction and shared reservoir and process system information. The primary control of the production process will remain offshore. The onshore support centers will provide advice and support in decision-making. Due to limitations in technological development they will still be required to perform measurements in the field manually, but the readings may be registered in real time. In Generation 2, production optimization will become a fully automated process. The availability of downhole measurements such as temperature, pressure and flow will improve the understanding and lead to even more optimized production. Process surveillance and control will be performed onshore.

*Maintenance management:* In Generation 1, all planning and preparatory work is carried out onshore and the preventive maintenance processes will be integrated with other onshore processes. The use of external specialists will increase. It is claimed that decision cycles will be shorter and that time spent on shutdowns of the production system for maintenance work will decrease. In Generation 2, the onshore planning will be supported by offshore teams through the use of portable video conferencing equipment and updated 3D models. Experts from around the world will participate when necessary. Condition-based maintenance will fully replace traditional maintenance, as more instrumentation is available that will replace manual data gathering. Smart decision support software will ensure that only the necessary data are sent onshore.

## 5.2 Case description of modifications in offshore oil and gas production installations

Traditionally, work carried out on installed equipment or systems has been divided into maintenance and modifications. Maintenance comprises actions carried out to maintain or bring back the functionality of the equipment or to the system. The purpose is not to change functionality or appearance. Nowadays, maintenance is normally divided into the subcategories corrective and preventive. Preventive maintenance is carried out according to decided intervals or criteria. The goal for preventive maintenance is to reduce the probability of failure or degradation of equipment (Schjølberg, 2002). Preventive maintenance may be condition-based (monitoring and inspection are important) or periodical. Condition-based maintenance may lead to corrective maintenance in the case of function failure before any action is taken on the identified condition. Corrective maintenance is carried out after a failure in the equipment or system and the goal is to bring the functionality of the equipment or system back to what it was before the failure. Corrective maintenance may be possible to postpone, or it may be sudden and action must be taken immediately. In most organizations, maintenance includes inspection, corrective and preventive maintenance, and the maintenance philosophy will provide information on what sort of maintenance program an equipment or system will need in order to optimize cost and production.

Modifications imply changing the functionality of the equipment or system, by changing it or replacing parts so that the appearance of the equipment or system changes, as well as the functionality. Drawings and manuals will need updating. The goal is normally to improve the system or to adjust the system to new requirements, etc. The modifications are normally either minor or major. The definitions of minor and major modifications differ, but are normally stated in terms of cost or the impact on operation, production or safety. Minor modifications will usually be carried out by own and/or contracted workers, but will follow a normal project work process. The decisions are local as long as the budget is followed. Major modifications involve larger parts of the organization and may imply project organization.

The difference between maintenance and modification will be an equal replacement of parts for maintenance and a non-equal replacement for modification. Modifications will typically be equipment or system changes that require a subscription service, and a design change in relation to documentation, instructions, competence, equipment or systems. Border projects (not purely maintenance or modifications) will be company-dependent and act on the value or size of the project. In the IO context, modifications usually take place on producing platforms and follow the approximate project work process. Maintenance will have a suitable process that includes inspection, preventive and corrective work.

Five years after the introduction of IO-related technology, maintenance and modification work is not greatly influenced, either in relation to technology or organizations. In a report from 2008, the authors stated that contractor companies have not met the expectations from the introduction of IO that were set, even though the volume of maintenance work is the same (though offshore work is somewhat reduced due to greater onshore planning and administration work) (Øien & Schjølberg, 2008).

As IO brings forward new technology that enables prolonged life for older installations, many installations will face challenges related to old equipment and constructions. Also, new modules may need to be installed in order to enable, for example, drilling, and/or subsea extensions if needed. When the petroleum authority issues consent for the operation of a field/installation, it is typically valid for 15 or 20 years (design life). At this point, when IO is introduced many installations have reached the end of the consent (design life) and need to apply for new consent. This has triggered ongoing activity on regulations and requirements for giving extended consent to older installations, as well as research on safety, reliability, maintenance and modifications on older installations. The following is a quote from the petroleum safety authority's (PSA) website in 2009:

*... A number of installations on the NCS are aging, but remain commercially attractive.... a petroleum installation is designed to last for a specific time, and a growing number of facilities on the NCS (the Norwegian continental shelf) are approaching the end of their original production life...but a number of considerations may have changed since they first became operational, making it desirable to keep them working beyond this period. That could involve methods which improve and extend recovery from the field, the tie-back of subsea production facilities, or conversion of the installation to new uses. The PSA has been concerned for a number of years about the challenges posed by such extensions, and has formed a picture of where its commitment needs to be strengthened.* (PSA, 2009)

In my work I studied the planning of minor modifications for a mature installation with reduced oil production. The field has reached its initial life expectancy, but has received further expectancies in production due to new technology and prospects in the oil and gas market. The need for modifications is thus increasing. The acting resources within modifications are managed by an integrated service contract with a large offshore construction company. Integrated service contracts are long-lasting and include a broader service concept that may include the contractor providing all planning, administration, cost estimates, etc. The integrated service contract between the two parties involved in modification work for this specific installation had been in operation since 2005. A project for modifications follows manuals from the operating company and from the construction contractor. It has been attempted to combine the two manuals in a figure that shows how the different phases in a modification project for the two companies relate to each other (Figure 4). The planning phase consists of identifying a problem or an opportunity, finding possible solutions, as well as defining a concept for carrying out the modification with cost estimates and risk assessment before executing pre-engineering activities.

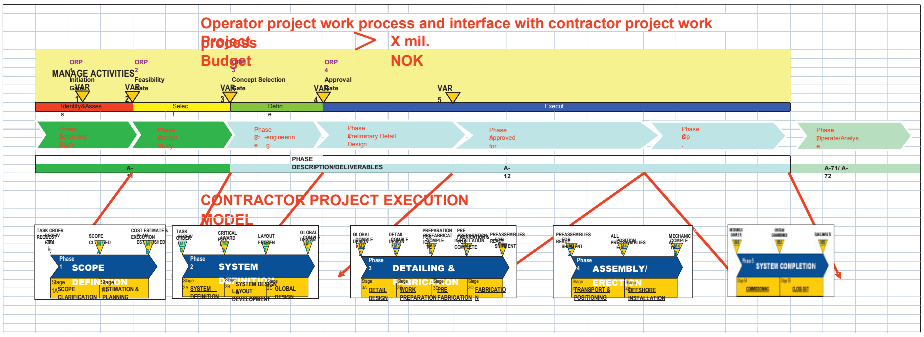


**Figure 4 Interface between operator and contractor project execution models.**

## 5.3 Case description of emergency management

Emergency management may be defined as all activities (both administrative routines and informal processes) conducted in a more or less coordinated way to control emergencies before, during and after an event. This includes planning, training, handling, learning, anticipation and monitoring. This definition represents a wider definition than that found in the NORSOK standard Z-013 *Risk and emergency preparedness analysis* (NTC, 2001, p. 6), which focuses on emergency preparedness as *"technical, operational and organizational measures that are planned to be implemented under the management of the emergency organization in case hazardous or accidental situations occur, in order to protect human and environmental resources and assets"* and other definitions of emergency management, e.g. *"the process of coordinating an emergency or its aftermath by communication with participants and organizing the deployment and use of emergency resources"* (Alexander, 2003, p. 18). The petroleum safety authority refers to the NORSOK Standard Z-013 as requirements for handling risks in the oil and gas sector on the NCS (NTC, 2001). The requirements are in accordance with traditional risk assessment procedures and follow the ALARP principles. Defined situations of hazards and accidents (DSHA) form the basis for the planning and execution of the risk, and emergency preparedness analysis. The emergency preparedness plan is established in an installation's design and building phase and is executed, for example, for training and manning purposes throughout operation. Oil and gas companies rely on the NORSOK standard and the work carried out based on this standard for establishing their emergency management and for training.

An emergency management organization for offshore operation is typically set up with three emergency-handling groups within an organization: local or first line, second line and third line. The local, first-line team is located on site offshore and handles evacuation, firefighting, problem-solving, prevention of escalation of the event, and treatment of acute injuries. They also manage communication with nearby vessels and installations. The first-line emergency management team consists of the platform manager, who is normally the emergency team manager or action leader, and other managers of personnel offshore. The nurse is also normally a member of the emergency team, though the nurse carries out his or her work in the sick ward. There will normally also be a firefighting team and a lifeboat team, in addition to other possible specialized teams or specialists within the installation organization.

The onshore, second-line emergency team is led by an emergency team leader and further consists of an emergency coordinator, a next-of-kin contact, a person in charge of media and press and other identified functions specific to the organization. In addition, the safety authorities may require a seat in the emergency management room. There are also seats available for oil spill and pollution experts or other external functions relevant for the emergency scenario.

Third-line emergency management consists of top management and contact with external media. The top management team normally holds the main responsibility for emergency operations.

Several other actors, depending on the accident scenario, participate in emergency handling. A contractor company may have a similar organization to the one described above if they are working on larger projects or programs (e.g. construction or drilling). Experts on the scenario at hand may be called upon and participate in emergency handling. The role of different actors is part of the study of emergency management in an IO context, presented in Paper 4: *Building resilience into emergency management*.

## 5.4 Methodology

The theoretical approaches presented in chapter 3 call for qualitative methodology such as the use of observations, interviews and field studies. Data from socio-material systems can only be retrieved from observations and field studies as interactions between humans and technology are present in real life and less in descriptions or even in explicit knowledge. The importance of observing real-life carrying out of work, rather than work as planned to be carried out, is stressed in the resilience engineering literature as well as in HRO and mindfulness literature.

I have mainly applied qualitative methodology for exploring risks related to the introduction of IO. This has been an explorative study and I have found it important to be able to follow up on the issues that have emerged. The methods applied have been literature reviews, observations, workshops and qualitative interviews for the study on risk images, on the use of FRAM for risk analysis and the study of resilience in emergency handling. In the paper on safety comprehension among offshore workers, my co-writer relied on quantitative data from a survey, whereas I, in my analysis of the findings from the quantitative analysis, applied theoretical and empirical knowledge. The use of quantitative data for the article on risk perception at the sharp end (offshore workers) was mainly due to the lack of access to qualitative data from this area.

Document study has been applied for the study on resilience in emergency handling, as well as in the study of risk images. An overview of the distribution of interviews, observations, workshops, literature reviews and use of quantitative data is presented in table 1.

Table 1 Overview of methodology used in empirical studies

| Article/study | Interviews | Workshops | Observations and field studies | Literature review | Quantitative data |
|---|---|---|---|---|---|
| **Risk images in a changing high-risk industry** | 10 | 1 | 2 (observed seminars) | yes | - |
| **Safety perception among different groups** | - | - | - | yes | yes |
| **Resilient planning of modification projects** | 4 | - | 5 (3 days of visits over a period of 18 months) | yes | - |
| **Building resilience into emergency management** | 5 | 1 | 2 (crisis management training sessions) | yes | - |

### 5.4.1 Review of documents and texts

Gale Miller (1997) points to the importance of reading documents in social research. Miller argues that texts are aspects of the sense-making activities through which we construct and maintain our sense of reality, and thus provide important information about the sense-making of reality within a certain time frame. He points to the fact that texts and documents are especially interesting when conducting observation studies in institutions and organizations, as texts are often constructed in the context of the setting being studied. The context in which the text has been constructed is of great importance, as the text itself seldom provides information about the circumstances, possible conflicting arguments and other social processes that surround the text construction. Hammersley and Atkinson (2007, p. 121) state that texts are documentary constructions of reality and that collective social activities involve the creation, use and circulation of material artifacts.

I have used text and document reviews for most of my studies. Some of these have been traditional literature reviews; that is, the academic review of theories, models and research within a subject. Others have been readings of company documents, statements, manuals, procedures and web pages. The context in which these texts are constructed is not always clear and thus I have little information about how these texts have been constructed. Rather than treating the texts as artifacts, they have been sources of knowledge and information about the author's/s' construct of reality. The document reviews have in all studies been conducted in addition to other methodological assessments such as observations and interviews. In this sense, the documents have provided images of constructs of reality, e.g. in the study of risk images of IO, where the studying of websites, reports and memos from the industry gave an insight into how the construction of IO may be expressed in the industry.

### 5.4.2 Observations and interviews

During observations of meetings between actors during planning of modification projects, of workshop discussions and of emergency-handling training situations I took field notes, either by hand or directly chronicled on a computer. Where I was allowed by the persons present, I recorded conversations and statements. The data in the different studies were partly obtained using open-ended or semi-structured interviews with individuals and through group discussions. The topic was planned and exemplified with questions that could be applied, but emphasis was placed on the interviewees being able to talk about the subject from their own viewpoint. The conversations were digitally recorded for later analysis. Otherwise, notes were taken by the interviewers and used in the analysis.

The recordings, either auditory or written, were analyzed using coding schemas, mainly in a process resembling what is described within grounded theory (Glaser & Strauss, 1967).

### 5.4.3 Use of workshops as a source of data

Farner (2008) describes workshops as an efficient tool for collecting data and getting opinions from several stakeholders as well as an arena for coordination and interdisciplinary problem-solving. The workshop is seen as an arena for communication within interactive cooperation where the content is created by the participants within an organized process that is partly controlled, but that may be adapted to the development of the communication. Workshops are seen as good arenas for making tacit knowledge available and as good forums where experts and lay people can meet. Within a research setting, workshops are seen as providers of richer information than, for example, questionnaires and surveys (Farner, 2008, pp. 19–20).

Data collection from the workshops for the work presented in this thesis was partly from observations where I as a researcher had the role of an observer or facilitator, and partly from group interview settings where I asked the participants questions to start group discussions. The observations of group dynamics in discussions of, for example, risk images were seen as a good source of information about how authority and role-specific attributes influence the construction of risk images. The observed dynamics in the group conversations were later checked with the audio recordings in order to validate what was observed.

### 5.4.4 Questionnaires and surveys

The Norwegian Offshore Risk and Safety Climate Inventory (NORSCI) is part of the study of trends in risk levels on the NCS (in Norwegian known as the RNNP).

The NORSCI survey was developed by health and safety researchers, and used experts from occupational health and safety in the industry and representatives from the unions to review, test and examine it. The survey is limited to factors of relevance to safety and the working environment, excluding the external environment. The aim of the survey is to measure employees' perceptions of HSE in the Norwegian offshore industry. The survey consists of a total of 124 questions divided into six main parts relevant to health and safety.

## 5.5 Data gathering

Data were collected from different sources for the different topics:

### 5.5.1 Data for the study of construction of risk images

In the study on constructions of risk images I used qualitative techniques to analyze the data. I first listened to all audio recordings and read all notes from the workshop and interview settings. I identified central issues and topics related to safety, risk, change, technology and IO work practices. Then I aggregated these to arrive at a set of common or recurring themes. Preliminary findings were shared with informants and colleagues and this provided helpful comments for further interpretation of the data/understanding of the results. I used the following procedure to analyze the data from the interviews and workshops:

1. Coding based on a process of establishing first preliminary categories. The preliminary categories were as many as necessary to distinguish the different statements from each other. Later, the categories were modified so that preliminary categories that were similar in nature were combined.
2. Formation of themes. Themes were formed by defining a description that represented the interpretation in the coded statements.
3. Alignment of themes with groups of informants. A group would consist of people with the same education/background (human factor researcher or consultant, petroleum engineer, etc.) or type of employment in an organization (managers, project managers, developers, trade union representative, etc.).

**Data for the study of risk comprehension in different groups**

The NORSCI was performed among personnel in the Norwegian offshore industry in the period January 7th to February 15th 2007. In addition to demographic and other background data, the survey included 35 statements about daily HSE prioritization and risk communication, own and others' safety skills and behavior connected to role clarity, safety training, competence and workplace conditions influencing health and safety such as management and prioritization, in addition to individual motivation and follow-up systems and procedures. The results for the 35 statements were analyzed. In the analysis all items were graded from "1" ("*totally agree*"), which is the lowest, to "5" ("*totally disagree*"), the highest. The mean score on each individual statement was calculated for the three variables: (a) OIMs; (b) safety representatives; and (c) the rest of the offshore organization.

The estimated response rate for the 2007 NORSCI was about as low as 30. Nevertheless, the number of responses, N=6850, is sufficiently large to perform statistical analysis and to split the data material into different categories. The distribution of responses among different groups corresponds reasonably well on the whole with the distribution in previous years' studies and with the reported number of hours for different groups. The number of installation managers responding was N=105 and the safety representatives constitute a larger group (N=226).

### 5.5.2 Data for the study of risk assessment of the planning phase for minor modifications

The planning process was studied through a literature review of manuals and procedures provided by the operating company and the contracting company. Functions relevant for carrying out the planning process were identified in the texts. Validation of the work procedure was conducted through observation of how work was carried out in meetings where I participated as well as through conversations with the participants. The question I asked in the process of validating the functions in the work process was "How is work <u>really</u> carried out?" Information about potential variability in how these functions were carried out was gathered in observations and interviews. I was not able to make audio recordings of the meetings and conversations. The observations and conversations were recorded in notes and later analyzed.

### 5.5.3 Data for the study of emergency management in IO

The study of emergency management was conducted in two parts. The first part had the purpose of describing requirements and contents of DSHAs currently applied by the industry, and to explore the demand for new or changed DSHAs related to IO. Opportunities and challenges for the use of DSHAs in an IO context were also explored. A literature review was conducted on existing literature on IO and safety issues. In addition, an interview study was performed. Five interviews with central stakeholders in the Norwegian petroleum industry were conducted to study DSHAs currently applied by the companies and how the current DSHAs were used, communicated, produced and updated.

In the second part of the study, I participated in a research team that observed two emergency management training scenarios. The two emergency-handling training sessions were observed in two different companies. The first training session included two DSHAs: loss of control of a well and a subsequent oil spill. We observed the identification of the event in a morning meeting between the onshore operation support center and the offshore installation, the establishment of the second-line emergency organization, and the following actions in the emergency-handling center and in the well support center. Third-line emergency handling was also partly present in the areas that we observed. The second session included training in handling the loss of control of a well with a subsequent oil spill and injuries to personnel. We observed second-line emergency handling onshore (the emergency-handling room/center) and third-line handling at the company's head office. The participants in the workshop were representatives from three operating companies, a contractor and consultants within the emergency-handling field. The meeting lasted for six hours with informal discussions. The group of 19 participants was divided into two smaller groups during the day to make it easier for everyone to contribute to the discussions. The results were recorded by researchers taking notes during both discussions and presentations following guidelines to sort the data into the following categories: emergency preparedness exercise and training, transition from normal to emergency situation, interfaces, ICT, information flow and visualization, and finally a miscellaneous category.

The results from the observations were recorded in field notes during the sessions. The field notes followed an observation guide that included the role of the actors and groups, interfaces between actors, communication between co-located actors, formal and informal information sharing, use of ICT, and observations made on the transition from normal to emergency situation.

Following the observations, a workshop was held where the overall question asked to the group at the beginning of the workshop was "Which opportunities and challenges do you foresee related to emergency handling in 2015?" The participants in the workshop were representatives from three operating companies, a contractor and consultants within the emergenc-handling field.

For the observation study we also conducted document studies of organizations' charts, emergency procedures, work process descriptions, etc. in the organizations that we observed.

### 5.5.4 Important aspects when interpreting qualitative data

In qualitative interviews and in observations where the researcher participates, e.g. as a facilitator, the data are extracted from an interaction in dialogue between the interviewer and the interviewee. The interviewer influences what is said by the way questions are formulated, what she or he focuses on when following up with new questions, etc. The value in this is that it is possible to explore and get a richer description of a topic than through other methodological approaches. This is essential when exploring new and unknown fields like IO. It is not necessarily seen as a good measure of reliability if two interviewers get the same answers when conducting a qualitative interview; this may be a result of using leading questions or because the interviewee may have stuck to the "official version" of the topic (Rosness et al., 2010).

It is not possible, nor desirable, to generalize the data from my studies. The objects of my research have been case studies. In order to obtain a broad picture of the topics I have tried to involve several companies and many informants as case studies, but the goal for this has never been to generalize the findings so that they are valid for all other companies that introduce IO. The findings may, however, be transferable. Companies within and outside the petroleum industry may find that the results fit them as well. This way of thinking about naturalistic rather than rational generalization is well described in the works of Lincoln and Guba (Lincoln & Guba, 1985).

### 5.5.5 Research ethics

All data for the studies presented in this thesis have been made anonymous. The data files are all stored in secured servers. Audio recordings have been stored for analytical purposes only. They are not labeled with anything that can identify the interviewee or participants. Coding schemas for categorizing participants etc. have been kept separately from the recorded and transcribed material.

The companies that have admitted me for my research are partners in the IO Center, and thus they may be identified as a group. When particular companies have participated in my research, or provided documentation or information, they have been made anonymous. This is also the reason why company-specific manuals and procedures are not referred to in this thesis.

### 5.5.6 A constructivist approach to interpretation

Faced with these different data sets all based on case studies, interviews, observations or survey data that I had not collected myself, I applied an inductive data analysis and made an effort to interpret the findings within their context. I have thus followed what is described as the constructivist program (Lincoln & Guba, 1985). The constructivist strategies face problems of a theory and value-laden nature and ambiguities (Denzin & Lincoln, 2008).

### 5.5.7 Reliability and validity – trustworthiness of and possible weaknesses in my research

As described by Lincoln and Guba (1985), trustworthiness relates to the credibility, validity, reliability and objectivity of the research.

***Response bias and socially desirable responding***

There is always a chance that informants in interviews or participants in workshops tell the interviewer or other participants what they think the other(s) wants to hear. The reason for this behavior differs, but the behavior itself is generally termed "response bias." A response bias is a systematic tendency to respond to a range of survey items or questions on the basis that it is different to the content of the item or question. In research on risks and safety issues, this may be a significant problem. In high-risk organizations such as in the petroleum industry, there are clear expectations of safe behavior and attitudes. As participants in the petroleum industry, the informants and participants in my interviews, workshops and seminars may have experience of different situations where "the right way of viewing risks and safety" has been emphasized, or they may have experienced that their own or others' attitudes toward safety have influenced their work possibilities and reputation. Sometimes a person's response style develops into a pattern (e.g. always choosing the extreme part of the scale). Psychologists have identified a phenomenon called *socially desirable responding*. Socially desirable responding is a tendency to answer in a way that makes the respondent look good (Palhus, 1991). What is socially desirable depends on the situation and the individual's perception of what is desirable in their situation. In my research, I find socially desirable responding a threat to the reliability of data from workshops and seminars where representatives from the safety authorities as well as safety managers in petroleum companies are present as participants or as speakers. Former experience, in addition to the presence of significant others in the workshops and seminars, may have contributed to response biases that threaten the reliability of my findings. I have made the issue of bias part of the focus in my research in the paper on risk images (Paper 1), and on safety perception and comprehension among OIMs and safety managers (Paper 2).

#### ***Reliability and validity in my analysis***

I have read and listened to all the notes and voice recordings from the interviews and observations myself, thus avoiding different patterns in the extraction of findings, but at the same time missing the opportunity for inter-reliability checks. I have, as far as possible, tried to make available information about the settings and questions asked when describing my approach to gathering data in the papers. Though trying to follow a strict line when selecting and coding data, all analyses are influenced by my interpretation. In the studies within emergency management, there were several researchers, myself included and all participated in selecting and coding data for the analyses. The data collection and the quantitative assessment for the NORSCI data for the paper on differences in risk comprehension were conducted by other researchers and I have only checked the consistency in the output of the analyses, based on the raw data that have been presented to me.

I have tried to obtain external validation through read-throughs and checks by colleagues and the informants themselves. It is still possible that the interpretations made are influenced by my values, thoughts and ambitions. It is my view that research is never unbiased. I have very possibly influenced the answers and utterances in interviews and workshops by being present and asking questions. It is also quite possible that other researchers would come to conclusions that differ from mine, due to both different extractions of findings from available information and to different interpretation of the findings.

#### ***Difficult access to data***

It is always difficult to acquire data from organizations that are busy and in operation. The partners in the IO Center participate in many research studies and they have been reluctant to admit all those who want access to their employees and office premises. I would have preferred to spend more time within the organizations that I have studied, however this has not been possible due to distance and priorities. This would have also probably led to a more limited scope.

When studying the modification project process I visited the company for shorter stays both onshore and offshore on a petroleum production installation where modification projects took place. I value the opportunity to conduct interviews with workers on their own premises as I believe that more valid information is acquired. Being present on the informant's home ground, I have also had the opportunity to observe situations myself, thus collecting richer information on issues than is possible through interviews alone.

# 6 Summary of papers

The research questions presented in section 5 of this thesis called for a study of risk images among stakeholders of the technological development in IO, a study of a work process where IO was introduced and of emergency-handling situations where IO had not yet been formally introduced. My research has followed a path of curiosity over how to deal with risks in a transition in the way a high-risk industry is operated. The path starts with research of what IO means and what sorts of risk image stakeholders hold at the beginning of the transition period. This is dealt with in the paper on risk images in a changing high-risk society. The paper presents risk images from the stakeholders at the blunt end: authorities, managers, researchers and experts in different areas. Risk images at the sharp end were approached individually through union representatives who participated in the study of risk images presented in this first paper. In 2007 and 2008, when conducting the study of risk images, IO had reached the sharp end in only a limited sense. Video conferences existed and there had been some smaller organizational adaptations, although the broader picture was that work was carried out as usual and bore little resemblance to what was pictured in Generations 1 and 2 in OLF's description. I still felt a need to know more about how risks were perceived offshore. The study presented in Paper 2, on safety comprehension among installation managers and safety managers, provided information about the perceived risk level offshore in 2007, but without addressing particular IO-related issues. The studies of an IO-influenced work process and a work process where IO had not been introduced resulted in the study of emergency management presented in Paper 4 and the study of how a systemic model could be applied for risk assessment of the planning phase for offshore modifications presented in Paper 3. The planning of modifications was found to be interesting because maintenance and modifications was singled out as one of the main areas where IO would have an impact. Risk handling in an emergency management setting was not identified as an area where IO would have an impact; however, for me it was clear that the ongoing transitions in the industry would influence risk management and thus I found it valuable to study. The study of emergency handling was valuable due to the reluctance to apply new technology in the crisis-handling situation, despite still having to deal with the technological alterations in the environment of the crisis.

The papers are presented in the same order as the related research questions have been presented in the previous text.

## 6.1 Risk images in a changing high-risk industry

Risk images held by actors involved in the planning and execution of operations with a high-risk potential are critical components of risk governance. The principal concern in this paper was to investigate the forming and development of risk images in a high-risk industry when introducing new advanced operational technologies. The case studied was the planning and implementation of IO in offshore oil and gas production.

The importance of risk images in a high-risk setting is twofold. The first argument is that an adequate risk image is a precondition for the sufficient understanding of the actual technology, operational procedures and organizational arrangements necessary to identify possible hazards of different kinds. These kinds of understanding strongly influence risk analyses and the forming of accident scenarios. A relevant and comprehensive risk image is, therefore, a precondition for developing necessary surveillance systems and barriers to prevent possible accidents. The second argument concerns risk perception, which relates to the ability to interpret signals and warnings and react to these in adequate ways, so that potential incidents and accidents can be avoided. These arguments are strongly supported in the theory of man-made disasters (B. A. Turner, 1978; B. Turner & Pidgeon, 1997) where among other things it is stressed that a reluctance to perceive changes or incidents as relating to a change or a new paradigm may lead to an incubation period where information about possible increased risk is not interpreted as valid and thus creates the basis for an accident.

The informants in the study were representatives from different groups involved in the development of IO on the NCS, groups that participated in making decisions, gave consent and permission for operation in an IO setting or were involved in protecting HSE. They performed work such as R&D, inquiries, reports and statements in the mass media. They also participated in workshops, discussions, seminars and other kinds of arenas where IO was discussed.

Information about risk images was gathered in various settings such as interviews, workshops, seminars and informal talks. Visual and written representations of risk images were gathered from presentations and reports in meetings, and on the Internet. Open-ended interviews and workshops with stricter agendas but with open discussions in planned groups were the dominant sources of data collection.

In the interviews, seminars and the workshop, the informants could express their risk images in comments and as answers to questions from the interviewer or from other participants in the group. Expressed images of IO in general varied from opportunities based on technology to changes in organizations and competences. The definition of IO, and what kinds of technological and organizational changes this development comprises, was not clear in any of the statements from companies or in official reports. Images of IO, therefore, were related to the informants' experiences with IO in their own environments and from what they had read or heard outside their own organizations or positions at work.

The analysis showed that the informants' statements revealed such consistent patterns of reasoning on risk images that it became empirically feasible to group them into distinct categories that could describe the features of the risk images:

- Technological optimism;
- Traditional risk images; and
- Reconfigured risk images.

The dominant point of view in the technology optimism risk image is that things seem to be in good shape and that there is no specific reason why this should not be the same, or better, as progress is made towards more advanced IO. According to the traditional risk image, IO means business as usual. The development of IO is not seen as significantly introducing new kinds of risks and the view is that risks in IO can be handled with traditional measures. The development and implementation of IO does not call for any specific increase or change in risks compared with traditional operations. The reconfigured risk image is characterized by acknowledging that IO is something that moves the operation of petroleum production from a more closed to a more open system, and that this may be considered a significant change in perspective. It may be that making this acknowledgement is essential for constructing risk images related to IO.

The second finding from the analysis was that the distribution of the three types of risk images among different categories of informants was inconsistent. There seem to be no clear differences between groups when it comes to risk images, nor do those who may be labeled "experts" show a different risk image to the others. This finding supported the writing about the perspective-making process presented by Boland and Tenkasi (1995). The social arenas that the informants attend seem to contribute to the formation of what looks to resemble a kind of community of knowing where specialized knowledge workers interact in perspective making and perspective taking, facilitating the emergence of new meaning and knowledge.

The results from the study imply that we need further research on risk images among those that take part in risk appraisal, and that social science models such as social constructionism, arena models and knowledge about communities of knowing should be included to enable understanding of how risk images are constructed and formed in the process of risk appraisal.

## 6.2 Safety perception and comprehension within different groups

The background for the study was for the corresponding author related to studying safety culture and impacts on possibilities for accidents. In his work with data from the 2007 NORSCI, he came across significant differences in measured safety comprehension between the different groups; in particular, the fact that the OIM and the safety representatives showed a significantly more positive comprehension of the risk level and their ability to cope with risks when compared to the rest of the respondents. The OIMs also showed an overall significantly more positive comprehension compared to the safety representatives. Though differences in risk comprehension between different groups and the more positive attitudes among managers are not unfamiliar in the research literature, the finding still attracted my interest. The NORSCI questionnaire of 2007 had been administered in the early days of the introduction of IO to offshore installations and I found it interesting to investigate the risk images of the offshore workers during this period, albeit only through their scorings on a questionnaire. I also found it interesting in relation to my previous study on risk images at the blunt end, where I had found that group belonging and organizational role had little impact on the forming of risk images. This made it interesting to look into what influences an individual's comprehension of risk and how this influenced a group of people, such as the OIMs.

The OIM is responsible for all matters of health and safety on board an offshore installation. The OIM also supervises the day-to-day aspects of the oil and gas production operation, generally including budgets, personnel, production, maintenance, and logistics (helicopters/supply boats/dive vessels, etc.). The OIM represents a key link between the onshore and offshore facets of the organization, and as such the OIM plays an important role in communicating the safety message from senior levels within the onshore organization to the workforce at the sharp end. OIMs have a critical role to play in developing and maintaining the safety culture in the offshore environment.

Safety representatives play an important role in occupational health and safety management on offshore platforms. All installations have a safety representative. The safety representative can have different titles such as Offshore Safety & Environment Coordinator, Safety Leader and Safety Manager. At some installations the function is shared with the role of being a trained nurse. The safety representative is usually a part of the OIM's leadership team and emergency management team. The safety representative is usually the contact person with the government and has responsibilities related to tracking and reporting safety, health and environment issues.

Reasons for differences in responses between groups may be related to socially desirable responding, cognitive biases and power and conflict issues. Socially desirable responding is related to the respondent's role in society or in an organization as well as a number of other attributes of the person. A response bias is a systematic tendency to respond to a range of survey items on a basis that is different from the content of the item. Socially desirable responding has been identified as a tendency to answer in a way that makes the respondent look good (Paulhus, 1991). What is socially desirable depends on the situation and the individual's perception of what is desirable in their situation. For a group to answer homogenously in a socially desirable way, the group must be uniform to a large extent, and the surroundings must be comparable for the different individuals of the group. There is no indication that socially desirable responding is controlled for in the NORSCI survey. There is still little evidence of systematic differences between groups in their tendency to answer in a socially desirable way. Cognitive biases may lead individuals to perceive less risk. Cognitive biases are common types of mental shortcuts used to make judgments. Overconfidence refers to the failure to know the limits of one's knowledge. The illusion of control occurs when individuals overemphasize the extent to which their skill can increase performance in situations where chance plays a large part and skill is not necessarily the deciding factor. Because the individuals believe that they can control largely uncontrollable events, they also think they can accurately predict the outcome of the events. Issues of power and conflict are rarely addressed in safety comprehension research. Safety issues, like other organizational issues, are subject to discussion and disagreement. Although most organizations in the oil and gas production sector in Norway are normally nonhierarchical in nature, power issues of course exist. Hierarchy and authority discussions arise in safety- and efficiency-related issues as well as in emergency handling, where it is natural that the emergency organization has clear leadership and strict procedures for handling resources and information.

Our findings echo the fact that the managers of organizations who are closer to the planning and strategy of the operation generally express a more positive view of the safety level. The findings thus correspond to previous research, although the OIMs and the safety representative have not been isolated as groups in such studies. In later studies, it will become important to address the role of groups that show a different risk comprehension than others in the construction of risk images.

## 6.3 Resilient planning of modification projects in high-risk systems

Following the study of risk images of operations within the offshore petroleum industry and the introduction of IO, the plan was to look at how to assess risks in such a system. The background consists of the argument that traditional risk assessment methods may be insufficient when assessing risks in a complex socio-technical system with a great deal of uncertainty about what may or may not be risky. The chosen case was one of the areas where IO had been described as something that would have an impact on how it was handled: the modifications and maintenance work for offshore installations. The aim of the study was to investigate how risks may be identified in a complex system with interactions between persons, technology, organizations and parallel processes. It was the planning phase of modifications on a mature installation that has earned the right for a prolonged life partly because of new technological development that was chosen as the case for studying how a systemic risk model and method like the Functional Resonance Analysis Method (FRAM) may be applied in risk assessment. FRAM has previously been used to identify emergent risks due to the variability of normal performance in the minimum safety altitude warning system (MSAW) within air traffic control (L. Macchi et al., 2009).

The planning phase of a modification project is typically described in procedures. The procedure is a detailed description of all aspects to consider and attend to in a planning phase. The described procedure is very detailed and thorough in order to account for any installation in the company. As with most procedures like this, the way work is conducted relates to the procedure, but a more manageable "procedure" is used in daily work. This daily "procedure" is not described in manuals or the like, but is shown through the tasks, meetings and documentation that are carried out when planning for modifications. In line with the FRAM analysis, the functions identified for the analysis are the ones observed in work as done, not in work as planned in the guidelines.

The identification of risk in FRAM is based on the evaluation of the variability of normal performance. How to evaluate variability is under discussion within the development of the method, and some different attempts had been presented elsewhere. My application of FRAM was on an operation at the organizational level and I found that the variability may be evaluated slightly differently than in a previous study where FRAM had been used for risk assessment. I found that organizational functions are not stable for the system I assessed; in fact, organizational functions (providing resources, allocating budget, etc.) may vary over the time span for the planning phase, which may last several months (e.g. time of year for budgets and seasonal variations for staffing and personnel). Also, I found that technological functions are not necessarily stable, though they may be designed for stability. It could be argued that they may vary (in performance, due to power supply and network access, access to information in protected data catalogues, etc.) and have the possibility of dampening variability by providing warnings and alarms. I found it important to evaluate variability in the interwoven socio-technical system, not treating technological functions as different from human or organizational functions.

The evaluation of performance variability revealed several interesting results that shed light on possible risks in the planning phase. Hidden or not easily accessible information about the system where the modification takes place causes unwanted variability. Growing organizations with an introduction of new employees that do not know the history of the installation also causes variability. In combination, this constitutes variability that may lead to unwanted outcomes from the planning phase. It probably leads to more delays than necessary and thus jeopardizes the precision in the decision to execute for pre-engineering. It was also found, though not properly shown in the analysis, that more complexity is introduced as there are parallel modification projects going on in different phases of planning and execution.

It may also be a source of unwanted variability that the procedure for modification projects is detailed and to a large extent far away from the daily carrying out of the planning phase. As any “normal way of doing it” then becomes a habit that has little reference to any general description that is accessible to all, different mental models of “how it is done” and “how thorough this needs to be” may develop in the organization.

Safety and efficiency in modification planning may be improved by showing “work as is” more than “work as planned.” The FRAM model may be a helpful tool in the way it stresses that each function has an origin, this being that all aspects can be related to other aspects of other functions.

It may also dampen variability and thus functional resonance to make information about the system and installation (models, drawings, historic data, etc.) visible and accessible to all and to work as a team and not as two separate organizations in the work of planning and carrying out the modification. Modification planning will benefit from the sharing of updated and real-time information of the installation and the systems. In order to dampen variability that may stem from other modification projects as more proposals are made and more modification projects are carried out in parallel, it may be useful to develop a FRAM model for the system of parallel modification projects and identify variability that should be dampened.

The study revealed that further development of FRAM as a risk assessment tool is needed in order to make FRAM a manageable and practical tool for use in the industry. This especially applies to the evaluation of possible variability and how this should be presented.

## 6.4 Building resilience into emergency management

Emergency management faces a changed reality in terms of possibilities and threats with the introduction of new technology and related changes in work forms as well as organizational forms. In the study we attempted to look at how new technology and new work processes influence emergency management in the oil and gas industry, with the introduction of IO. Emergency management had not been singled out as an area where IO would have influence. In fact, it was the general opinion in the industry that emergency management should be left alone. This view was expressed in many settings when we first started our study on defined situations for hazards and accidents.

Emergency management may be defined as the total amount of activities (both administrative routines and informal processes) conducted in a more or less coordinated way to control emergencies before, during and after an event. This includes planning, training handling, learning, anticipation and monitoring. This definition is broader than most definitions of emergency management, as they mainly focus on emergency handling during an event.

The theoretical basis of the study was taken from the field of RE and HRO. Both perspectives are relevant for handling emergencies as well as representing a proactive approach to emergency management. RE looks for ways to enhance the ability of systems to succeed under varying conditions (Hollnagel, 2009b). This includes the ability to respond effectively to both expected and unexpected conditions; to monitor both threats and opportunities; to anticipate future developments that may affect the system's ability to achieve its goals; and to learn from past events in order to correctly understand both what happened and why. The HRO literature provides input on how organizations develop a capacity to handle unexpected events and detect risk. The theory is grounded in studies of organizations that have demonstrated an outstanding capacity to handle fairly complex technologies without generating major accidents (LaPorte & Consolini, 1991; G. Rochlin, 1997). Important aspects from this research tradition are organizational redundancy and the capacity of organizations to adapt to peak demands and crises (Weick, 2001; Weick & Sutcliffe, 2001, 2007). In HRO theory, mindfulness points to a constant awareness and an ability in an organization to search for evolving practices and mechanisms to handle the unexpected through the principles of anticipation and containment.

The interest in studying emergency handling from a resilience point of view also came from the literature study. From a total of 16 reports from accident investigations conducted by the safety petroleum authority during the period 2007–2009, we found deficiencies in risk anticipation and assessment in 11 of the reports (eight out of eight occupational accidents and three out of eight major accidents). Deficiencies in learning were found in four of the reports (all major accidents), and deficiencies in monitoring were found in three of the reports (all major accidents). Nevertheless, the emergency response (evacuation of personnel, rescue, etc.) was described as sufficient in seven of the 16 reports (four occupational accidents and three major accidents).

We carried out two observation studies of training sessions and arranged a workshop with participants from the industry where the future of emergency management was debated. The overall question asked to the group at the beginning of the workshop was “Which opportunities and challenges do you foresee related to emergency handling in 2015?”

Results indicate that there are possibilities for more efficient and earlier handling of possible hazardous deviations in the transition stage between normal operation and emergency handling. This acknowledgement is supported by the introduction of new technology and work processes and more integrated information. The main results are related to *early risk anticipation*, *interaction between different actors*, and *communication during distributed emergency handling*. The results are relevant for opportunities that should be incorporated into the future of emergency management, as well as representing challenges that follow the introduction of IO.

Both the observation studies and the workshop revealed that there was a need for more focus on detecting and responding to deviant situations at an earlier stage. The role of the recently established operation centers that (continuously) support the operations offshore and how these could be involved at an early stage was an issue. Early anticipation of events was generally described as non-existing or hidden, outside the emergency management teams.

The challenges regarding interaction between actors were related to the increased number and complex map of actors involved in emergency handling in the industry due to changes brought on by IO. These actors are different in terms of responsibilities, interests, proximity to hazard and resources, and thereby there is a need to focus on new forms of cooperation, coordination and awareness when planning and handling emergencies. Furthermore, it was identified that involvement of some of these actors at an earlier stage in normal operation and in developing new ways of including these actors in emergency management could be a step in the right direction in detecting deficiencies or a drift from normal operation to incidents or accident situations.

Communication challenges in existing emergency management were related to the increased number of actors and the large amount of available information. Sharing of information in real time plays an even more crucial part than before in the coordination of activities at different vertical and horizontal levels in emergency handling. It was found that both poorer and richer forms of communication should be used, but that these have both strengths and weaknesses in emergency handling that need to be considered further. Additionally, the reliability and integrity of the information shared and received in an emergency situation should be seen as important factors when reviewing the data, channels and tools used.

There may be different approaches to designing resilience into a system. An organization should aim to identify potential contingencies in order to ensure an effective, customized response to such situations (first layer of defense), but it is not possible to accomplish this for all contingencies. A second layer of response should be to identify contingencies at a less complete level of detail and to develop generic responses to these. A third level of defense is needed for complex systems, one that makes it possible to detect and respond to novel and yet unanticipated scenarios. One of the main key factors for achieving this may be the onshore teams being introduced with IO. These teams monitor and work with real-time data, which means that more people see the same things within the operation. Expert knowledge is often used in onshore teams. Their knowledge and expertise may imply a reluctance to simplify and more sensitivity to the operations. This may move the focus of handling crises from handling top events. The implications of the changes will be changed scenarios for, and roles within, emergency management training sessions. In order to prevent distrust in new tools and unfamiliarity with new work forms and new actors, the use of collaboration tools and technology for information sharing must be expressly considered in training sessions.

## 6.5 Essence of articles

The articles outlined above may be summarized as follows based on the research questions outlined in the general problem formulation in section 1.5:

*What risks are people aware of in the early phases of IO development?*

Risk images at the starting point of IO were characterized by technology optimism and traditional risk images, though reconfigured risk images exist, mainly among researchers and others who are further away from the implementation of IO. At the starting point of IO development, offshore workers were generally satisfied with the handling of risks though differences existed between OIMs that perceive a lower risk level than the remaining population. The results also suggest that risk images are influenced by which group stakeholders belong to or which arenas they have attended. There may be possible bias among stakeholders of risk management and technology development.

*How may risk be managed in an increasingly complex system such as IO?*

The results from the FRAM analysis of the planning process of modifications suggest that risks stemming from root causes such as information breakdown may be captured by systemic risk models. Such models may help the management of the risks in the reconfigured risk image found in Paper 1.

*How may IO influence the way of working in crisis management?*

Emergency handling will benefit from adapting to the technological changes with IO and may become more proactive in the management of risks if new technology is used wisely. Nevertheless, relying solely on modern information communication technology in crisis handling is risky.

The general finding from the articles is that one cannot be too sure that the risk level remains the same as technological alterations introduce new risks or changed ways of handling risk, though some risks are reduced due to the new technology.

# 7 Discussion and concluding remarks

The question asked at the start of this thesis was: *How do technological alterations influence risk comprehension and management in a high-risk industry?* I chose the technology-driven development called "Integrated Operations" (IO) as an arena to study this question. Through my work I have tried to understand what IO within the Norwegian offshore petroleum industry means, especially in relation to what the risks are within this development. I have tried to uncover the risk images that existed in the early days of the transition from traditional operations to IO, and how to assess and manage these risks. IO in the offshore petroleum production industry is many things. IO includes technology, work processes, organizational developments and changes, and importantly the general information technology development in the society. In order to grasp this broad picture I have taken a constructivist perspective. The constructivist perspective enabled me to study risk images of inexperienced situations based on the perception and comprehension of descriptions and early IO initiatives within the industry. The constructivist perspective also enabled my perspective on risk image forming as processes in arenas with various participants rather than as processes in hierarchical structures.

The existing research had not revealed specific knowledge on how the altered technology in IO influenced risks, nor how possible altered risk images were formed. In general, there was a lack of research on the implications of altered technology on work processes in high-risk environment.

I have tried to capture a broad image of risk, risk assessment and risk handling through the socio-technical perspective of safety. The socio-technical perspective treats technology and human beings as equal entities, and presumes that social processes and technological entities are inherently inseparable. The socio-technical perspective forced me not only to study the technological development, nor only the organizational changes, but also to look at all entities of IO development as inseparable agents that influence each other. This also directed my research to everyday practices where the material and the social actors interact.

I have focused on three research questions: *From a socio-technical and socio-material point of view, what risks are people aware of in early phases of IO development? From a system perspective and considering a specific work process, how may risk be managed in an increasingly complex system such as IO? And finally, not all work practices were in focus for the IO development, leading to the final question: How may IO influence the way of working in crisis management?*

The theoretical perspectives were chosen because they all involve technology as an element that humans and the organization must manage, though the technology in these theoretical perspectives is static elements that do not change. The general constructivist perspective, as an open-minded approach to the forming of risk images, was chosen due to my belief that risk images involve technology, either in a static or dynamic phase, as well as human actions and organizational aspects.

## 7.1 Risk images in early phases of IO

I asked the following question related to this field of interest at the beginning of my thesis: From a socio-technical and socio-material point of view, what risks are people aware of in early phases of IO development? Also: What risk images exist between stakeholders of IO at the blunt end (far from where the operation takes place)? Is risk comprehension equally distributed in different groups of offshore petroleum workers at the sharp end (close to where the operation takes place)?

The study of risk images among stakeholders at the blunt end and OIMs and safety leaders at the sharp end shows that different risk images exist in the industry. Risk images may be within what can be called a traditional area where people think that the industry knows how to handle the risks of any matters, including IO. Others rely on the technology reducing the risk as it removes unreliable humans from dangerous operations. Some face IO with a reconstructed risk image, where they regard IO as significantly different from traditional operations and thus they see that new risks may come along with such a transition. Are risk images individual or do groups also differ in how they perceive risks? Not necessarily. Findings from one of the studies (covered in Paper 2) indicate that managers perceive risks in a different way than others such as the sharp end workers do on the NCS, whereas these findings are not confirmed within the study of risk images among stakeholders of IO where some sharp-enders were included (treated in Paper 1). Such findings are supported in studies of risk perception, but the underlying reasons for this difference and how the different risk images are formed are rarely addressed in risk perception studies. Different methodical assessments may influence the findings, as may the forming of groups that may be different in other studies. Also, the OIMs and other sharp-enders were asked about the present state of risk in 2007, whereas the stakeholders in the risk image study answered questions about future risks. At the sharp end in 2007–2008 IO was new, and few had experienced risks with it or felt "that was close..." when operating in an IO setting. They may not have been exposed to risks related to IO. The stakeholders at the blunt end had neither been exposed to any risks or hazards related to IO, though some of them were presented with possible future accident scenarios.

Based on the study of risk images among stakeholders it seems that the reasons for differences in risk images are not related to background or experience in traditional terms of education or role in organizations, but rely more on the areas of how people attend to and are exposed to risk and safety utterances from others and discussions about safety and risks. Risk images may differ among the informants due to social issues and personal factors, but there seems to be little support for such explanations in the data other than the possible loyalty issues among the managers. However, this is a hypothesis and not a finding, as loyalty or other social issues were not measured in the survey where the data set comes from. The offshore petroleum production industry in Norway is normally described as having a very flat hierarchy when it comes to authority and power, though power and authority issues do of course exist. The description of the Norwegian offshore petroleum industry as a flat structure with open arenas for all who like to attend at least holds when talking about arenas where people, safety and risks are discussed. These arenas are relatively open. People also tend to move between roles and positions in the industry and are thus exposed to several groups throughout their working life. Findings in this thesis related to risk images, perception and comprehension suggest that groups, either one's role in an organization or one's academic background, and arenas of discussion and debate such as conferences, seminars and workshops, matter in terms of the forming of risk images of technological alterations. Risk images both at the blunt and the sharp end differ between groups, meaning that risk management in general and in each organization may differ depending on representativeness in risk management groups and departments. It can be argued that the use of a constructivist approach to the forming of risk images has given new insight into how risk images are formed.

### 7.1.1 The belief in technological development

Technology optimism is found in this industry as well as in others. The improvements in safety in the offshore oil and gas production in Norway are partly based on technology development such as sensors, emergency shutdown systems, safety valves, etc., and this explains much of the technology optimism risk image in the industry. Limitations in the technology are barely addressed in accident investigations. Deviations from procedures, lack of risk analysis of operations, lack of competence etc. are addressed in the investigation and normally attributed to deficiencies in the organization. The belief that development in industries "saves the day" and decreases risks on a general level is also partly the basis of Turner's Man-made Disaster Theory (B. A. Turner, 1978; B. Turner & Pidgeon, 1997), where new elements are not necessarily seen as a threat that may lead to narrowed interpretation. It is generally argued that technological development has formed the basis for growth in the Norwegian petroleum industry as well as having a strong impact on safety issues. There is a strong belief in the use of physical and organizational barriers for accident prevention. The energy-barrier perspective (Haddon, 1980) as a risk mitigation perspective is found in most regulations and manuals in the industry, and measures taken based on the energy-barrier perspective have traditionally proved to be effective. Based on the history of technology development as being successful for the industry with respect to safety issues, I argue that technology optimism is also a traditional risk image. Technology and automation of human operations (e.g. on the drill floor) have been seen as improvements rather than threats.

## 7.2 Risk management in an increasingly complex system

My second research question was: From a system perspective and considering a specific work process, how may risk be managed in an increasingly complex system such as IO?

According to some authors, maintenance errors (including what is described as minor modifications in this thesis) have been among the principal causes of several major accidents in a wide range of technologies (Reason & Hobbs, 2003). Within the oil and gas sector, the Piper Alpha accident (1988) is the best known. In their book of 2003, Reason and Hobbs focus on the human errors related to human interactions with equipment and systems and on the error-provoking conditions that one must try to avoid in high-risk technology environments. On the organizational level, it is argued that maintenance personnel come in contact with the largest number of failures at an earlier stage of development. In the HRO tradition, maintenance work is described in relation to "being preoccupied with failure" as a process of mindful organizing (Weick & Sutcliffe, 2001). Maintenance departments in HRO may become central locations for organizational learning (Weick et al., 1999). As maintenance and modification work processes were identified in early publications on IO as areas in which IO would have a strong impact, I chose the planning phase of minor modification projects as a case for the assessment of risks. The study showed that there are many possibilities for variability in performance of the planning process. The variability in performance may interact in such a way that hazardous situations emerge. The variability is mainly due to a lack of proper information and communication between organizations, which may lead to the right information about the history and state of an installation not being present or found. If the future image of IO in which the seamless integration between operator and vendor companies comes true, some of these issues may be addressed, but problems will still be present for mature installations where critical safety information and history may be impaired or lost. I propose that socio-technical, systemic models of, for example, modification projects, where risk is assessed continuously and through the evaluation of the possible emergence of hazards due to unwanted variability, is a promising approach to deal with such a challenge. It is important that risk assessment is conducted in an arena where all have access, including contractor personnel, sharp-end workers, planners, etc. The FRAM model may offer the opportunity to include all necessary evaluations, and to continuously reassess risks. This is important in order to ensure that all parts of a resilient organization are present: monitoring, learning, anticipation and response. Efforts should be made not only to dampen unwanted variability, but also to support wanted variability in performance. Within the planning phase of minor modifications on a mature installation that is operating within an IO context, this may be things like making information about the history of the aging installation available to all and making it easier to exchange real-time information between the operator and the contractor organization. Organizational borders should be torn down in order to support integration between employees that share the same goals for their work: safe and efficient modifications.

## 7.3 IO influence on crisis management

The third research question asked was: How may IO influence the way of working in crisis management?

The need for more proactive safety management was emphasized in the study of emergency management. It was found that emergency management traditionally starts too late, losing the opportunity to handle deviances in system performance at an early stage where the escalation of events into an accident may be hindered. Accident investigation reports indeed show that this opportunity is missed and may even contribute to the accident. A read-through of 16 reports from the period 2007–2009 revealed that attention is drawn to matters that indicate insufficient risk anticipation and evaluation. The investigations revealed inadequate learning in organizations by pointing to insufficient learning from earlier similar incidents or accidents, since they have not changed any procedures, behaviors or attitudes towards safety in similar operations.

In IO, the use of onshore support teams in normal operation has enabled a conversion into a dynamic problem-solving work process rather than an "expert-on-call in case of problems" way of working. The handling of crises still seems to be either "on" or "off"; the emergency-handling organization is established by a call in case of emergency, usually late in the problem-solving process. In order to become more adaptive and resilient in the handling of operational problems, emergency management needs to include the transition period from normal operation to the actual emergency handling by use of available resources, such as the different support centers, in a more coordinated manner. The claim that most emergency management models are based on a belief that the system is known or knowable, i.e. that the cause and effect are understood and predictable or can be determined with sufficient data (S. French & Niculae, 2005), makes the concern that traditional emergency management may not be able to handle emergencies in the IO context even more considerable. In various phases of the transition from traditional operations, the "IO system," with all its new or altered technology, is probably less known or not known at all. Crises in such systems may be difficult to handle based on pre-established scenarios and procedures. Handling of major accident events is mainly characterized by systems or situations that are either complex (i.e. cause and effect may be explained after the event) or chaotic (i.e. cause and effect are not discernible).

It was suggested that new operational teams onshore, as well as other actors that may anticipate risks in operations at an early stage, should be more integrated in the emergency management organization, meaning making use of the technology introduced with IO rather than avoiding it. The ICT that accomplishes IO, as well as technology specially adapted for the emergency-handling area, may help this integration and move emergency management into proactive rather than reactive management if the technology is properly introduced without disturbing the trust in the tools, technology and people within emergency handling. The results from the study of emergency management in offshore petroleum operations in an IO context may have relevance for emergency management outside the oil and gas industry, as other sectors such as energy supply, the financial system and transport systems also face challenges with new technology and distributed organizations. The challenges with emergency management in other industries, and especially at the societal level, have been exposed to disasters and accidents in the last few years, and seem to resemble the challenges that were seen in our study.

## 7.4 Socio-technical systems with considerable leeway for action

It was argued in the introduction of this thesis that IO and the technology that supports the transition can be interpreted in different ways. People, through project groups in the organizations, must find out how to use the technology themselves, whether it is ICT in meeting rooms or in the offices and workplaces, sensor technology that provides data from the wells or automated production-optimizing tools. As use of the technology is uncertain and changes depending on who uses the technology and who operates the installation, it is a socio-technical system that is difficult, if not impossible, to describe in detail. It is a system that can be described as complex and intractable. Such a system will always be underspecified; work procedures may help some situations, but they will be insufficient for many operations.

## 7.5 Will the industry enter an incubation period?

At present it seems that the offshore oil and gas production industry in Norway has left the concept of IO as something that needs special focus. IO as a concept has been removed from websites and other focus areas have taken its place. This does not mean that the development and the transition period have ended. The process still goes on, but with less attention from top management and probably also from researchers. The status is that the oil and gas industry is entering a tail end period, with lower production and fewer discoveries of large fields of gas or oil, though some exceptions exist. In order to maintain the market goals, the oil companies will have to move north, into harsher environments and drilling for and production of petroleum in deeper and less accessible fields. The IO images have been the new fields that are used for promotion – the reality is that many older fields that should have been closed down for production by now still operate and receive prolonged life expectancies because of technological development and changes in the market situation. These installations must be modified to meet standards and requirements, a topic that I have assessed in the study of modifications of a mature installation (Paper 3).

I have shown that the industry has a strong belief that strict procedures are effective means of meeting hazards and challenges. The procedures are only valid to the extent that they fit the surroundings in which they are used. Modifications influence the construction and functioning of the installations and it is often found that procedures and drawings are not updated to match the modified system. It may then be that parts of the industry imagine that they have the barriers to handle hazards, but it is very possible that they do not. It follows that it may be argued that, not only because of IO but because of IO in combination with aging installations that have undergone many modifications, the industry may face a process similar to that described by Turner and Pidgeon in their Theory of Man-made Disasters (B. A. Turner, 1978; B. Turner & Pidgeon, 1997). The strong belief in technology and that IO "saves the day" may lead to narrow-minded risk comprehension and to deviances and incidents being left unnoticed or misunderstood. The chance is that this becomes an incubation period, with chances of "decoys" that distract attention from real problems. Drilling for and the production of oil and gas are never risk-free and safety barriers are vulnerable, as has been shown in the recent Deepwater Horizon accident in the Gulf of Mexico.

## 7.6 Technological alterations' influence on risk comprehension and management in a high-risk industry – concluding remarks

Overall, though the development of IO has followed its planned path, little attention has been paid to the risk assessment of the whole socio-technical system and how other parts of the system are influenced by changes in the system parts that are in focus.

I find evidence from my study that altered risk images are formed at an early stage of a technological development, and that risk comprehension is influenced by the technology involved in the development as well as one's position in groups such as being part of the management. The strong belief in barriers as efficient risk- or consequence-reducing factors is based on experience and will also influence the individual's perception of risk in future IO work processes.

Changes in risk management related to the development of IO were not evident in my study. The industry still relied on traditional risk assessment, and emergency management did not enter a significant transition period during the period of this study. This was the case, even though IO generates changes in different elements of the operation system and the interaction between these elements that may lead both to accident scenarios and changes in how accident scenarios may be handled.

Among those who regarded new technology as more than just "black boxes," but rather as a known manner of operation but with uncertain influence on work in the industry, it was possible to see how the technology will work in a socio-technical or system perspective. In their view, the technologies were "actors," though the phrase was not used by the informants.

Accident investigations of most major accidents reveal unbalance in the human-organization-technological system, often referred to as the MTO model, and in the interaction between the different items of this model. My argument is that there is no need to wait for a major accident associated with IO before the industry should plan for managing the altered risk image that accompanies it. It will be difficult to establish probabilistic risk analyses, but it is possible to identify possible accident scenarios. The risks should be treated as accident scenarios that have not yet happened. These possible accident scenarios can be included in training for emergency management and in plans for competence and roles in the teams that operate the IO-based operations. It is possible to establish arenas where stories about the changed way of working in the industry could be communicated and discussed across organizational borders. The industry, including the authorities and the unions, has a good history of cross-group cooperation regarding health, environment and safety issues. The stories on how IO has improved safety are important in these arenas, but stories about the concerns and intuitions of uncertainty are crucial for maintaining a resilient, highly reliable industry that is able to anticipate and respond to risks before they combine and emerge as major accidents.

This calls for a revitalization of the social-technological perspective and new research on this perspective within the organizational-safety research area. Theoretical perspectives presented in this thesis are promising but need to be reviewed in the light of safety, especially related to risk assessment and management.

# 8 References


Alexander, D. (2003 ). Towards the development of standards in emergency management training and education. *Disaster Prevention and Management,, Vol. 12* (Iss: 2), pp.113 - 123.

Apneseth, K. (2010). *Resilience in integrated planning.* Master thesis, Norvegian university of science and technology (NTNU).

Berger, P. L., & Luckmann, T. (1966). *The social construction of reality a treatise in the sociology of knowledge*. Harmondsworth: Penguin.

Boland, R. J., & Tenkasi, R. V. (1995). Perspective making and perspective taking in communuties of knowing. *Organization Science, 6*(4), 350-372.

Brattbakk, M., Østvold, L.-Ø., Zwaag, C. v. d., & Hiim, H. (2004). Granskning av gassutblåsning på Snorre A, brønn 34/7-P31 A 28.11.2004. Stavanger: Petroleum Safety Authority.

Callon, M. (1986). Some elements of a sociology of translations: Domestication of the scallops and the fishermen in St Brieuc bay. In J. Law (Ed.), *Power, action and belief: A new sociology of knowledge*. London: Routledge.

Clegg, S., Kornberger, M., & Pitsis, T. (2008). *Managing and organizations: an introduction to theory and practice*. Los Angeles: SAGE.

Damasio, A. R. (1994). *Descartes' error: emotion, reason, and the human brain*. New York: Grosset/Putnam.

Denzin, N. K., & Lincoln, Y. S. (2008). *Collecting and interpreting qualitative materials*. Los Angeles, Calif.: Sage.

Emery, F. E. (1959). Characteristics of socio-technical systems. London: : Tavistock Institute.

Emery, F. E., Thorsrud, E., & Trist, E. (1969). *Form and content in industrial democracy: some experiences from Norway and other European countries*. London: Tavistock.

Emery, F. E., & Trist, E. L. (1960). Socio-technical systems. In C. W. C. a. M. V. (eds) (Ed.), *Management science,models and techniques* (Vol. 2, pp. 83-97): Pergamon.

Endsely, M. R. (1995). Measurement of situation awareness in dynamic systems. *Human Factors, 37*, 65-84.

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in dynamic systems. *Human Factors, 37*, 32-64.

Endsley, M. R. (1997). The role of situation awareness in naturalistic decision making. In Zambok & Klein (Eds.), *Naturalistic decision making,* (pp. pp296-284). Mahwah: Erlbaum.

Farner, A. (2008). *Verksted som verktøy / å planlegge og lede workshops* (2. utg. ed.). Oslo: Kommuneforl.

Flin, R., Mearns, K., O'Connor, P., & Bryden, R. (2000). Measuring safety climate: Identifying the common features. *Safety Science, 34*(1-3), 177-192.

Flin, R., & Slaven, G. (1993). Managing offshore installations: A survey of UKCS offshore installation managers. *Petroleum Review, 47*, 68-71.

Flin, R., & Slaven, G. (1994). The selection and training of offshore installation managers for crisis management. In H. Books (Ed.). Aberdeen: HSE.

Flin, R., Slaven, G., & Carnegie, D. (1996). *Managers and supervisors on offshore installations. Managing the Offshore Installation Workforce*. Tulsa: PennWell Books.

French, S., Carter, E., & Niculae, C. (2007). Decision support in nuclear and radiological emergency situations: Are we too focused on models and technology? *international journal of emergency management, 4*(3), 421-441.

French, S., & Niculae, C. (2005). Believe in the Model: Mishandle the Emergency. *Journal of homeland security and emergency management, 2*(1).

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory strategies for qualitative research*. Chicago: Aldine.

Groth, L. (1999). *Future organizational design: the scope for the IT-based enterprise*. Chichester: Wiley.

Grøtan, T. O., Albrechtsen, E., Rosness, R., & Bjerkebæk, E. (2008). *The influence on organizational accident risk by integrated operations in the petroleum indusrty*. Paper presented at the Working on safety conference, Crete.

Grøtan, T. O., Størseth, F., & Albrechtsen, E. (2010). Scientific foundations of risk in complex and dynamic environments. In R. Bris, C. G. Soares & S. Martorell (Eds.), *Reliability, risk and safety: Theory and applications* (pp. 437-444). London: Taylor and Francis group.

Guldenmund, F. W. (2000). The nature of safety culture: a review of theory and research. *Safety Science, 34*, 215-257.

Haddon, W. (1980). The Basic Strategies for Reducing Damage from Hazards of all Kinds. *Hazard Prevention, Sept/Oct*.

Hammer, M., & Champy, J. (1993). *Reengineering the corporation: a manifesto for business revolution*. New York: Harper Business.

Hammersley, M., & Atkinson, P. (2007). *Ethnography : principles in practice* (3rd ed.). London: Routledge.

Heath, C., & Luff, P. (2000). *Technology in action*. Cambridge: Cambridge University Press.

Hendrick, K., & Benner, L. (1987). *Investigating accidents with STEP*. New York: Marcel Dekker.

Herrera, I. A., & Woltjer, R. (2009). Comparing a multi-linear (STEP) and systemic (FRAM) method for accident analysis. In S. Martorell, C. G. Soares & J. Barnett (Eds.), *Safety, Reliability and Risk Analysis. Theoy, Methods and Applications* (Vol. 1, pp. 19-27): CRC Press, Taylor and Francis Group.

Hilgartner, S., & Bosk, C. L. (1988). The rise and fall of social problems. A public arenas model. *American Journal of Sociology, 94*, 53-78.

Hollnagel, E. (2004). *Barriers and accident prevention*. Aldershot: Ashgate.

Hollnagel, E. (2009a). The four cornerstones of resilience engineering. In C. P. Nemeth, E. Hollnagel & S. Dekker (Eds.), *Resilience engineering perspectives; Preparation and restoration*. Ashgate: Aldershot

Hollnagel, E. (2009b). *The ETTO Principle: Efficiency-Thoroughness Trade-Off . Why Things That Go Right Sometimes Go Wrong*. Aldershot: Ashgate.

Hollnagel, E. (2011). Epilouge: RAG - the resilience analysis grid. In E. Hollnagel, J. Paries, D. D. Woods & J. Wreathall (Eds.), *Resilience engineering in practice: A guidebook*. London: Ashgate.

Hollnagel, E., & Besnard, D. (2009). Project memo: Elaboration of different understandings of safety and risk management *Interdisiplinary risk assessment of integrated operations addressing human and organizational factors (RIO)* (pp. 9).

Hollnagel, E., Nemeth, C. P., & Dekker, S. (2008a). *Remaining sensitive to the possibility of failure*: Ashgate.

Hollnagel, E., Nemeth, C. P., & Dekker, S. (2008b). *Resilience engineering perspectives* (Vol. 1). Farnham: Ashgate.

Hollnagel, E., Paries, J., Woods, D. D., & Wreathall, J. (Eds.). (2011). *Resilience engineering in practice: A guidebook*. Farnham, Surrey, England ; Burlington, VT: Ashgate.

Hollnagel, E., & Speziali, J. (2008). Study on Developments in Accident Investigation Methods: A Survey of the "State of the Art": SKI.

Hollnagel, E., Woods, D. D., & Leveson, N. (2006). *Resilience engineering : concepts and precepts*. Aldershot: Ashgate.

Iannella, R., & Henricksen, K. (2007). *Managing Information in the Disaster Coordination Centre: Lessons and Opportunities.* Paper presented at the ISCRAM, Delft.

Jaafar, M., Aziz, A. R. A., Ramayah, T., & Saad, B. (2007). Integrating information technology in the construction industry: Technology readiness assessment of Malaysian contractors. *International Journal of Project Management, 25*, 115 - 120.

Johnsen, S. O., Ask, R., & Roisli, R. (2007). Reducing risk in oil and gas production operations. In E. Goetz & S. Shenoi (Eds.), *Critical infrastructure protection* (Vol. 253, pp. 83-95). Boston: Springer.

Kahneman, D., Slovic, P., & Tversky, A. (1982). *Judgment under uncertainty heuristics and biases*. Cambridge: Cambridge University Press.

Kasperson, R. E. (1992). The social amplification of risk: Progress in developing an integrative framework. In S. Krimsky & D. Golding (Eds.), *Social theories of risk*. CT, USA: Praeger Publishers.

Kasperson, R. E., Renn, O., Slovic, P., Brown, H. S., Emel, J., Goble, R., . . . Ratick, S. (1988). The social amplification of risk: A conceptual framework. *Risk Analysis, 8*(2), 177-187.

Kitschelt, H., & Offe, C. (1980). *Kernenergiepolitik Arena eines gesellschaftllichen Konflikts*. Frankfurt [am Main] and New York: Campus Verlag.

Kurtz, C. F., & Snowden, D. J. (2003). The new dynamics of strategy: Sense-making in a complex and complicated world. *IBM systems journal, 42*(3).

La Porte, T. R. (1975). *Organized social complexity: challenge to politics and policy*. Princeton, N.J.: Princeton University Press.

LaPorte, T., & Consolini, P. M. (1991). Working in practice but not in theory: Theoretical challenges of "high-reliability organizations". *Journal of Public Administration Research and Theory, 1*, 19-47.

Latour, B. (1987). *Science in action: how to follow scientists and engineers through society*. Milton Keynes: Open University Press.

Latour, B. (2005). *Reassembling the social: an introduction to actor-network-theory*. New York: Oxford University Press.

Leveson, N. (2004a). A New Accident Model for Engineering Safer Systems. *Safety Science, 42*(4), 237-270.

Leveson, N. (2004b). Model-based Analysis of Socio-Technical Risk *Working Paper Series*: Massachusets Institute of Technology Engineering Systems Division.

Levin, M. (2008). Organisasjonspsykologien som norsk fagdisiplin - skapt i skjæringspunktet mellom aksjonsforskning og disiplinær tradisjon. *Tidsskrift for Norsk Psykologforening, 45*(3), 301-307.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, Calif.: Sage.

Macchi, L. (2010). *Safety assessment methodology development: a FRAM analysis of Air Traffic Management performance variability.* PhD Monography, Mines Paris Tech Sophia Antipolis.

Macchi, L., Hollnagel, E., & Leonhard, J. (2009). *Resilience Engineering approach to safety assessment: an application of FRAM for the MSAW system*. Paper presented at the EUROCONTROL Safety R&D seminar, Munchen, Germany.

Mann, D. (1999). Using s-curves and trends of evolution in R&D strategy planning Retrieved February 14th, 2008, from http://www.triz-journal.com/archives/1999/07

Nemeth, C. P., Hollnagel, E., & Dekker, S. (2009). *Preparation and restoration* (Vol. 2). Farnham: Ashgate.

NTC. (2001). NORSOK Standard Z-013: Risk and emergency preparedness analysis: Norwegian Technology Centre.

Nystad, A. N. (2005). BRU project. A strategic plan for focused petroleum research at NTNU (D. o. p. e. a. a. geophysics, Trans.). Trondheim: Norwegian University of Science and Technology.

OLF. (2003). eDrift på norsk sokkel - det tredje effektivitetspranget Retrieved January 1. , 2010, from http://www.olf.no/getfile.php/zKonvertert/www.olf.no/Rapporter/Dokumenter/eDrift-rapport%202003.pdf

OLF. (2005). Integrated work processes. Future work processes on the Norwegian continental shelf Retrieved January 1. , 2010, from http://www.olf.no/rapporter/category229.html

OLF. (2006a). Potential value of Integrated Operations on the Norwegian Shelf Retrieved March 2011, 2011, from www.olf.no http://olf.no/no/Nyhetsarkiv/Integrerte-Operasjoner/250-milliarder-kroner-i-okt-verdiskaping-pa-norsk-sokkel/

OLF. (2006b). Verdipotensialet for Integrerte Operasjoner på Norsk Sokkel Retrieved January 1., 2010, from www.olf.no

OLF. (2007). HMS og Integrerte Operasjoner Retrieved January 1., 2010, from http://www.olf.no/getfile.php/zKonvertert/www.olf.no/Aktuelt/Dokumenter/070115%20-%20IO%20og%20HMS.pdf

OLF, N. O. I. A. (2004). Integrated Operations. Presentation from the first meeting for the steering group for digital services on the 19 October 2004, from http://olf.no/no/Nyhetsarkiv/HMS-og-drift/Ga-fagforeninger-status-om-e-drift/

Orlikowski, W. J. (2001). Improvising organizational transformation over time. A situated change perspective. In J. Yates & J. V. Maanen (Eds.), *Information technology and organizational transformation. History, rhetoric and practice*. Thousand Oaks: Sage Publications.

Orlikowski, W. J. (2010). The socio-materiality of organizational life: considering technology in management research. *Cambridge Journal of Economics, 34*, 125-141.

Orlikowski, W. J., & Barley, S. R. (2001). Technology and Institutions: What can research in information technology and research on organizations learn from each other? [Research article]. *MIS Quarterly, 25*(2), 145-165.

Orlikowski, W. J., & Scott, S. V. (2008). Chapter 10: Socio-materiality: Challenging the separation of technology, work and organization. *The academy of management annals, 2*(1), 433-274.

Palhus, D. L. (1991). Measurement and control of respons bias. In J. P. Robinson, P. R. Shaver & L. S. Wrightsman (Eds.), *Measures of personality and social psychological attitudes*. San Diego, California: Academic press.

Perrow, C. (1984). *Normal accidents living with high-risk technologies*. New York: Basic Books.

Perrow, C. (1986). *Complex organizations: a critical essay*. New York: McGraw-Hill.

Perrow, C. (1999). *Normal accidents living with high-risk technologies*. Princeton, N.J.: Princeton University Press.

Pidgeon, N., & O'Leary, M. (2000). Man-made disasters: Why technology and organizations sometimes fail. *Safety Science, 34*(1-3), 15-30

PSA. (2009). Aging and extending production life Retrieved August 6th, 2009, from http://www.ptil.no/priority-areas/extending-production-life-article4336-173.html (not available)

Rasmussen, J. (1997). Risk Management in a Dynamic Society. *Safety Science, 27*(2/3), 183-213.

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

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

Reason, J., & Hobbs, A. (2003). *Managing maintenance error a practical guide*. Aldershot: Ashgate.

Renn, O. (1991). Risk communication and the social amplification of risk. In R. E. K. a. P. J. M. Stallen (Ed.), *Communicating risks to the public: International perspectives.* (pp. 287 - 324). Dordrecht: Kluwer Academic Publishers.

Renn, O. (1992). Concepts of risk: A classification. In S. Krimsky & D. Golding (Eds.), *Social theories of risk* (pp. 53-79). Westport, Conn.: Praeger.

Ringstad, A. J., & Andersen, K. (2006, 2-4 April 2006). *Integrated Operations and HSE - major issues and challenges.* Paper presented at the SPE Int. Conf. on Health, Safety and Environment, Abu Dhabi.

Roberts, K. H. (1993). *New challenges to understanding organizations*. New York: Macmillan.

Rochlin, G. (1997). *Trapped in the net*. Princeton: Princeton University Press.

Rochlin, G. I. (1993). Defining"High Reliability" organizations in practice: A taxonomic prologue. In K. H. Roberts (Ed.), *New challenges to understanding organizations*. New York: Macmillan.

Rogers, E. M. (1962). *Diffusion of innovations*. New York: Free Press of Glencoe.

Rosness, R. (2004). *Organizational accidents and resilient organizations : five perspectves* (Rev. 1 ed.). Trondheim: SINTEF, Industrial Management, Safety and Reliability.

Rosness, R., Forseth, U., & Wærø, I. (2010). Rammebetingelsers betydning for HMS-arbeid (S. T. a. Society, Trans.). In SINTEF (Ed.). Trondheim: SINTEF.

Rosness, R., Grøtan, T. O., Guttormsen, G., Herrera, I. A., Steiro, T., Størseth, F., . . . Wærø, I. (2010). Organizational accidents and resilient organizations: Six perpectives (s. r. SINTEF Technology and society, Trans.) *SINTEF report* (Rev. 2 ed.): SINTEF.

Sassen, S., & Latham, R. (2005). *Digital formations: IT and new architectures in the global realm*. Princeton, N.J.: Princeton University Press.

Schiefloe, P. M., Vikland, K. M., Torsteinsbø, A., Ytredal, E. B., Moldskred, I. O., Heggen, S., . . . Syvertsen, J. E. (2005). Årsaksanalyse etter Snorre A hendelsen 28.11.2004 Stavanger: Statoil ASA.

Schjølberg, P. (2002). *Moderne vedlikehold* (Vol. NTNU 200205). Trondheim: Instituttet.

Senge, P. M. (1992). *The fifth discipline: the art and practice of the learning organization*. London: Century Business.

Senge, P. M. (1994). *The Fifth discipline fieldbook: strategies and tools for building a learning organization*. London: Nicholas Brealey Publ.

Senge, P. M. (1999). *The Dance of change: the challenges of sustaining momentum in learning organizations*. New York: Currency/Doubleday.

Sjöberg, L. (1999). Risk perception by the public and by experts: A dilemma in risk management. *Human Ecology Review, 6*(2), 1-9.

Sjöberg, L. (2009). Precautionary attitudes and the acceptance of a nuclear waste repository. *Safety Science, 47*(4), 542-546.

Skjerve, A. B., Albrechtsen, E., & Tveiten, C. K. (2008). Defined situations of hazards and accidents related to integrated operations on the Norwegian continental shelf. In SINTEF (Ed.): SINTEF.

Slovic, P., Finucane, M. L., Peters, E., & MacGregor, D. G. (2004). Risk as analysis and risk as feelings: Some thoughts about affect, reason, risk and rationality. *Risk Analysis, 24*(2), 1-12.

Slovic, P., Peters, E., Finucane, M. L., & MacGregor, D. G. (2005). Affect, risk and decision making. *health Psychology, 24*(4), 35-40.

Slovic, P., Pidgeon, N. F., & Kasperson, R. E. (2003). *The social amplification of risk*. Cambridge: Cambridge University Press.

Suchman, L. (1996). Constituting shared workspaces. In Y. Engstrom & D. Middleton (Eds.), *Cognition and communication at work* (pp. 35-61). Cambridge: Cambridge university press.

Suchman, L. A. (2007). *Human-machine reconfigurations : plans and situated actions* (2nd ed.). Cambridge: Cambridge University Press.

Thorsrud, E., & Emery, F. E. (1969). *Mot en ny bedriftsorganisasjon: eksperimenter i industrielt demokrati*. Oslo: Tanum.

Tichy, G. (2004). The over-optimism among experts in assessment and forsight. *Technological Forecasting & Social Change, 71*, 341 - 363.

Trist, E. L., & Bamforth, K. W. (1951). Some social and psychological consequences of the Longwall method of coal-getting: An examination of the psychological situation and defence of a work-group in relation to the social structure and technological content of the work system. *Human Relations, 4*(1), 3-38.

Turner, B., & Pidgeon, N. F. (1997). *Man-made Disasters* (2nd ed.). London: Butterworth-Heinemann.

Turner, B. A. (1978). *Man-made disasters*. Bristol PA: Taylor & Francis, Incorporated.

Tveiten, C., Lunde-Hanssen, L.-S., Grøtan, T. O., & Pehrsen, M. (2008). What is actually implied by integrated operations? Understanding the phenomenon and generic elements with a potential impact on the risk of system accidents: IO Center NTNU.

Tveiten, C. K., Albrechtsen, E., & Skjerve, A.-B. (2009). Defined Situations of hazard and accident related to integrated operations on the Norwegian continental shelf In R. Bris, C. G. Soares & S. Martorell (Eds.), *Reliability, risk and safety. Theory and applications* (pp. 2183 - 2190): Taylor and Francis.

Tveiten, C. K., & Schiefloe, P. M. (2009). Risk Images in Integrated Operations. In S. Martorell, C. G. Soares & J. Barnett (Eds.), *Safety, Reliability and Risk Analysis, Theory, Methods and Applications* (Vol. 4). Leiden: Taylor & Francis.

Vaughan, D. (1996). *The Challenger launch decision : risky technology, culture, and deviance at NASA*. Chicago: University of Chicago Press.

Weick, K. E. (1979). *The social psychology of organizing*. Reading, Mass.: Addison-Wesley.

Weick, K. E. (1995). *Sensemaking in organizations*. Thousand Oaks, Calif.: Sage.

Weick, K. E. (2001). *Making sense of the organization*. Oxford: Blackwell.

Weick, K. E., & Sutcliffe, K. M. (2001). *Managing the unexpected. Assuring high performance in an age of complexity*. San Francisco, Calif.: Jossey-Bass.

Weick, K. E., & Sutcliffe, K. M. (2007). *Managing the unexpected. Resilient performance in an age of uncertainty* (2nd ed.). San Francisco, Calif.: Jossey-Bass.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (1999). Organizing for high reliability: Processes for collective mindfulness. *Research in Organizational Behavior, 21*, 81-123.

Wenger, E. (2004). Communities of practice and social learning systems. In K. Starkey, S. Tempest & A. M. Kinley (Eds.), *How organizations learn: Managing the search for knowledge* (pp. 238 - 257). London: Thomson Learning.

Westrum, R. (1993). Cultures with requisite imagination. In J. Wise, P. Stager & J. Hopkin (Eds.), *Verification and Validation in Complex Man-Machine Systems,* . New York Springer.

Westrum, R. (2004). A typology of organizational cultures. *Qual. Saf. Health Care, 13*, 22 -27.

Woltjer, R., & Hollnagel, E. (2007). *The Alaska Airlines flight 261 accident: A systemic analysis of functional resonance.* Paper presented at the The 14th International Symposium on Aviation Psychology (ISAP), Dayton, OH.

Woltjer, R., Lindgren, I., & Smith, K. (2006). A case study of information and communication techology in emergency management training. *International journal of emergency management, 3*(4), 332-347

Yates, J., & Maanen, J. V. (Eds.). (2001). *Information technology and organizational transformation. History, rhetoric and practice*. Thousand Oaks: Sage Publications.

Øien, K., & Schjølberg, P. (2008). Kartlegging av bruken av integrerte operasjoner i vedlikeholdsstyring *SINTEF rapport* (pp. 55 bl.). Trondheim: SINTEF, Teknologi og samfunn, Sikkerhet og pålitelighet.

# 9 Appendices

Paper 1

# Risk images in a changing high risk industry

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## Summary

We present the study of the forming and development of risk images in a high risk industry when introducing advanced new operational technologies. The case studied is the planning and implementation of integrated operations (IO) in offshore oil and gas production. We define a *risk image* as a combination of *hazard identification* and *risk perception*. The informants were representatives from different groups involved in the evaluation or development of IO on the Norwegian continental shelf. Data were collected through interviews and observations in workshops and of text representations. The analysis of the data revealed three groups of risk images: Technological optimism; Traditional risk images; and Reconfigured risk images. The individual risk images seem to be primarily connected to participation in distributed communities of knowing, operating on different arenas. These constructed risk images at the same time may act both to allocate attention to some hazards and to divert attention from others. We conclude

that we need further research on risk images among those that take part in risk appraisal.

# 1 Introduction

Risk images which are constructed by actors involved in the planning and execution of operations with a high risk potential are critical components of risk governance. Our principal concern in this paper is to investigate the forming and development of risk images in a high risk industry when introducing advanced new operational technologies. The case studied is the planning and implementation of integrated operations (IO) in offshore oil and gas production.

# 2 Theory and framework

## 2.1 Risk images

In this paper we will define a risk image as a combination of hazard identification and risk perception. In other words, a risk image is a combined result of the identification of a specific risk and an evaluation of the perceived probability and possible negative consequences of this.

There are two main arguments for focusing on the status and development of risk images in a high risk industrial setting. The first argument is that an adequate risk image is a precondition for the sufficient understanding of the actual technology, operational procedures and organizational arrangements necessary to identify possible hazards. These kinds of understandings strongly influence risk analyses and the forming of accident scenarios. A relevant and comprehensive risk image is, therefore, a precondition for developing organizational procedures, surveillance systems and barriers to prevent possible accidents. The second argument concerns risk perception, which relates to the ability to interpret signals and warnings and react to these in adequate ways, so that potential incidents and accidents can be avoided. The Deepwater Horizon catastrophe in the Gulf of Mexico in 2010 illustrates the importance of this factor. Analysis of the accident shows that the blowout and following explosion was caused partly by insufficient understanding of the situation in the well and by misinterpretation of the signals indicating that a blowout was emerging (US Congress, 2010).

## 2.2 Risk perception

Risk perception can be described as a subjective judgment about the characteristics and severity of a risk. The phrase is most commonly used in reference to natural hazards and threats to the environment or health, and risk perception is claimed to be a part of individual judgments and decisions about risk. Risk perception as a term is mainly applied within psychological research. Within this tradition, the approach in early research was on understanding how people process information (Kahneman et al., 1982). These early works maintain that people use cognitive heuristics to sort and simplify information, which leads to biases in comprehension. Later work built on this foundation and developed into the psychometric paradigm. This approach identifies numerous factors responsible for influencing individual perceptions of risk, including dread, newness, stigma and other factors (Kahneman et al., 1982). Findings from studies within the psychometric paradigm generally state that an individual risk image is formed by the individual's knowledge about the phenomenon or related phenomena or technologies, and the facts associated to it, and his or her perceived uncertainty and fear about the phenomenon or related phenomena. Jaafar et al. (2007) state that risk perception is dependent on an individual's perception of his or her own knowledge about the risky matter. According to this view, those that claim themselves experts or have high knowledge about, for example, a technology demonstrate a lower perception of risk associated to the implementation of that technology (ibid.). In general, in the literature on risk perception a correlation can be found between lower perceived risk and higher knowledge about the issues involved (Sjöberg, 1999).

Most of this research focuses on risks that may hit an individual personally, such as illness, poisoning or damage to his or her local community. Research on how people perceive a risk that is more distant to them, but where they may be directly or indirectly responsible for risk mitigation, has not been so much in focus.

## 2.3 Sensemaking and communities of knowing

The general constructivist perspective in sociology takes as its starting point that when it comes to action, people develop interpretations of the situations they are facing and make decisions on the basis of their 'social construction of reality' (Berger & Luckmann,1967). This means that "reality" is a subjective phenomenon, which may take on different forms for different persons. The processes whereby reality is "constructed" are, however, "social", which means that they take place in social settings, where people interact, communicate, discuss and influence each other. This also goes for how actors in a certain setting perceive and act towards specific risks. Situations and occurrences which may be considered dangerous by some actors or in some situations may be overlooked and ignored in other situations or by other actors. Feldman (1989: 19), referring to works by Weick

(1979) and March & Olsen (1976) argues that in most situations organizational members engage in interpreting both events and contexts, and that "This interpretive process is necessary for organizational members to understand and share understandings about such features of the organization as what it is about, what it does well and poorly, what the problems it faces are, and how it should resolve them."

Sackmann (1991:33), referring to the cognitive (or interpretative) perspective on culture in organizations, underlines the importance of sensemaking in construction processes, describing this as "those mechanisms that organizational members use to attribute meanings to events…which include standards and rules for perceiving, interpreting, believing and acting that are typically used in a given cultural setting."

Weick (1995:17) says that sensemaking is a process which implies seven distinguishing characteristics: "(1) grounded in identity construction, (2) retrospective, (3) enactive of sensible environments, (4) social, (5) ongoing, (6) focused on and by extracted cues, and (7) driven by plausibility rather than accuracy." Among these factors, Weick points to the focus on retrospect as perhaps the most distinguishing characteristic of the sensemaking process. Clegg, Kornberger & Pitsis (2008:19) elaborates this by stating that one always makes sense of something as it is elapsing, and that even when they are forecasting, people will examine the future as if it had already been accomplished. They also point to the importance of images: "We often work with representations of things – models, plans and mental maps – as we navigate our way around unfamiliar territory."

From the above follows that risk images, which again influence attention, policy development, surveillance, safety culture and work practices can be understood as products of collective sensemaking and construction processes.

A general trend in knowledge-intensive organizations and industries is that they are composed of communities of highly educated professionals representing specialised technologies and knowledge domains. Related to theories and research on communities of practice that originate from the work of Wenger (2004), these kinds of knowledge-creating groups have been named communities of knowing, described as inter-organizational or inter-institutional communities of specialised knowledge workers where dynamic interactions make possible the emergence of new meaning and knowledge (Boland & Tenkasi, 1995). The term "perspective making" is explained as a process whereby a community of knowing develops and strengthens its own knowledge domains and practices, whereas “perspective taking” denotes the process of taking account of the knowledge and expertise of others. Boland and Tenkasi claim that communities of knowledge workers who deal with parts of an overall organizational problem through perspective making and taking will interact to 'create the patterns of sense making and behaviour displayed by the organization as a whole' (1995:351). One can also say that such communities 'develop unique social and cognitive repertoires which guide their interpretations of the world' (1995:351). Or, in other words: They construct their images by collective sensemaking processes.

Another important point in Boland and Tenkasi’s (1995) paper is that communities of knowing can operate within specific forums, which serve as a kind of “container” for dialogue on certain topics, issues, concerns or tasks. Different kinds of forums reflect the way knowledge work is being focused, as well as pointing to the kinds of knowledge structures that are emerging. Boland and Tenkasi are especially preoccupied with forums based on electronic communication media, but the reasoning may also be relevant for knowledge work and construction processes taking place in other kinds of communication settings. Five classifications of forums are presented: task narrative forums where stories and other oral communication including videos enables information for all that attend; knowledge representation forums where the communication is not only narrative in an auditory or visual way, but involves written material that is discussed and reformulated; interpretive reading forums that involve an intended criticism or search for tacit information about the knowledge; theory building forums where communication on the theories that underlie the decisions is the matter; and finally the intelligent agent forums where agents outside the organization or system are involved, such as libraries, databases or other information sources.

# 3 IO in the petroleum industry

Within the offshore petroleum industry, development is towards smaller and more deepwater fields where incomes and expenditure, as well as practical obtainable solutions, demand remote and cost-efficient operations. This trend has been named differently in various companies (e.g. Smartfield, i-field, e-drilling, e-operation); however, the dominant solution, which also includes changes in work processes and organizations, is termed IO. IO includes the use of integrated real time data technology and the increased use of automation and remotely controlled operations. For mature fields, IO is also seen as an opportunity to expand the life expectancy with the more extensive use of onshore planning, support and operation, and correspondingly reduction of staff offshore.

Improved information and communication technology enables the comprehensive use of distributed work across organizational borders or among workers located at geographically different sites. "Around the clock" or 24/7 (24 hours a day, 7 days a week) onshore work gives possibilities for global network organizations with "follow the sun" principles, where distributed work may include work across nations as well as cultural borders. Vendors play a more prominent role and operational responsibilities may be distributed in a global network of cooperating organizations (OLF, 2005).

The implication of these changes is an increased complexity in organizations and systems that may make them more vulnerable in terms of both safety and security. Fibre optic cables carry all real time data and are thereby central elements in the operations. The use of remote control implies more distance between the operators and the operation. The operators on the Deepwater Horizon in the Gulf of Mexico were present and could perceive the situation in the well directly and use data they could control and validate with the real situation, whereas workers within IO can only evaluate representative data on computer screens and make use of sensor data and remote operations.

We argue that these changes in combination imply a new paradigm in the operation of offshore petroleum fields. This new paradigm includes changed work processes and partly also new organization models. Modern information technology particularly developed for the offshore petroleum industry makes distant control and communication just as everyday as traditional face to face communication and human – technology interfaces. Large production fields may be controlled and operated from distance. Real time data from production fields prepare for future decision making by using semantic webs or automated decision making processes. Organization models evolve into distributed organizations with experts and operating staff working from where they are in the world. Also, these changes impose new models of organizing in companies that are established in the later years; they tend to build up small operating organizations with very essential staff and use national and international contractors even for what used to be in-house activities such as emergency management, risk management, human relations and working environment management.

Norway is one of the world's largest offshore oil and gas producers. The industry comprises most major international oil and gas companies either as operators or as license partners. The development of IO has come far on the Norwegian shelf. The solutions that have been developed are to a growing extent also put into use in other countries which are producing oil and gas from offshore fields. This makes Norwegian offshore oil and gas production a good object to study if these new technologies influence the forming of risk images.

# 4 Methodology

The informants in this study were representatives from different groups involved in the technological development of IO on the Norwegian continental shelf, groups that participated in making decisions, gave consent and permission for operation in an IO setting or were involved in protecting Health, Safety and the Environment (HSE). They performed work such as R&D, inquiries, reports and statements in mass media. They also participated in workshops, discussions, seminars and other kinds of arenas where IO were discussed. The informants were all representatives from groups of people involved in planning, developing, supporting, operating or regulating IO. In this study, they were placed in a category based primarily on their formal work positions or roles at the time of the study. Individuals' placements were, in some cases, ambiguous because many of the informants had held different positions in the past or were involved in several roles at the time of the study. When selecting informants as in this study, one can of course not generalize the findings statistically. The selected procedure was preferred, however, because the study is of a clearly exploratory nature.

Information about risk images was gathered in various settings such as interviews, workshops, seminars and informal talks and supplemented by visual and written representations of risk images gathered from presentations and reports in meetings and on the Internet. Open-ended interviews and workshops with stricter agendas but with open discussions in planned groups were the dominant sources for data collection. The groups of informants and how their risk images were assessed using interviews, workshops or other methods are listed in Table 2

Table 2: Groups of informants

| Role | Number | Methodology |
|---|---|---|
| **Trade union representatives** | Four | Workshop |
| **Technological researchers**[6] | Six | Interviews |
| **Technological professionals in operating and contractor companies** | 10 | Interviews and workshops |
| **Managers with economical responsibilities** | Four | Interviews and workshop |
| **Human factor professionals**[7] | 20 | Participation study and interview |

[6] They all belong to a centre for research on IO where they work on the innovation and development of new technological solutions for the petroleum industry.

In the interviews participants were first asked to describe their on-going IO activities and future plans and strategies. Questions focused on safety in terms of system accidents, HSE and risks related to the development and implementation of IO. Questions were formulated in general as well as more specifically and concerned factors such as technological hardware, software, work processes, human factors and organization models. The objectives for the different interviews and observation sessions differed somewhat because they were conducted in relation to different projects. In the interviews the respondents were asked to point out HSE-related strengths, weaknesses, threats and opportunities in the new operating environment, related to the technology or product development they were working with.

The workshops were planned events with invited participants. The topic for the workshops was "changes related to IO in the petroleum industry and the impact on changed risk". The participants were selected based on their roles in their organizations as well as on their abilities to reflect upon their own and other's views and opinions. This selection procedure was preferred because participants were asked to consider the risks of major and system accidents, a task that requires participants to see parts of operations in relation to other parts and to the whole system surrounding specific operations and organizations. Some of the group sessions included representatives from both operating companies and contractors. For the discussions, the instruction was to identify generic changes in ways of operating and organizing certain described scenarios. Participants were then instructed to think of the consequences of these changes on risk. The participants were directed to discuss HSE issues and not costs and benefits with IO or other related issues unless they were concerned with HSE. The data from the workshops were divided into two sets. One set was from the interviews with representatives from projects in the industry that had showed the most progress as far as IO was concerned. The second set was from the group discussions in the workshop.

Interviews and group discussions were digitally recorded. The analysis included searching for statements that directly and indirectly concerned risks and safety in new technological modes of operating. The analysis was challenging because the orders and topics of the conversations varied, both within and between different settings. This was solved by repeated listening to recordings and reading through of notes to reveal insights into risk images. The statements were then categorized into

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[7] These are members of a human factor network where they meet and discuss human factor issues related to petroleum activities in general as well as concerning the development of IO. One of the members participated in a separate interview.

groups based on empirical concurrence and their similarities. Four such groups materialized, concerning technology, work processes, risk management and human and organizational factors. The groups and how different statements relate to these are shown in table 3.

Table 3: Groups of factors

| Factors | Examples of risk statements | | | | | | |
|---|---|---|---|---|---|---|---|
| Technology | Information technology will improve decisions | Technology will improve safety | Risks can be diminished if technology has been tested in simulators. | Technology is used in situations that it is not designed for. | The dependencies between technological systems is not always known | Older installations are pushed to operate longer than expected. | We do not really know what we develop |
| Work processes | IO implies a busier workday. | The total amount of work (within IO) is larger, but the daily work load is the same | Some of those in the onshore support centre still know things from the platform. | Local experts are still on call | Onshore centers mainly deal with questions that can await answers until the next day. | Remote operation by use of technology is already successfully used today | I question reduced manning in critical situations. How can we ensure emergency - and deviation management? |
| Risk management | We rely on safety system to stop any escalation | Any risk assessment and HF method we have are suitable for identifying an dealing with risks that come with IO | Traditional risk assessment methods are not good to find complex risks that may come with IO | | | | |
| Human and org. factors | Humans are unreliable | The feeling of" fire under your feet" disappears. | The demand in an onshore operation room was so high that the workers cannot sit there for longer than two hrs. | Cross training and multiple work tasks may result in situations where one person needs to do two or more tasks at the same time | Loss of control over well is exposed because of low manning. Always a bad scenario. | Less people means less problems and sources of failure | Less people offshore means less complexity (in the work processes) |

| Traditional risk image | Technology optimism | Reconfigured risk image |
|---|---|---|

## 5 Findings

In the interviews, seminars and the workshop, the informants could express their risk images in comments and as answers to questions from the interviewer or from other participants in the group. Expressed images of IO in general varied from opportunities based on technology to changes in organizations and competences. The definition of IO, and what kinds of technological and organizational changes this development comprises was not clear in any of the statements from companies or in official reports. Images of IO, therefore, were related to the informants' experiences in their own environments and from what they had read or heard outside their own organizations or positions at work. In the following section, the statements are meant to illustrate the different risk images that were revealed in the analysis of the recordings. The following text explains in more detail what was said about the three risk images.

The data analysis followed a grounded theory approach (Glaser & Strauss, 1967). The statements were at first coded as "concerned" or "optimistic". The statements concerning risk were then reviewed and categorized according to their resemblance. However, the analysis showed that the informants' statements revealed such consistent patterns of reasoning on risk images that it came out as empirically feasible to group them into distinct categories that could better describe the features of the risk images. The categorization "concerned" and "optimistic" was thereby left and substituted by three new categories:

- Technological optimism;
- Traditional risk images; and
- Reconfigured risk images.

Labeling was not based on predefined categories from earlier publications and thereby the name and content of the category were related to this study only. The category "technology optimism" was formed because technology as an enabler for safer operations appeared in many of the optimistic statements. Technology optimism occurs in the literature as a phenomenon observed among respondents in surveys, interviews and focus groups where attitudes towards, and perceptions of, technology and the future is the topic. The basic thought is that these characteristics vary within groups of people in terms of their attitudes (sceptic, pioneer, paranoid) towards technology (Jaafar et al., 2007). In studies of differences between experts and lay people, the experts are normally attributed the highest optimism when judging risk with new technology, for example (Tichy, 2004). The term technology optimism used in this paper does not necessarily correspond to any of the descriptions in these studies.

After identifying the statements within the technology optimism category, the remaining "concerned" and "optimistic" statements were further analyzed and divided into traditional risks where the focus was on the way risks are handled before IO and new risks or reconfigured images of risks that may emerge from the new ways of operating the petroleum production. The categories "traditional risk images" and "reconfigured risk images" were formed based on these groups of statements. All three risk image categories include the possible identification of risk – whether or not new technology, new work processes and changed roles and responsibilities imply that any risk is formed, as well as the perception of this risk – if it is perceived as something to worry about or that requires action in any way.

## 5.1 The technological optimism risk image

The dominant point of view is that things seem to be in good shape and that there is no specific reason why this should not be the same, or better, as progress towards more advanced IO is taken further. Among some of those that regard IO as something that will improve safety, a strong trust in technology is revealed:

*'Humans are unpredictable. When we leave the identification of criteria, planning and decisions to automated processes, we eliminate the unpredictable components from the critical decisions.'*

This statement represents an image of a reduced risk level. The main argument is that improved ICT and corresponding technologies promote more and better representation and sharing of information, and thereby will reduce risk by giving enough and correct information to decision makers. Such views are based on a strong belief in reliable, automated technology, as seen in the following statement:

*'Hands on is important now but in five years not as important. Back in the history of aviation – the earlier the pilot felt the wind and temperature and smell – now he does not need that, he has other information. We need to think about the new generation, they do not have a need for hands on experience.'*

A corresponding argument is that automated optimizing tools will contribute positively to the risk level by taking some of the burden away from humans by automating decisions. Automated decisions are also believed to remove any elements of human unreliability, thereby assuring correct analysis and decision making.

*'...but I feel technology can really help us. There is too much information for a human to handle, we develop pattern recognition systems to recognize and handle the information.'*

## 5.2 The traditional risk image

This statement reveals a basic trust in the way the oil and gas production is operated:

*'It does not really matter what changes are introduced. If the operation reaches a predefined level of uncertainty, the emergency shutdown system will kick in and save the situation anyway.'*

According to this and similar statements, IO means business as usual. The development of IO is not seen as significantly introducing new kinds of risks or the view is that risks in IO can be handled with traditional measures (technological barriers, shutdown systems, training, emergency procedures). Control by the use of emergency shutdown or strict procedures are common in the offshore petroleum industry and represent a traditional view on handling risks. Central to this way of reasoning is the belief that if all the different subsystems are reliable and equipped with the necessary instrumentation, the overall operation of the total production and transportation system is believed to be reliable and safe. Within this view, the development and implementation of IO do not imply any specific increase or change in risks compared with traditional operations. This does not, however, mean that safety and risk are not taken seriously, as seen in the following statement:

*'Fewer people offshore and on deck reduces the exposure to hazards and thereby the risk.'*

Technology that makes it possible to operate installations from onshore facilities is seen to have a positive influence on safety, for example by removing people from important sources of risk, such as blowouts, fires and explosions. A corresponding argument is linked to the fact that fewer people offshore will reduce the need for helicopter transportation, which is a high risk activity.

## 5.3 The reconfigured risk image

Acknowledging IO as something that moves the operation of petroleum production from a more closed to a more open system may be considered a significant change of perspective. It may be that making this acknowledgement is essential for constructing risk images related to IO. As a technology expert put it:

*'When we develop technology that enables operations in difficult reservoirs, the management of the companies wants to use the technology in even more marginal and difficult reservoirs. These are environments that we haven't even tested the technology for.'*

Technological developments can open new opportunities such as drilling in reservoirs that earlier seemed too difficult or risky or accelerating production to a greater extent than planned for with optimising tools. Some also fear the increased complexity in systems and that the reliability of technology to be introduced into existing installations has not been properly tested.

Furthermore, some informants fear that the installations that have an expanded lifespan through IO were not designed for this. This means a possible reduction in efficiency and also places a strain on organizations during unforeseen work and possible emergency handling. This risk image is prominent both between informants who have work experience from the older installations, representatives from authorities and some researchers.

*'Today we have a mixture of remotely and locally controlled equipment. The rigs are different…and there are old wells as the one we talk about here…when the Nintendo generation comes in they do not have the knowledge about relevant things from before. Someday the operation will suit the Nintendo generation, but not yet.'*

Some informants point to the fact that information overflow from real time data is a possible threat towards the human mind's ability to understand and process information. Automating such processes takes away some of the daily burden, but also makes systems opaque so that risks can "hide" between automated tasks.

A well-accepted positive effect of including onshore staff in operations in real time is that people onshore in an operations centre may have the best overview of the operation, and may therefore make the best decisions concerning the prioritization of tasks and optimization of operation and safety. The expressed viewpoint is that competence is better or wider onshore, where more experts in different fields of work are in the proximity of the information and decision processes. Leaving the responsibility to people other than your local peer workers is not necessarily seen as negative:

*'…If you look at barrier functions today… the control (we have) offshore today is a little bit that because you yourself are in control of everything, then it is not*

*required that everything is in perfect shape… if (the task) it is outsourced we need to be clearer on the requirements. That is not necessarily a bad thing…'*

Owing to the differences between installations and local technical solutions, the way things are controlled and handled has historically been very much up to the local management. Although this is not as much the case nowadays as companies have standardized many of the procedures and work processes, it may still create different atmospheres and cultures between installations. This means that knowledge about local technological solutions and work processes is important for understanding the system. The growing distribution of roles and authority between organizations is also the reason for the forming of a risk image that concerns a lack of control, intractable systems and autonomous instead of shared situation awareness. One example given in one of the workshops is that of giving suppliers access to the safety instrumented systems and how this is seen as a possible threat to safety, as they can misinterpret the systems' behavior in relation to other systems offshore. If the suppliers are not integrated well enough into the organization, chances are that they may carry out maintenance work or other activities of the safety instrumented systems that may be misinterpreted or taken as signals of failure within the operation organization. As for all ICT systems, some point to the possibility that these systems are hacked or otherwise threatened by outsiders.

## 5.4 Distribution of actors on the three risk images

The second main finding from the analysis concerns the distribution of the three types of risk images among different categories of informants. A summary of the distribution is shown in

Table **4**. The technology optimism risk image is found primarily among technologists and researchers. The reconfigured risk images are primarily revealed among the researchers, trade union representatives and people working with human factors. The concerned, reconfigured view that includes a high degree of a perceived increased or changed risk level is also shared by a few of the representatives from the operating and contracting companies, although they primarily tend to reveal positive images; IO mean solutions to problems they see present today. Human factor professionals express statements that are related to changed allocation between technology and humans, and between humans in terms of geographical distance, with the introduction of possible new risks. The traditional risk image is found among representatives of all groups. Many of the human factor professionals also reveal a traditional risk image expressed through beliefs in standard methodologies for risk assessment.

**Table 4: Distribution of informants in the three risk image categories**

| Risk image | Informant group(s) represented |
|---|---|
| Traditional | Technological professionals in operating and contractor companies<br>Technological researchers<br>Experts in operating and contracting companies<br>Human factors professionals<br>Managers with economic responsibilities<br>Trade union representatives |
| Technology Optimism | Technological professionals in operating and contractor companies<br>Researchers |
| Reconfigured | Researchers<br>Human factor professionals<br>Trade union representatives |

Managers with economic responsibilities in companies are primarily preoccupied with "risk" as an economic risk – i.e. that IO will not have the economic effect that was hoped for. When "pushed" towards the risk of accidents and system failure they point to new risks, such as the hacking of ICT systems. Another viewpoint is that IO opens possibilities for reengineering the organization and introducing new management principles. Many of the informants state that only ICT threats are seen as new risks in IO, whereas other risk elements are considered unchanged or improved. This seems to be linked to the fact that improved ICT is what is considered "new" in the operation and that other factors are as before, only "helped" by ICT – the risk level is perceived as decreasing with IO.

# 6 Discussion

The *traditional risk image* may be a representation of not identifying any risk at all with the change, or just presenting a former and present risk image in the oil and gas industry, with relatively few severe system accidents, and, even with some disturbances in the past few years, a decreasing number of incidents and accidents in total. Most informants in this traditional risk image category state that they rely on the existing competences of technical experts and skilled workers in the new, high tech environments because they know the nature of operations and know how to handle the instruments and equipment. Managers and experts in operating, as well as contracting companies trust the transfer of "installation" or "factory" competences; a popular expression for the explicit and tacit knowledge developed among those who have worked on an installation for a long time. The expression is widely used among the informants in the study.

The *technology optimistic risk image* can also be considered partly traditional in the sense that the majority of informants representing this view express a strong belief that reliable technology and continuous technological improvements are what has made operation in the petroleum industry safe up until now. The visual representation of IO development reveals a strong technological development aspect that will result in better, faster and more efficient work processes.

The *reconfigured risk image* includes, to some extent, the notion of something unknown in IO. The statements included in this category reveal a feeling of unease. IO introduces changes at many levels and in many parts of the socio-technical system. The reconfigured risk images take into account the fact that the way of operation will change with IO so that the basis of learning (knowing what has happened) and monitoring is limited. In such situations, it becomes difficult to know what to look for and thereby the anticipating phase becomes limited. According to the risk governance framework, it may be argued that there have been no *early warnings* with IO that brings out the need for the reassessment of risk. If any earlier accidents included IO-related challenges or causes, it is naturally not clearly stated since IO is a new concept. One possibility is that the industry is on the verge of entering an incubation period (Turner & Pidgeon, 1997) where deviations and events go unnoticed or they are misunderstood because the information about a new risk image does not come through.

Constructing a reconfigured risk image seems to require an understanding of the change and that the change requires a way of operating that is significant from the former way of operating or organizing. This may be looked upon as a paradigmatic change. Boland and Tenkasi (1995) argue that Thomas Kuhn's insights into paradigms as a shared sense of the metaphysical nature of the world, the associated important problems and what serve as good examples for a domain of concern are particularly relevant for understanding how knowledge is produced in a community of knowing. The process of paradigmatic change relates to the community of knowing, refining and clarifying the perspective of the community. Without a strong perspective, Boland and Tenkasi (1995) argue that the 'the community cannot tell an anomaly from noise; a challenge to their knowledge from an irrelevancy' (p. 354).

Reflecting upon technological development as an enabler for exploring and developing more marginal fields in more vulnerable environments than those that the technology was originally developed for, or focusing on how things might be handled better from a distance, reflects a risk image formed at a higher level. The risk image combines systems such as the technology and management level in an organization or partners in an operating license and touches the societal level in terms of environmental risks that may be associated. It seems that the reconfigured risk image is present among those that have been, or are attending, many arenas and thereby are probably exposed to many different views of IO, or have been part of technology developments in industrial settings for a long time.

Given the outlined change where vendors play a more crucial role in operations and where global, virtual organizations operating across traditional organizational borders form the basis for operation (OLF, 2005), there is a paradox in the findings that little attention is given to risks at the organizational level. The informants, as individuals or as communities, do not consider potential misunderstandings, coordination challenges or conflicts between vendors and operating companies' policies, HSE practice or safety climates. Nor do most of them see particular limits in the existing regulations when it comes to regulating relationships between companies that are integrated and operate more as long-term communities of practice than those in traditional roles as buyers and vendors. The challenge is that some of these possible new risks may be overlooked within the present set of experiences and assumptions that form the basis for the collective sense-making processes. This is also a situation that may be the start of an incubation period, as stated in the manmade disaster model (Turner, 1979).

The majority of the informants would have been categorized as "experts" on a high level in a traditional risk perception study because they are so familiar with the technological or organizational developments in the field. "Experts" in risk perception studies normally have a lower risk perception compared with others (Sjöberg, 1999; Jaafar et al., 2007). The findings in this study do in some ways confirm this, since many statements from expert informants relate to "traditional risk images" or "technology optimism", which both express a low degree of risk perception. The findings are, however, not consistent, as there are also some experts among the proponents of reconfigured risk images.

## 6.1 Are there possible IO communities?

There is little evidence of a strong division between actors and their constructed risk images based on where they work or to what organizations they belong. The social arenas that the informants attend to, however, seem to contribute to the formation of what looks to resemble a kind of community of knowing where specialized knowledge workers interact in perspective making and perspective taking, making possible the emergence of new meaning and knowledge (Boland & Tenkasi, 1995). This can also be seen as reflecting the social dimension of sensemaking, as expressed by Sackmann (1991) and Weick (1995). These findings call for a new way of looking at risk image construction among groups and individuals. The communities of knowing which are formed in connection with the development of IO correspond with people's work practices and environments, but they are not confined by organizational borders. Professional background contributes to the forming of the communities but does not explain the coherence in statements by itself.

Following Boland and Tenkasi's (1995) classification, the frequent meetings, conferences and workshops that the actors involved in IO development attend correspond to at least three of the abovementioned forums: "Forums for narrative processes through dialogue and discussion"; "Represented knowledge through presentations and reports" and, in some cases, "Interpretive processes". These different meeting places seem to function as arenas for the social construction of risk images and development of a set of communities of knowing. There are many such arenas within the oil and gas industry, such as those provided by oil producers' organizations, authorities, universities and research institutions. These arenas provide research, conferences and workshops. The typical pattern is that there are a restricted number of actors who participate in, and contribute to, the different arenas and associated meetings, workshops and seminars. The arenas with the hubs of people stretching across organizational borders and professional backgrounds function as "workshops" for social construction processes among certain segments of actors, and it is perhaps possible to speak of a limited number of "IO families".

## 7 Conclusion

In the work presented here, it has been assumed that risk images are expressed at different levels of abstraction and that the words and expressions used to present an image will vary. That is why an explorative design was chosen. Based on the analysis of statements in the study, three categories of risk images are suggested: *traditional risk images, technology optimism* and *reconfigured risk images.* These three risk images are all present among the informants and seem to be relatively equally represented. What risk images an individual presents, seem to be primarily connected to participation in distributed communities of knowing, operating on different arenas such as research centers, seminars and formal meetings. Neither organizational belonging nor academic background seems to play a decisive role. Possible risk images that did not come to the surface in this study are connected to increased system complexities (technological, organizational, operational), operating oil fields through global, distributed organizations, new roles for vendors and contractor companies and how cooperation over distance, and across national, linguistic and cultural borders as well as new systems for information handling may influence risk in operations. These findings illustrate a point often mentioned in the discussion on safety culture, namely that risk images constructed in specific communities at the same time may act both to allocate attention to some hazards and to divert attention from others (Pidgeon 1998). Illustrating the last point is that none of the informants touched upon the question of how emergencies will be handled in geographically distributed and heavily technology-dependent operating environments.

The results from this study imply that we need further research on risk images among those that take part in risk appraisal and that social science models such as social constructionism, sensemaking processes, arena models and knowledge about communities of knowing should be included for understanding how risk images are constructed and formed in the process of risk appraisal.

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## 8 References


Berger, P. L. & T. Luckmann (1967) *The social construction of reality a treatise in the sociology of knowledge*. Harmondsworth, Penguin.

Boland, R. J. & R. V. Tenkasi (1995) Perspective making and perspective taking in communities of knowing. *Organization Science* 6 (4), 350–372.

Clegg, Stewart, Kornberger, Martin & Tyrone Pitsis (2008) *Managing & Organizations. An Introduction to Theory & Practice.* London: Sage

Feldman, Martha S. (1989) *Order Without Design. Information Production and Policy Making.* Stanford: Stanford University Press

Glaser, B. G. & A. L. Strauss (1967) *The discovery of grounded theory strategies for qualitative research*. Chicago, Aldine.

Jaafar, M., A. R. A. Aziz, et al. (2007) Integrating information technology in the construction industry: technology readiness assessment of Malaysian contractors. *International Journal of Project Management* 25 (2), 115–120.

Kahneman, D., P. Slovic, et al. (1982) *Judgment under uncertainty heuristics and biases*. Cambridge, Cambridge University Press.

March, James G. & Johan P. Olsen (1976) *Ambiguity and Choice in Organizations*. Bergen: Universitetsforlaget

Nævestad, T.-O. (2010) Culture, crises and campaigns: examining the role of safety culture in the management of hazards in a high risk industry. Centre for Technology, Innovation and Culture (TIK), Faculty of Social Sciences. Oslo, University of Oslo. PhD.

OLF. (2005) Integrated work processes. Future work processes on the Norwegian continental shelf." Retrieved January 1, 2010, from **http://www.olf.no/rapporter/category229.html**.

Pidgeon, N. (1998) Safety culture: key theoretical issues. Work and Stress 12 (3), 202–216.

Sackmann, Sonja A. (1991) *Cultural Knowledge in Organizations. Exploring the Collective Mind*. Newbury Park: Sage

Sjöberg, L. (1999) Risk perception by the public and by experts: a dilemma in risk management. *Human Ecology Review* 6 (2), 1–9.

Slovic, P., N. F. Pidgeon, et al. (2003) *The social amplification of risk*. Cambridge, Cambridge University Press.

Tichy, G. (2004) The over-optimism among experts in assessment and foresight. *Technological Forecasting & Social Change* 71, 341–363.

Turner, B. A. (1979) *Man-made disasters*. Bristol PA: Taylor & Francis.

Turner, B. & N. F. Pidgeon (1997) Man-made Disasters. London, Butterworth-Heinemann.

US Congress. (2010) "Letter to BP CEO Tony Hayward." Retrieved November, 2010 from **http://energycommerce.house.gov/documents/20100614/Hayward.BP.2010.6.14.pdf**.

Weick, Karl E. (1979*) The Social Psychology of Organizing*, Reading: Addison-Wesley

Wenger, E. (2004) Communities of practice and social learning systems. In: Starkey, K., Tempest, S. & Kinley, A. M. (eds.) *How organizations learn: managing the search for knowledge*. London, Thomson Learning. pp. 238–257.

Paper 2

# Safety perception and comprehension among offshore installation managers on the Norwegian Continental Shelf

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**Abstract**

The study presented in this article shows that the perceptions and comprehensions of safety differ significantly between offshore installation managers (OIMs) and the rest of the organization on Norwegian offshore installations. The basis for the analysis is a safety climate survey answered by 6850 offshore petroleum employees in 2007. OIMs had the most positive perception in all the categories: safety prioritization, safety management and involvement, safety versus production, individual motivation and system comprehension. These different perceptions and comprehensions of safety may be a result of issues of power and conflict and may also be based on different knowledge and control. The phenomenon of different safety perceptions and comprehensions between these groups is important to bear in mind when planning surveys as well as planning and implementing safety measures. In particular, the significantly different opinions related to safety versus production are of interest because of the earlier distrust between unions and management.

**Keywords: Safety climate; safety perception; safety comprehension; offshore installation manager;**

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## Abbreviations

| | |
|---|---|
| HSE | health, safety and environment |
| NORSCI | Norwegian Offshore Risk and Safety Climate Inventory |
| NPD | Norwegian Petroleum Directorate |
| O&G | Oil and gas |
| PSA | Petroleum Safety Authority Norway |
| RNNP | Trends in Risk Levels on the Norwegian Continental Shelf |

# 1 Introduction

The Macondo blowout of 20 April 2010 raised serious concerns about the safety culture in the offshore oil and gas (O&G) industry (Graham et al., 2011). Deepwater Horizon and its owner suffered serious safety management system failures and a poor safety culture manifested in continued maintenance deficiencies and training and knowledge gaps (USCG, 2011). The National Commission on the BP Deepwater Horizon Oil Spill and Offshore (hereafter, the Commission) concluded that the errors, mistakes and management failures that caused the disaster were not the product of a single rogue company, but instead revealed both the failures and inadequate safety procedures of the three key industry players. What the men and women who worked on Deepwater Horizon lacked – and what every drilling operation requires – was a culture of leadership responsibility (Bartlit et al., 2011). According to the Commission, the lessons learned from the Deepwater Horizon disaster were not confined to only the US government and industry, but were relevant to the rest of the world. The Commission demanded no less than a fundamental transformation of the industry's safety culture (Graham et al., 2011).

The terms ''safety culture" and ''safety climate" have often been used interchangeably, although safety culture is considered to be a more complex and enduring phenomenon compared with safety climate, reflecting the fundamental values, norms, assumptions and expectations (Mearns and Flin, 1999) which, to some extent, is assumed to be linked to national and societal culture (Høivik et al., 2009b). Over time, consensus among industrial psychologists has emerged to differentiate safety climate as the surface features of an organization's safety culture, as discerned from the workforce's comprehensions and perceptions at a given point in time, namely a "snapshot of the state of safety" (Cox and Flin, 1998; Edkins and Pfister, 2003; Flin et al., 2000). Safety climate is normally measured by surveys based on levels of agreement with pre-developed statements. Although surveys often form the bases for the measurements of safety culture/safety climate, there is more evidence to suggest that these so-called "attitudes" to risk and safety are "perceptions" or "descriptive beliefs" rather than "normative beliefs" (Mearns and Flin, 1999). The Commission's findings stress the need for an improved understanding of surveys and their relevance as indicators of safety performance.

The Petroleum Safety Authority Norway (PSA) states that the Deepwater Horizon accident must be seen as a wake-up call to the Norwegian petroleum sector, that it must lead to a big improvement in managing major accident risk and that the conclusion that the safety culture needs improvements throughout the industry must also be considered relevant for Norway's petroleum activity (PSA, 2011a).

There are a number of papers related to the important role of managers in developing a strong safety culture (Clarke and Ward, 2006; Kath et al., 2010; Lofquist et al., 2011; Martínez-Córcoles et al., 2011; Mearns and Flin, 1995; Mearns et al., 2003; Mearns and Yule, 2009; Nielsen et al., 2008; Njå and Fjelltun, 2010; Vinodkumar and Bhasi, 2010; Wu et al., 2008; Wu et al., 2010). The literature suggests that safety climate represents employees' perceptions about organizational support, particularly management's commitment to safety in the organization (Wills et al., 2006). Høivik et al. (2009a) conducted a qualitative study of 31 employees, with and without leadership responsibilities, employed in a Norwegian petroleum company and the findings support the importance of management's commitment to safety.

A culture consists of several sub-cultures including executive culture, engineer culture and operator culture. Each sub-culture possesses cultural elements and influences the culture emerging from the interactions of the sub-cultures within an organization. Different employee groups exhibit different safety attitudes/climate structures. For example, Cheyne et al. (2003) investigated two large manufacturing organizations and concluded that while managers, supervisors and general employees shared the same definition of safety factors, their perceptions of these factors and how they interrelated proved to be different. Findley et al. (2007) examined group differences in safety climate among job positions in the nuclear decommissioning and demolition industry in the United States and observed significant differences in mean safety climate scores, factor scores and item scores among job positions.

(Zohar, 2000) offered empirical support for two validation criteria of safety climate as a group-level construct in a manufacturing company. Employees develop homogeneous perceptions about supervisory safety practices (i.e., within-group homogeneity) and these perceptions vary between subunits, resulting in significantly different safety climate scores (i.e., between-group variance). Zohar and Luria (2005) incorporated a new dispersion model that focused on between-group climate variability in individual organizations, showing that climate variability was negatively related to organization climate strength and procedural formalisation.Cox and Cheyne (2000) examined the differences among managers, production teams and drilling teams in UK offshore environments. A series of one-way analyses of variance were performed for each factor in the attitude questionnaire. The results were not discussed because the objective of the research was to develop and test an assessment technique, which provided a practical tool for both the assessment of safety climate and the promotion of a 'positive' safety culture.

The offshore installation manager (OIM) is responsible for all matters of health and safety on board an offshore installation. The OIM supervises the day-to-day aspects of O&G production including budgets, personnel, production, maintenance and logistics. The OIM plays an important role in communicating the safety message from senior levels within the onshore organization to the workforce at the sharp end. The OIM is supported by a safety adviser. The safety adviser supports in matters concerning occupational health and safety management on the offshore platform. All installations on the Norwegian Continental Shelf are required to have a safety adviser. The safety adviser has different titles depending on the company and installation (e.g., offshore safety & environment coordinator, safety leader and safety manager). On some installations, the function is shared with the role of being a trained nurse. The safety adviser is usually a part of the OIM's leadership team and emergency management team. The safety adviser is usually the contact person for the government and has responsibilities related to tracking and reporting safety, health and environmental issues.

## 1.1 Objective

The PSA has since 2001 performed the Norwegian offshore risk and safety climate inventory (NORSCI) among all offshore workers on the Norwegian Continental Shelf. The NORSCI is part of the project Trends in Risk Levels on the Norwegian Continental Shelf (RNNP). The objective of this paper is to reveal whether the perceptions and comprehensions of the safety climate measured in the NORSCI differ between the OIMs and the rest of the organization. Moreover, the safety advisers' safety perceptions and comprehensions are analysed because of their close co-operation with OIMs and the rest of the management team. This analysis is performed using the NORSCI carried out in 2007 (PSA, 2008). The hypothesis is that the OIMs have more positive perceptions and comprehensions of the safety climate compared with the rest of the organization.

Working offshore is unlike most working places. The O&G installations on the Norwegian Continental Shelf are located 40 to 185 miles from the coast. The crews are transported by helicopter to these offshore installations and the working period is normally 14 continuous days with 12-hour shifts, day or night, followed by a four-week off period at home (i.e., the so-called "2-4" schedule; (Høivik, 2010). Employees that work regularly on an installation tend to talk about their offshore co-workers as their ‘‘second families" (even ‘‘first families") or of the installation as their ‘‘second homes" (Tharaldsen et al., 2010). On the offshore installations, managers and employees live together 24 hours a day. This provides a greater opportunity for communication during meals and coffee breaks and should make communication and confidence building easier (Høivik, 2010). This may influence on the perceptions and comprehensions of safety.

Apart from an earlier survey on OIMs (Flin and Slaven, 1993) and two subsequent studies (Flin and Slaven, 1994; O'Dea and Flin, 2001), this group has largely been ignored by researchers. Understanding the system of beliefs that determines how people feel and react to safety issues on an offshore installation is particularly relevant for the international O&G industry in which workers may be expected to work anywhere in the world at very short notice (Mearns et al., 2004).

The first part of this article describes the data, theoretical background and central concept;, safety perception and comprehension, safety climate and safety culture. Furthermore, the RNNP and the NORSCI are briefly explained. The results from the data analysis follow. The potential causes and implications of the results are then discussed.

## 1.2 About the data

The NORSCI was performed among personnel in the Norwegian offshore industry between 7 January and 15 February 2007. This was the fourth time the data had been acquired using this questionnaire. The first survey was performed in December 2001, the second in December 2003 and the third at the turn of the year 2005/2006. The survey was developed by health and safety researchers, and it used experts from occupational health and safety in the industry and representatives from the unions to review, test and examine it. The survey was limited to factors of relevance to safety and the working environment, excluding the external environment (Tharaldsen et al., 2008). The aim of the survey was to measure employees' perceptions of health, safety and environment (HSE) management in the Norwegian offshore industry (PSA, 2008).

In previous years, there was a response rate of approximately 50%. For the 2007 survey, a new procedure was implemented for the distribution and collection of the questionnaires. As a result, many problems were reported in connection with the distribution of forms at the heliport. It is the PSA's opinion that this led to a lower number of responses than that expected. The estimated response rate was approximately 30%, which is a low response rate. The number of OIMs responding was N=105, whereas safety advisers constituted a larger group (N= 226). Nevertheless, the total numbers of responses (N=6850) was sufficiently large to perform statistical analyses and to split the data into different categories. The distribution of responses among different groups corresponded reasonably well with the distribution in previous years' studies. As in previous years, there was again a slight overrepresentation of operator personnel in relation to contractor personnel on production installations (PSA, 2008). The RNNP is an important fulfilment of sections of the O&G regulations (PSA, 2011b) that focus on the working environment. The companies can get the result the result for their company and compare them with the overall result for the industry.

# 2 THEORETICAL BACKGROUND

Historically, the opinions of safety culture in the Norwegian offshore industry have varied. It is therefore of importance to have a historical view to understand the background of the NORSCI. After the Piper Alpha tragedy (Cullen, 1990) on the British shelf, the whole industry was reminded of the dangers related to the offshore O&G industry. The period after the Piper Alpha accident was characterised by a strengthening of HSE management by all parties involved in which safety was prioritised. Behavioural science became a hot topic within safety management. In 1998, a drastic fall in oil prices resulted in belt-tightening, reorganizations and downsizing, and management turned its attention to costs and efficiency. The trade unions claimed that safety matters were deteriorating and that safety was at an all-time low. Their view was confirmed by several research communities and fronted by the Norwegian Petroleum Directorate (NPD). (The NPD changed its name to the PSA in 2004). At the same time, several managers claimed that safety had never been better. The conflict peaked during the summer of 2000 and culminated in a serious accident on 24 December 2000, in which a worker was crushed to death under a pile of drilling pipes (Haukelid, 2008). The NPD then introduced the RNNP project, which aimed at identifying risk indicators that were critical for safety and the working environment. Questionnaires, interviews, workshops and fieldwork formed the basis of the analyses in the RNNP. The findings stated that important safety matters in the oil industry were perceived very differently by the oil companies and the unions, and that there was little trust between these parties (NPD, 2002). As a result of these negative developments, the NPD/PSA introduced several measures. One unique measure was a regulation enforcing a HSE culture. The Framework Regulations, Section 11 stated: "*The party responsible shall encourage and promote a sound health, environment and safety culture comprising all activity areas and which contributes to achieving that everyone who takes part in petroleum activities takes on responsibility in relation to health, environment and safety, including also systematic development and improvement of health, environment and safety*" (PSA, 2009).

The UK Health and Safety Regulator was also at same time aware that organizational factors influenced safety culture. It pointed out that senior management commitment, management style, visible management, good communication between all levels of employees [management action] and a balance of health and safety and production goals [management prioritisation] were essential (Health and Safety Executive, 1999).

## 2.1 Safety climate versus safety culture

Schein (2004) defined the term organizational culture as “observed behavioural regularities when people interact (language, customs and traditions, rituals), group norms, espoused values, formal philosophy, rules of the game, climate, embedded skills, habits of thinking/mental models/linguistic paradigms, shared meanings and ‘root’ metaphors or integrating symbols”, which shows the complexity of the meaning of culture. Reason (1997) emphasised the role of organizational cultural in safety management. According to Reason (1997), organizational culture most closely captures the essence that shared values (what is important) and beliefs (how things work) interact with a company’s people, organizational structures and control systems to produce behavioural norms (the way we do things around here). Richter and Koch (2004) stated that safety culture is “the shared and learned meanings, experiences and interpretations of work and safety – expressed partially symbolically – which guide peoples’ actions towards risks, accidents and prevention”. Safety culture is shaped by people in the structures and social relations within and outside the organization.

Although there have been reservations from some investigators, safety culture has acquired a significant place in the literature, and there is agreement that safety culture is a proactive stance towards safety (Guldenmund, 2000). Guldenmund (2010) summarised the various definitions of organizational safety culture, one being that safety culture is those aspects of the organizational culture that will impact on attitudes and behaviour related to increasing or decreasing risk.

Several studies have found safety management, colleague involvement and collaboration to be important dimensions for safety climate (Flin et al., 2000; Guldenmund, 2007; Rundmo, 2000). Safety climate is reflected in the workforce’s perceptions of the organizational atmosphere. It is more superficial and transient than is culture (Guldenmund, 2007). According to Hahn and Murphy (2008) safety climate refers to the shared perceptions of employees about the safety of their work environments and provides a background against which day-to-day tasks are performed. These shared perceptions derive from several factors, including management decision-making, organizational safety norms and expectations and safety practices, policies and procedures, which together serve to communicate the organization’s commitment to safety (Hahn and Murphy, 2008).

In this analysis, the OIMS and safety advisers are separated from the rest of the organization. Their answers form part of the overall safety climate, but it does not make sense to describe this as their safety climate. It is therefore called perception and comprehension of safety. Each individual has his or her perception and comprehension of safety, which were summarised in the overall safety climate.

When analyzing a small group, such as OIMs, the analysis includes their safety perceptions and comprehensions as part of the overall safety climate.

## 2.2 Can safety culture be measured?

Can safety culture be measured? Anthropologists and psychologists tend to disagree on this question. Many psychologists seem to believe that it is possible to measure culture – or at least to measure safety climate (Haukelid, 2008). According to Hopkins (2006) survey methods are regarded as a well-suited way to study the attitudes, values and perceptions of organizational practices.

There has been continuing debate about the fundamental dimensions of safety climate. Flin et al. (2000) examined 18 safety climate instruments used in industry and extracted the following dimensions: "Management/Supervision" (especially in relation to perceived commitment to safety), "Safety System" (procedures, practices and equipment), "Risk" (attitudes to risk-taking), "Work Pressure" (work pace; production versus safety) and "Competence" (knowledge, skills, training). "Procedures/Rules" was a factor also found in a number of studies. Guldenmund (2000) identified similar factors from the 16 articles he reviewed. In both reviews, management was the dominant variable. This included first-line supervisors, site managers and senior managers. The level of management is not always well specified. Some researchers, such as Zohar and Luria (2003), have argued that the essential dimension is management's commitment to safety and that this suffices as a measure of safety climate (Yule et al., 2007).

All but one of the seven empirical articles in *Safety Science's* special issue on safety culture used survey methods to measure safety culture/climate (see *Safety Science* volume 34, 2000). For survey methods to be considered useful as safety assessments, their results should provide some basis for making judgements about how safe or unsafe an organization is as well as some sort of prediction as to whether the organization is prone to having accidents (Antonsen, 2009b). One way of answering the question is to analyse the relationship between safety climate surveys and occupational accidents. This is done in several studies e.g. (Høivik, 2010). The management of occupational accidents is different from that of major hazard risk management. Two recent studies have analysed safety climate surveys and precursor incidents with the potential to cause major accidents. Hydrocarbon leaks are important precursor incident in the O&G industry as they may rapidly escalate to major accidents. An extensive study using the NORSCI concluded that there were significant correlations between the number of hydrocarbon leaks and safety climate indicators (Vinnem et al., 2010). A second study explored the extent to which a safety climate indicator from a survey on working conditions undertaken in an O&G company (n = 2188) could be used as a safety indicator in relation to hydrocarbon leaks on 28 offshore installations. It was found that more negative safety climate scores were associated with increasing numbers of hydrocarbon leaks over a 12-month period following the survey. The safety climate indicator explained more of the variance in hydrocarbon leaks than did the technical indicators (Kongsvik et al., 2011).

The knowledge of the relationship between safety climate surveys and safety results is still rather limited, but the promising results should be followed up by more knowledge about surveys as tools for measuring safety climate.

# 3 RESULTS

The survey consisted of 124 questions or statements divided into the six main parts relevant to health and safety. In addition to demographic and other background data, the survey included 43 statements about daily HSE prioritisation and risk communication, own and others' safety skills and behaviour connected to role clarity, safety training, competence and workplace conditions influencing health and safety such as management and prioritisation and individual motivation and following up systems and procedures. In the present study, the results for these 43 statements were analysed. In the analysis, all items were graded from "1" ("*totally agree"*) to "5" ("*totally disagree"*). To counteract response style bias, 28 of the statements were formulated positively (e.g., ''my colleagues are very preoccupied with HSE"), while the remaining 15 statements were formulated negatively (e.g., ''I sometimes violate safety rules to get the job done"). The questionnaire has been continually developed and new questions have been introduced. A basic set of questions has been retained in order to monitor trends over time.

The following table shows the different questions categorized into six categories. The categories are similar to those used by Høivik et al. (2009b) which also used the NORSCI. For the purpose of our analysis, the categorization is purely a matter of order and not an object of the analysis. The mean of score of each individual statement was calculated for the three variables: (a) OIMs, (b) safety advisers and (c) the rest of the offshore organization. The standard deviation (95% confidence interval) is listed for the three groups. The differences between the three variables were then calculated.

| Safety prioritisation | (a) OIM | Std.Dev. (a) | (b) Safety advisers | Std.Dev. (b) | (c) Organisation | Std.Dev. (c) | Difference [a-b] | Difference [a-c] |
|---|---|---|---|---|---|---|---|---|
| 1 Occasionally I'm required to work in a manner that jeopardizes safety | 4,90 | *,33* | 4,77 | *,69* | 4,29 | *1,09* | ,13 | **0,61** |
| 2 When it comes to one's career it is a disadvantage to be too concerned with HSE | 4,87 | *,54* | 4,36 | *1,04* | 3,99 | *1,18* | ,50 | **0,88** |
| 3 I sometimes violate safety rules to get the job done | 4,90 | *,51* | 4,79 | *,62* | 4,06 | *1,17* | ,11 | **0,84** |
| 4 My lack of knowledge of new technology can sometimes lead to an increased risk of accidents | 4,38 | *1,00* | 4,43 | *,97* | 4,12 | *1,13* | ,05 | **0,26** |
| 5 I do not participate actively at safety meetings | 4,95 | *,40* | 4,54 | *1,04* | 3,82 | *1,28* | ,41 | **1,13** |
| 6 My work site is often untidy | 4,53 | *,74* | 4,19 | *1,07* | 3,91 | *1,09* | ,33 | **0,62** |
| 7 I find it uncomfortable to call attention to violations of safety rules | 4,69 | *,75* | 4,02 | *1,24* | 3,61 | *1,30* | ,67 | **1,09** |
| 8 The regulatory requirements on HSE are not good enough | 3,83 | *1,17* | 3,61 | *1,15* | 3,58 | *1,12* | ,22 | **0,25** |
| 9 One may be easily be seen as disputatious person if one call attention for hazardous conditions | 4,54 | *,86* | 3,99 | *1,21* | 3,55 | *1,31* | ,55 | **0,99** |
| 10 The manning is sufficient to ensure that health, environment and safety is well taken care off | 1,44 | *,89* | 1,99 | *1,14* | 2,11 | *1,17* | ,54 | **0,67** |
| | | | | | | | | |
| **Safety management and involvement** | | | | | | | | |
| 1 The company I work for take HSE seriously | 1,04 | *,19* | 1,35 | *,63* | 1,50 | *,78* | ,31 | **0,46** |
| 2 My supervisor is committed to working with HSE on the installation | 1,13 | *,37* | 1,35 | *,67* | 1,68 | *,87* | ,22 | **0,54** |
| 3 The safety deputies' suggestions are taken seriously by the management | 1,21 | *,68* | 1,55 | *,73* | 1,92 | *,93* | ,34 | **0,71** |
| 4 Risky work operations are always carefully examined before they are commenced | 1,13 | *,48* | 1,39 | *,60* | 1,37 | *,67* | ,26 | **0,24** |
| 5 my colleagues are very preoccupied with HSE | 1,23 | *,45* | 1,64 | *,75* | 1,91 | *,80* | ,41 | **0,67** |
| 6 I can influence the HSE-conditions at my workplace | 1,11 | *,52* | 1,31 | *,54* | 1,64 | *,79* | ,20 | **0,52** |
| 7 Information about undesirable incidents are effectively used to prevent them from recurring | 1,65 | *,80* | 1,77 | *,86* | 1,94 | *1,00* | ,11 | **0,29** |
| 8 The emergency preparedness is good | 1,26 | *,71* | 1,58 | *,77* | 1,88 | *,95* | ,33 | **0,63** |
| 9 The safety deputies are doing a good job* | 1,77 | *,88* | 2,00 | *,94* | 1,91 | *,89* | ,23 | **0,14** |
| 10 It is easy to tell the nurse/company health service about worries and sickness related to the work situation | 1,21 | *,57* | 1,57 | *,90* | 1,89 | *1,05* | ,36 | **0,68** |
| 11 The work permit system is always lived up to | 1,37 | *,64* | 1,75 | *,82* | 1,72 | *,88* | ,38 | **0,34** |
| 12 My manager do appreciate that I point out conditions that influence on SHE | 1,10 | *,33* | 1,25 | *,58* | 1,59 | *,86* | ,16 | **0,50** |
| | | | | | | | | |
| **Safety versus production** | | | | | | | | |
| 1 Lack of maintenance has resulted in reduced safety | 3,86 | *1,24* | 2,86 | *1,31* | 2,87 | *1,36* | ,99 | **0,99** |
| 2 In practice concern for production precedes the concern for HSE | 4,88 | *,33* | 3,75 | *1,21* | 3,36 | *1,31* | 1,13 | **1,52** |
| 3 Reports on accidents or dangerous situations are often "smartened up" | 4,86 | *,38* | 4,04 | *1,13* | 3,33 | *1,29* | ,82 | **1,53** |
| 4 There are often parallel work operations proceeding that leads to dangerous situations | 4,56 | *,78* | 3,90 | *1,07* | 3,63 | *1,18* | ,66 | **0,94** |
| | | | | | | | | |
| **Individual motivation** | | | | | | | | |
| 1 I report dangerous situations when I see them | 1,08 | *,43* | 1,14 | *,45* | 1,34 | *,62* | ,07 | **0,27** |
| 2 Safety has top priority when I do my job | 1,01 | *,10* | 1,18 | *,52* | 1,33 | *,59* | ,17 | **0,32** |
| 3 I ask my colleagues to stop work when I think the task in question is being carried out in a risky manner | 1,03 | *,17* | 1,33 | *,69* | 1,45 | *,71* | ,30 | **0,43** |
| 4 I stop working if I think it can be dangerous for me or other to continue* | 1,11 | *,59* | 1,30 | *,89* | 1,31 | *,80* | ,19 | **0,20** |
| 5 I use personal protective equipment | 1,10 | *,56* | 1,06 | *,41* | 1,18 | *,51* | ,03 | **0,08** |
| | | | | | | | | |
| **System comprehension** | | | | | | | | |
| 1 I think it's easy to find the right steering document | 2,50 | *1,04* | 2,65 | *1,15* | 2,99 | *1,23* | ,14 | **0,48** |
| 2 I always know which person within the organization to report to | 1,31 | *,70* | 1,54 | *,97* | 1,88 | *1,09* | ,23 | **0,56** |
| 3 The HSE procedures are suitable for my work tasks | 1,39 | *,51* | 1,58 | *,80* | 1,86 | *,90* | ,19 | **0,47** |
| 4 I have easy access to the procedures that are relevant for my work | 1,34 | *,48* | 1,37 | *,79* | 1,88 | *1,00* | ,03 | **0,54** |
| 5 Different procedures and routines on different installations may threaten the safety* | 2,34 | *1,10* | 2,30 | *1,15* | 2,43 | *1,19* | ,04 | **0,09** |
| 6 Communication between colleges and myself do often fail causing possible dangerous situations | 4,71 | *,76* | 4,71 | *,73* | 4,50 | *,87* | ,01 | **0,21** |
| 7 I experience group pressure that influence my judgement realted to SHE | 4,60 | *,88* | 4,26 | *1,05* | 3,97 | *1,11* | ,33 | **0,63** |
| | | | | | | | | |
| **Competence** | | | | | | | | |
| 1 I have the necessary competence to perform my job in a safe manner | 1,29 | *,71* | 1,26 | *,47* | 1,45 | *,77* | ,03 | **0,16** |
| 2 I have easy access to personal protective equipment | 1,14 | *,69* | 1,05 | *,26* | 1,27 | *,68* | ,09 | **0,13** |
| 3 I have received sufficient safety training | 1,28 | *,61* | 1,62 | *,89* | 1,65 | *,80* | ,34 | **0,37** |
| 4 I have received sufficient education when it comes to occupational health and work environment | 1,50 | *,68* | 1,80 | *,94* | 1,95 | *,94* | ,29 | **0,45** |
| 5 I have good knowledge about the HSE procedures | 1,25 | *,75* | 1,20 | *,41* | 1,58 | *,73* | ,05 | **0,33** |



33

One-way analysis of variance (ANOVA) is a technique used to compare the means of two or more samples. The one-way ANOVA technique analyses variance for a quantitative dependent variable using a single factor (independent) variable and is used to test the hypothesis that several means are equal. This technique is an extension of the two-sample t test (Field, 2009). One-way ANOVA is a relatively robust procedure with respect to violations of the normality assumption. The questions were are all significant within the limit of ≥0.01, except for four questions: *The regulatory requirements on HSE are not good enough (Sign: 0.077); I stop working if I think it can be dangerous for me or other to continue (sign: 0.043); The safety deputies are doing a good job (sign: 0.093); and Different procedures and routines on different installations may threaten the safety (sign: 0.197)*. The response rate was above 98% for all the questions.

The purpose of the present study is to reveal whether the understanding of central elements related to safety climate (safety perception and comprehension) is shared by the different levels of the offshore organization. As seen, there is a significant difference in almost all the questions, and further categorization was thus not carried out.

# 4 Discussion

Managing an organization's safety requires a long-term approach focused on the key determinants of the safety culture. One of the prime factors is the degree of management commitment to safety at all levels, from the first-line supervisors to the managing director. Managers must check whether their safety commitment is being transmitted to others. This can be achieved by the use of safety climate surveys (Flin et al., 2002). As shown in the table and the one-way ANOVA calculation, there are significant differences in the scores between the OIMs and the rest of the organization. In particular, within the categories of *safety prioritisation* and *safety versus production,* the differences between OIMs and the rest of the organization were considerable.

Hale (2000) listed a number of elements for a good safety culture: importance of safety; involvement of workers at all levels; role of safety staff; caring trust (that all parties have a watchful eye and helping hand to cope with inevitable slips and blunders); openness in communication; belief in safety improvements; and integration of safety into the organization. The OIMs and the rest of the organization have different opinions about the questions: *I find it uncomfortable to call attention to violations of safety rules* and *Reports on accidents or dangerous* *situations are often ‘‘smartened up”.* These are important questions related to the elements listed by Hale (2000). A good organizational safety culture typically relies on good safety leadership (Conchie and Donald, 2006). A study in the UK showed that OIMs report difficulties in motivating and controlling crucial safety aspects of workforce behaviour even though they are aware of the importance of such leadership (O'Dea and Flin, 2001).

Transocean conducted surveys and interviews with hundreds of employees onshore and on four rigs, including Deepwater Horizon, which was surveyed from March 12 to March 16, 2010. The surveys and interviews focused on elements of the safety climate. The reviewers found Deepwater Horizon “relatively strong in many of the core aspects of safety management. However, there were also weaknesses. Almost half (46%) of the crew members surveyed felt that some of the workforce feared reprisals for reporting unsafe situations, and 15% felt that there were not always enough people available to carry out work safely. Some Transocean crews complained that the safety manual was “unstructured”, “hard to navigate” and “not written with the end user in mind”, and that there was a “poor distinction between what is required and how this should be achieved” (Graham et al., 2011). It was not the goal to draw any parallels between the findings in the NORSCI and the research conducted among Transocean’s crew. However, it is interesting to see that the differences between the OIMs and the rest of the organization are large for questions 2 and 10: *“When it comes to one’s career it is a disadvantage to be too concerned with HSE”* and *“The manning is sufficient to ensure that health, environment and safety is well taken care off”.* Indeed, what the Transocean crew members found problematic is the similar to the questions where OIMs and and the rest of organization have had the most different comprehensions.

A number of investigations into the safety climates on offshore petroleum installations have identified the importance of management, although in rather general terms. Alexander et al. (1995) reported that for UK offshore workers “management commitment to safety” was the dominant factor in their safety climate questionnaire. Rundmo (1994) analysed the association between organizational factors and safety in the Norwegian offshore environment and found that employees’ perceptions of greater management commitment to safety and the priority of safety over production goals were important predictors of employee satisfaction. This finding was replicated in a subsequent survey in the UK using a similar set of measures (Flin et al., 1996). As seen in the results, the difference between the OIMs and the rest of the organization was considerable (1.52) for the question: *In practice, the concern for production precedes the concern for HSE*.

## 4.1 Response bias

Differences in survey responses can be related to the respondent's role in an organization. Psychologists have identified a phenomenon called socially desirable responding, which is the tendency to answer in a way that makes the respondent look good (Paulhus, 1991). What is socially desirable depends on the situation and the individual's perception. For a group to answer homogeneously in a socially desirable way the group must be largely uniform and the surroundings must be comparable for the different individuals of the group. Response biases are controlled by using rational techniques such as forced choice or by using factor analysis or covariate techniques when analysing the data. A common way to bypass situational pressure for desirable responding is anonymity. Although anonymity is assured in the NORSCI, there is no indication that socially desirable responding is controlled for in the survey.

## 4.2 Safety as an arena for conflicting interests

The management of an offshore installation plant involves the task of finding a balance between a large number of sometimes conflicting requirements. These can be thought of as generic dilemmas of management, which have to be understood, resolved and integrated into organizational activities. One example is the balance between safety and efficiency, which has to be approached in a way so as not to allow one compromise the other. Management's need to express a positive view of the way safety is managed in the company may thus be strongly enforced, especially when scoring a safety survey from the safety authority.

As described earlier, there are still different opinions on safety levels between unions and operator companies. Issues of power and conflict in organizations are rarely addressed in safety culture research. Much safety culture research thus rests on a harmony model of organizational life. Antonsen, (2009a) argued that this is a fundamental shortcoming of the existing research. The most obvious but nonetheless most important lesson for safety culture research is that organizations are arenas for conflicting interests. Safety issues, like other organizational issues, are subject to discussion and disagreement. Hovden et al. (2008) found that safety advisers report more problematic relations to their managers than vice versa. This is expressed in terms of loyalty conflicts, priority of cost versus safety, manager's intolerance of safety advisers' use of time and resources and managers unwillingness to listen.

## 4.3 The role of trust

The role of trust and distrust has been argued to play an increasingly important role in modern, global, complex and ambivalent risk societies (Conchie and Donald, 2006; Tharaldsen et al., 2010). Low-trust relations between key stakeholders are assumed to have a negative impact on safety culture by reinforcing blame and fostering the non-reporting of safety-relevant information (Conchie and Donald, 2006; Cox et al., 2006; Schöbel, 2009). Trust can improve safety attitudes and performance (Cox et al., 2004) and trust is a significant predictor of perceived risk (Viklund, 2003).

In summary, studies on safety leadership suggest that trust within leader–worker relationships is necessary to develop and sustain good safety cultures within organizations (Conchie and Donald, 2006). Large differences in safety perceptions and comprehensions may lead to less trust. Different safety perceptions are especially evident when it comes to questions related to safety versus production. Both the PSA and the Health and Safety Executive UK have emphasised the importance of a balance between safety and production to ensure safe operations. Safety versus production issues are often seen as the cause of major accidents and the main conflict between unions and management. As organizational functioning relies on cooperation between different group members, trust may show varying degrees of importance depending on the tasks and associated interactions.

A study by Luria (2010) tested the contribution of trust to safety between leaders and subordinates and found that leaders that created a relationship of trust with their subordinates were more likely to create a safe working environment and achieve higher and stronger safety climate perceptions among their subordinates. The results reinforced the assumption that safety is related to social relationships, such as trust in a leader. It thus seems that trust is related to the effective communication of the importance of safety (i.e., strong safety climate), and trust relationships are also related to the perceived importance of safety to unit leaders (safety climate level), which ultimately contributes to fewer injuries. It also seems that safety management is linked to a broad spectrum of social relationships between leaders and subordinates. (Høivik, 2010) found that all HSE climate factors were negatively associated with recordable injuries, but only the factor "Confidence in management" was significantly negatively associated with recordable injuries. Thus, organizational surveys might be used as indicators of the risk of injuries. Management style and trust in the manager were also important factors for personnel injuries. This study did not conclude that there is mistrust, but drawing the historical lines related to trust and still observing that safety versus production is the category where OIMs differ most from their organizations is interesting and this could be followed up by more extensive studies. Indeed, there were different opinions about the safety level that triggered the RNNP in the first place.

## 4.4 Shared perceptions of safety as a basis for developing a safety culture

As culture is socially constructed in groups, it is unlikely that these processes will generate the same culture in different parts and at different levels of an organization (Antonsen, 2009a). This line of thought is rather marginal and poorly developed in the safety culture literature, which generally presupposes that safety cultures are shared by all members of organizations. The safety culture literature lacks a conceptualisation of how changes in shared frames of reference occur (Nævestad, 2010). Our study supports the hypothesis that managers in general have more positive perceptions and comprehensions of safety onboard. It also supports the notion that culture is socially constructed in groups. The results supported the hypothesis, but the overall low standard deviation and the distinctive differences for almost all questions is surprising. Major hazards always pose a threat to the whole crew from the OIMs to the roughnecks. In many industries, occupational accidents are the main hazard. Managers are not exposed to these hazards in the same way as are the rest of the blue-collar workers. Thus, the perceptions and comprehensions about the safety climate might therefore not necessarily differ between OIMs and the rest of the crew in the same way as in other industries.

# 5 Concluding remarks

Risk and safety perceptions offshore have been found to be framed by the installation you work on and whether you belong to a client or a contractor company (Høivik, 2009; Høivik et al., 2009a; Høivik et al., 2009b; Tharaldsen et al., 2010). This study adds that the risk and safety perception is framed by the executive position of OIMs and safety advisers for offshore workers on the Norwegian Continental Shelf.

Our findings support earlier research in that the managers of organizations that are closer to the planning and strategy of the operation express a more positive view of the safety level. Working offshore is special in the sense that all levels of the organization work, eat, have time off and sleep in a limited space far away from family. Thus, they interact differently than most other workplaces. Offshore workers often refer to the organization as “one big family” and state that there is a low level of hierarchy. It is thus of interest to see how this close interaction influences the perception and comprehension of safety and whether similar differences between managers and workers in their understanding of safety exist in such a “family setting”. The study presented in this article shows that safety perceptions and comprehensions differ significantly among OIMs, safety advisers and the rest of the organization on offshore installations. OIMs have the most positive perceptions and comprehensions of both personal and organizational safety. Safety advisers’ responses are between OIMs and the rest of the organization. These different safety perceptions and comprehensions may be influenced by group identity, different knowledge and control and issues of power and conflict. As OIMs and safety advisers have important roles in safety management and risk treatment on offshore installations, the difference is of significance for the communication and management of risks on offshore installations. These different safety perceptions and comprehensions are important to bear in mind when planning surveys as well as planning and implementing safety measures. Knowledge about the perception and comprehension might also give managers an appreciation of how other employees perceive the relationships between the elements of safety climate. Further research is needed to explain the differences. The significantly different opinions related to safety versus production are of special interest because of the earlier distrust between unions and management.

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## 7 REFERENCES


Alexander, M., Cox, S., Cheyne, A., 1995. The concept of safety culture within a UK offshore organization. HSE Books.

Antonsen, S., 2009a. Safety culture and the issue of power. Safety Science 47, 183-191.

Antonsen, S., 2009b. Safety Culture Assessment: A Mission Impossible? Journal of Contingencies and Crisis Management 17, 242-254.

Bartlit, J.F.H., Sankar, S.N., Grimsley, S.C., 2011. Macondo - The Gulf Oil Disaster - Chief Counsel's Report National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling.

Cheyne, A., Tomás, J.M., Cox, S., Oliver, A., 2003. Perceptions of safety climate at different employment levels. Work and stress 17, 21-37.

Clarke, S., Ward, K., 2006. The Role of Leader Influence Tactics and Safety Climate in Engaging Employees' Safety Participation. Risk Analysis 26, 1175-1185.

Conchie, S.M., Donald, I.J., 2006. The role of distrust in offshore safety performance. Risk Analysis 26, 1151-1159.

Cooper, M.D., Phillips, R.A., 2004. Exploratory analysis of the safety climate and safety behavior relationship. Journal of Safety Research 35, 497-512.

Cox, S., Flin, R., 1998. Safety culture: philosopher's stone or man of straw? Work and stress 12, 189-201.

Cox, S., Jones, B., Collinson, D., 2006. Trust Relations in High-Reliability Organizations. Risk Analysis 26, 1123-1138.

Cox, S., Jones, B., Rycraft, H., 2004. Behavioural approaches to safety management within UK reactor plants. Safety Science 42, 825-839.

Cox, S.J., Cheyne, A.J.T., 2000. Assessing safety culture in offshore environments. Safety Science 34, 111-129.

Cullen, W.D., 1990. The Public Inquiry into the Piper Alpha disaster. Department of Energy, London.

Edkins, G., Pfister, P., 2003. Innovation and consolidation in aviation: selected contributions to the Australian Aviation Psychology Symposium 2000. Ashgate Pub Ltd, Aldershot, England.

Field, A., 2009. Discovering statistics using SPSS, 3rd ed. Sage, Los Angeles.

Findley, M., Smith, S., Gorski, J., O'neil, M., 2007. Safety climate differences among job positions in a nuclear decommissioning and demolition industry: employees' self-reported safety attitudes and perceptions. Safety Science 45, 875-889.

Flin, R., Mearns, K., O'Connor, P., Bryden, R., 2000. Measuring safety climate: identifying the common features. Safety Science 34, 177-192.

Flin, R., O'Dea, A., Yule, S., 2002. Leadership Behaviours for Maximising Safety, SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production. the Society of Petroleum Engineers, Kuala Lumpur. March 20-22.

Flin, R., Slaven, G., 1993. Managing offshore installations: A survey of UKCS offshore installation managers. Petroleum Review, 68-71.

Flin, R., Slaven, G., 1994. The selection and training of offshore installation managers for crisis management. HSE Books.

Flin, R., Slaven, G., Carnegie, D., 1996. Managers and supervisors on offshore installations. Managing the Offshore Installation Workforce, PennWell Books, Tulsa.

Graham, B., Reilly, W.K., Beinecke, F., Boesch, D.F., Garcia, T.D., Murray, C.A., Ulmer, F., 2011. Deep Water. The Gulf Oil Disaster and the Future of Offshore Drilling. Report to the President. the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Washington DC, USA.

Guldenmund, F.W., 2000. The nature of safety culture: a review of theory and research. Safety Science 34, 215-257.

Guldenmund, F.W., 2007. The use of questionnaires in safety culture research - an evaluation. Safety Science 45, 723-743.

Guldenmund, F.W., 2010. (Mis)understanding Safety Culture and Its Relationship to Safety Management. Risk Analysis 30, 1466-1480.

Hahn, S.E., Murphy, L.R., 2008. A short scale for measuring safety climate. Safety Science 46, 1047-1066.

Hale, A.R., 2000. Culture's confusions. Safety Science 34, 1-14.

Haukelid, K., 2008. Theories of (safety) culture revisited - An anthropological approach. Safety Science 46, 413-426.

Health and Safety Executive, 1999. Reducing error and influencing behaviour HSG48. HSE Books.

Hopkins, A., 2006. Studying organizational cultures and their effects on safety. Safety Science 44, 875-889.

Hovden, J., Lie, T., Karlsen, J.E., Alteren, B., 2008. The safety representative under pressure. A study of occupational health and safety management in the Norwegian oil and gas industry. Safety Science 46, 493-509.

Høivik, D., 2009. Health, Safety and Environment Culture in the Petroleum Industry in Norway. University of Bergen.

Høivik, D., 2010. HSE and Culture in the Petroleum Industry in Norway, SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production. the Society of Petroleum Engineers, Rio de Janeiro. April 12-14.

Høivik, D., Moen, B.E., Mearns, K., Haukelid, K., 2009a. An explorative study of health, safety and environment culture in a Norwegian petroleum company. Safety Science 47, 992-1001.

Høivik, D., Tharaldsen, J.E., Baste, V., Moen, B.E., 2009b. What is most important for safety climate: The company belonging or the local working environment? - A study from the Norwegian offshore industry. Safety Science 47, 1324-1331.

Kath, L.M., Magley, V.J., Marmet, M., 2010. The role of organizational trust in safety climate's influence on organizational outcomes. Accident Analysis and Prevention 42, 1488-1497.

Kongsvik, T., Kjøs Johnsen, S.Å., Sklet, S., 2011. Safety climate and hydrocarbon leaks: An empirical contribution to the leading-lagging indicator discussion. Journal of Loss Prevention in the Process Industries 24, 405-411.

Lofquist, E.A., Greve, A., Olsson, U.H., 2011. Modeling attitudes and perceptions as predictors for changing safety margins during organizational change. Safety Science 49, 531-541.

Luria, G., 2010. The social aspects of safety management: Trust and safety climate. Accident Analysis & Prevention 42, 1288-1295.

Martínez-Córcoles, M., Gracia, F., Tomás, I., Peiró, J.M., 2011. Leadership and employees' perceived safety behaviours in a nuclear power plant: A structural equation model. Safety Science 49, 1118-1129.

Mearns, K., Flin, R., 1995. Risk perception and attitudes to safety by personnel in the offshore oil and gas industry: a review. Journal of Loss Prevention in the Process Industries 8, 299-305.

Mearns, K., Flin, R., 1999. Assessing the state of organizational safety—culture or climate? Current Psychology 18, 5-17.

Mearns, K., Rundmo, T., Flin, R., Gordon, R., Fleming, M., 2004. Evaluation of psychosocial and organizational factors in offshore safety: a comparative study. Journal of Risk Research 7, 545 - 561.

Mearns, K., Whitaker, S.M., Flin, R., 2003. Safety climate, safety management practice and safety performance in offshore environments. Safety Science 41, 641-680.

Mearns, K., Yule, S., 2009. The role of national culture in determining safety performance: Challenges for the global oil and gas industry. Safety Science 47, 777-785.

Nielsen, K.J., Rasmussen, K., Glasscock, D., Spangenberg, S., 2008. Changes in safety climate and accidents at two identical manufacturing plants. Safety Science 46, 440-449.

Njå, O., Fjelltun, S.H., 2010. Managers' attitudes towards safety measures in the commercial road transport sector. Safety Science 48, 1073-1080.

NPD, 2002. Trends in risk level in the petroleum sector, Norwegian Shelf, 2001. Norwegian Petroleum Directorate, Norway.

Næsheim, T., 1981. NOU, The "Alexander L. Kielland"-accident (In Norwegian), Oslo.

Nævestad, T.O., 2010. Evaluating a safety culture campaign: Some lessons from a Norwegian case. Safety Science 48, 651-659.

O'Dea, A., Flin, R., 2001. Site managers and safety leadership in the offshore oil and gas industry. Safety Science 37, 39-57.

Paulhus, D., 1991. Measurement and control of response bias. Measures of personality and social psychological attitudes 1, 17–59.

PSA (Petroleum Safety Authority Norway), 2008. Risk Levels in the Petroleum Industry. Norwegian Continental Shelf 2007.

PSA (Petroleum Safety Authority Norway), 2009. Regulations relating to health, enviroment and safety in the petroleum activities (The framework regulations) <http://www.ptil.no/framework-hse/category403.html> (12.10.10)

PSA (Petroleum Safety Authority Norway), 2011a. The Deepwater Horizon accident - assessments and recommendations for the Norwegian petroleum industry summary. Petroleum Safety Authority Norway.

PSA (Petroleum Safety Authority Norway), 2011b. Regulations. <http://www.ptil.no/regulations/category87.html?lang=en_US > (21.06.2011)

Reason, J., 1997. Managing the Risks of Organizational Accidents. Ashgate Publishing Company, Aldershot, UK.

Richter, A., Koch, C., 2004. Integration, differentiation and ambiguity in safety cultures. Safety Science 42, 703-722.

Rundmo, T., 1994. Associations between organizational factors and safety and contingency measures on offshore petroleum platforms. Scandinavian journal of work, environment & health 20, 122-127.

Rundmo, T., 2000. Safety climate, attitudes and risk perception in Norsk Hydro. Safety Science 34, 47-59.

Schein, E.H., 2004. Organizational culture and leadership, 2nd ed. Jossey-Bass, San Francisco.

Schöbel, M., 2009. Trust in high-reliability organizations. Social Science Information 48, 315.

Tharaldsen, J.E., Mearns, K.J., Knudsen, K., 2010. Perspectives on safety: The impact of group membership, work factors and trust on safety performance in UK and Norwegian drilling company employees. Safety Science 48, 1062-1072.

Tharaldsen, J.E., Olsen, E., Rundmo, T., 2008. A longitudinal study of safety climate on the Norwegian continental shelf. Safety Science 46, 427-439.

USCG (United States Coast Guard), 2011. Report of Investigation into the Circumstances Surrounding the Explosion, Fire, Sinking and Loss of Eleven

Crew Members Aboard the Moblie Offshore Drilling Unit Deepwater Horizon in the Gulf of Mexico April 20-22, 2010. Volume I MISLE Activity Number: 3721503.

Viklund, M.J., 2003. Trust and Risk Perception in Western Europe: A Cross-National Study. Risk Analysis 23, 727-738.

Vinnem, J.E., Hestad, J.A., Kvaløy, J.T., Skogdalen, J.E., 2010. Analysis of root causes of major hazard precursors (hydrocarbon leaks) in the Norwegian offshore petroleum industry. Reliability Engineering & System Safety 95, 1142-1153.

Vinodkumar, M.N., Bhasi, M., 2010. Safety management practices and safety behaviour: Assessing the mediating role of safety knowledge and motivation. Accident Analysis & Prevention 42, 2082-2093.

Wills, A.R., Watson, B., Biggs, H.C., 2006. Comparing safety climate factors as predictors of work-related driving behavior. Journal of Safety Research 37, 375-383.

Wu, T.-C., Chen, C.-H., Li, C.-C., 2008. A correlation among safety leadership, safety climate and safety performance. Journal of Loss Prevention in the Process Industries 21, 307-318.

Wu, T.-C., Lin, C.-H., Shiau, S.-Y., 2010. Predicting safety culture: The roles of employer, operations manager and safety professional. Journal of Safety Research 41, 423-431.

Yule, S., Flin, R., Murdy, A., 2007. The role of management and safety climate in preventing risk-taking at work. International Journal of Risk Assessment and Management 7, 137-151.

Zohar, D., 2000. A group-level model of safety climate: Testing the effect of group climate on microaccidents in manufacturing jobs. Journal of Applied Psychology 85, 587-596.

Zohar, D., Luria, G., 2003. The use of supervisory practices as leverage to improve safety behavior: A cross-level intervention model. Journal of Safety Research 34, 567-577.

Zohar, D., Luria, G., 2005. A multilevel model of safety climate: Cross-level relationships between organization and group-level climates. Journal of Applied Psychology 90, 616-628.

Paper 3

# Resilient Planning of Modification Projects in High Risk Systems: The Implications of Using FRAM for Risk Assessments

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Recent research into accidents, safety and risk assessment has implemented a resilience engineering framework for managing emergent risks and latent failures. The resilience engineering approach emphasizes the need to study the normal operation of a sociotechnical system to identify performance variability that may lead to unwanted consequences should interactions result in instability. The study discussed in this chapter implemented the Functional Resonance Analysis Method (FRAM) to identify potential performance variability in the planning of modifications to a mature offshore oil installation. In addition to identifying variability that may lead to unwanted outcomes in the planning phase of modifications, the study suggests that FRAM may be useful as a risk assessment method at the organizational level.

## 1 Introduction

Recent research has focused on understanding accidents, safety and risk assessment from a resilience engineering perspective (Hollnagel, Woods and Leveson 2006; Hollnagel, Nemeth and Dekker, 2008; Nemeth, Hollnagel and Dekker, 2009; Hollnagel et al., 2011). Earlier work by James Reason focused on the need to identify latent failures and highlighted latent errors as a hazard and a source of risk in maintenance activities (Reason, 1990; Reason and Hobbs, 2003). In the same vein, this chapter demonstrates the application of the resilience engineering approach as framework for managing emergent risks and latent failures.

A particular feature of the resilience engineering approach is that the study of normal operations can provide information about performance variability in the sociotechnical system. Performance variability can lead to unwanted consequences when the variability of individual system functions combines in a way that destabilizes the system. The study described here aimed to identify performance variability that might be the source of risk during the planning of modifications on an offshore petroleum installation.

The planning of modifications to offshore oil and gas platforms is almost a daily activity in the industry, especially as installations mature. The planning phase in itself is not considered a high-risk activity, but modifications to operational installations can imply potentially radical changes to high-risk systems that may have a significant impact on safety. Complex production processes and sophisticated operating systems can make it difficult to identify risks. This particularly applies to older installations, as the older the installation is, the greater the likelihood that modifications will require the introduction of completely new technology. The consequence of modifications may be an intractable system that emerges either simply as a result of the modifications themselves, or in combination with other changes such as working practices or the organization of human resources.

The FRAM method has traditionally been used in accident investigations to model and analyze accidents in order to identify ways of reducing future risk. However, it has been argued that one of the strengths of the method, like other system-based accident models such as the Systems-Theoretic Accident Model and Processes (STAMP), is that it can also be used for risk assessment (Hollnagel, 2004; Leveson et al., 2006). FRAM has already been used as a risk assessment method in analyses at the operational level that aim to identify emergent risks due to the variability of normal performance (Macchi, Hollnagel and Leonhardt, 2009; Macchi, 2010). Similarly, the study described in this chapter investigates whether the FRAM method is useful for risk assessment in the planning phase of operations to identify potential performance variability; in this case, in the planning of modifications to a mature offshore oil installation.

## 2 The FRAM method

The FRAM method was first presented in the book 'Barriers and Accident Prevention' (Hollnagel, 2004) and other comprehensive descriptions can be found in Macchi (2010) and Woltjer and Hollnagel (2007).

The basic element of the FRAM method is the function and its six descriptors (Input, Time, Control, Output, Resource and Precondition) as shown in Figure 1. A function is an action performed by a part of the system in order to fulfill the goals of the system. Functions can consist of both human activities and technological operations.

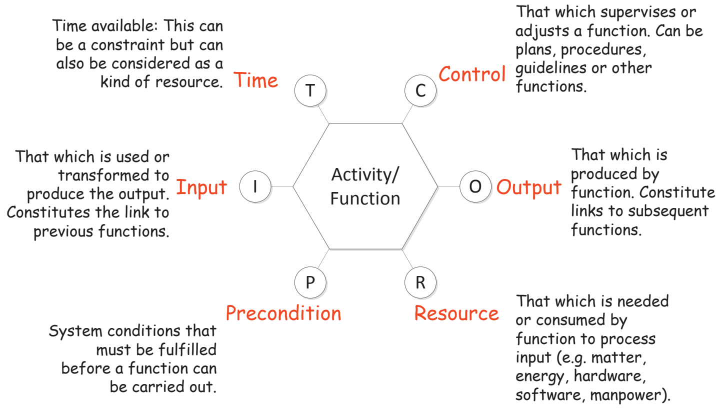


**Figure 5: A FRAM function (Hollnagel, 2008)**

The FRAM model initially provides a simple visual representation of a system's individual functions. At this stage the connections between the functions of the model are potential rather than actual (i.e. there is no attempt to evaluate function descriptors). It is only when the FRAM model is instantiated that function descriptors are evaluated and the actual couplings between functions are established. Whether the FRAM method is used for accident or risk analysis, features of the operational environment can be added to the instantiation, which then provides a representation of the system's functions in a given time frame, conditions or scenario chosen for the purpose of the analysis.

## 2.1 A FRAM Analysis

Whether it is used for accident investigation or for risk assessment a FRAM event analysis in general consists of the following five steps:

1. *Define the purpose of the analysis.* The FRAM method can be used for safety assessment (analysis of future events) or for accident investigation (analysis of past events).
2. *Identify and describe the relevant system functions*. A function, in FRAM terms, is an activity or task which has important or necessary consequences for the state or properties of another activity. In the FRAM method, functions are identified based on 'work as done' rather than 'work as planned' (e.g.

procedures or work descriptions). Each function is characterized by six descriptors: Input (I, what the function uses or transforms), Output (O, what the function produces), Preconditions (P, conditions that must be fulfilled), Resources (R, what the function needs or consumes), Time (T, the time available), and Control (C, what supervises or adjusts the function).

3. *Assess the potential performance variability of each function*. The potential performance variability of a function is characterized qualitatively. Variability may originate in human intervention, the organization or technology, i.e., the sociotechnical system. The FRAM method distinguishes foreground and background functions, which may both be affected by variability. Foreground functions indicate what is being analysed or assessed, i.e., the focus of the investigation and can vary significantly depending on the scenario, while background functions constitute the context or working environment and vary more slowly. The variability of both foreground and background factors should be assessed as far as possible using either information provided by accident databases or on the basis of issues that are known to influence the behaviour of the system.
4. *Identify where functional resonance may emerge*. Functional resonance occurs when the normal variability of the system's functions interacts in unintended ways. Each function in the system exists in an environment composed of the other functions and every function has a normal variability. In certain circumstances, the variability of one function may act in such a way as to reinforce the variability of another (i.e. resonate) and thereby cause variability to exceed normal limits. This phenomenon can be described as the resonance of the normal variability of functions, hence as *functional resonance*.
5. The fifth and last step is the *development of effective countermeasures*. These usually aim to dampen performance variability in order to maintain the system in a safe state, but they can also be used to sustain or amplify functional resonance that leads to desired or improved outcomes. Countermeasures are not discussed in detail here, but some measures to dampen variability are proposed.

## 2.2 The Evaluation of Performance Variability

The general purpose of a risk assessment is to identify how and where risks may arise. In the FRAM method, risk identification is based on an evaluation of the variability of normal performance. A review of case studies where a FRAM analysis has been applied shows that there are different ways of characterizing this variability. One approach was proposed by Hollnagel in the original description of the FRAM method (Hollnagel, 2004). Here, variability is evaluated by first identifying unexpected connections between system functions (e.g. control loops or checks that may fail) and then evaluating how failure may occur (e.g. the activity is not completed in time, lack of competence). The variability of each function and of the system as a whole is evaluated in the same way.

Another approach is to use common performance conditions (CPCs) to characterize the potential variability of a function. In this case, functions are evaluated as adequate, inadequate or unpredictable. CPCs were first introduced in the context of the Cognitive Reliability Error Analysis Method (CREAM) method (Hollnagel 1998/2007); they consist of eleven common conditions related to human performance. In more recent studies that have implemented the FRAM method, performance conditions are considered to be the outcome of other (typically organizational) functions (Herrera, Macchi and Hollnagel, 2010).

Another approach was proposed by Macchi, Hollnagel and Leonhardt (2009) who suggested that system functions could be categorized into three types:

- *Human functions* are usually variable as people adjust their performance to current working conditions (resources and demands) (Hollnagel, 2009). Human performance can vary on a short-term basis, but may also have a dampening effect.
- *Technological functions* depend on the technology implemented in the system. These are less subject to variability as they are designed to be stable, reliable, and predictable. Technical functions are not normally able to dampen performance variability (unless there are barriers in place in the system).
- *Organizational functions* are related to human functions but subject to a different kind of variability. Organizational functions are less variable than human functions – or rather their variability has a delayed effect on human functions. A typical example would be the production and updating of procedures.

The study then assessed the performance variability of the output of human functions using a three-by-three matrix that evaluated the temporal and precision characteristics of the function's inputs. Temporal characteristics were described as, 'too early, on-time and too late' and precision characteristics as, 'precise, acceptable and imprecise'. The result of this evaluation was an overall characterisation of the function where the quality of the output was represented by the median of the quality of the input characteristics.

## 3 The Case Study

Oil and gas productions installations on the Norwegian continental shelf are owned by a licenced group of companies. One of the companies in the group holds the role of operating company. For maintenance and modification activities, work is often managed through an integrated service contract that is established between the operating company and an offshore construction company (the vendor company), which has the role of contractor and which may in turn contract other vendors. Integrated service contracts are long-term and imply a broad concept of service that may require the contractor to undertake planning and administration responsibilities, provide cost estimates, etc.

Modifications to offshore oil installations can change the functionality of both a piece of equipment and the wider system. Updates to technology or the replacement of parts can make the system look and function differently. At the same time, drawings and manuals need to be updated. The goal is usually to improve the system or to adjust it to new requirements. Minor modifications can be carried out by the company's own staff or external contractors, and integrated into normal work processes. In this case decisions are taken locally within budgetary limitations. Major modifications however, involve the wider organization, including both the operating company and the contractor and may even require a temporary project team to be established.

At the installation in question, an integrated service contract had been in place since 2005. Modification projects followed procedures defined in manuals developed by the operating company and the construction contractor. Initially, each company had its own manual which was merged into a combined project plan detailing the roles and responsibilities of each of the two companies in different phases of the project. The planning phase consisted of: the identification of a problem or an opportunity; finding (a) potential solution(s); developing a modification procedure; preparing cost estimates; conducting a risk assessment; and pre-engineering activities. During this period the two parties communicated by telephone and email, and held formal meetings as prescribed by the project plan – typically when important decisions needed to be taken, or more generally to discuss and clarify ongoing work.

In this case planning activities involved the modification of an oil well. The problem was that production had fallen due to low well pressure. The proposed solution was to install a gas lift with subsea and topside components to increase well pressure. A gas lift involves injecting gas through a tubing-casing annulus. The injected gas aerates the fluid and reduces its density; the formation pressure is then able to lift the oil column and force the fluid out of the wellbore. This modification is one of several ways to increase oil well pressure and it is common in older wells. Nevertheless, the risk of a hydrocarbon leak during the installation and operation of the gas lift requires that a risk assessment be carried out. When the study began, the contractor had prepared a preliminary design for the topside construction of the lift. The modification was expected to be implemented during a planned maintenance period at the installation two months later. However, the work was postponed several times and still had not been carried out by the time the study ended.

## 3.1 Data Gathering

Data for the FRAM analysis was gathered in two parallel phases. One phase consisted of an examination of both companies' manuals for the planning of modification projects. These manuals contain detailed descriptions of all the issues that must be taken into account during the planning phase, and procedures are described thoroughly and in detail as they must be generally applicable to all of the company's installations. Because of this level of generality, the functions that constituted the planning phase were clarified in discussions with project staff in both companies. The combined project plan that merged the two companies' work processes was also studied. The essential functions of the planning phase were extracted from these documents and recorded in a spreadsheet, together with a description of each function.

However, it is often the case that the detailed procedures prescribed in manuals describe the way work *should* be done; this frequently translates into a more manageable 'procedure' for day-to-day activities. This day-to-day 'procedure' is not described in any manual, but can be seen in the tasks, meetings and documentation that occur when modifications are planned. Therefore, the second data gathering phase consisted of observations of meetings between the operating company and the contractor, interviews with personnel in both companies and email exchanges with staff. The purpose of these observations and interviews was to validate that the analysis was based on the way planning activities were actually executed. It also provided the scenario that formed the basis for the instantiation of the FRAM model (the actual risk analysis). Field notes were taken of the observations and interviews for later use in the analysis. Particular care was taken to include variability in the way functions were executed.

## 3.2 Identification of System Functions

Based on the information gathered from written procedures, interviews and observations, the functions of 'work as done' were identified. These functions are essential for completing the task when things go right in planning a modification project. Table 1 shows the functions that were identified, together with a description of their purpose and general characteristics.

**Table 5: Planning phase functions for modification projects**

| | Function | Description |
|---|---|---|
| 1 | **Identify a problem or an opportunity** | The need for a modification starts with either the identification of a problem or a proposal for improvement. A member of staff identifies a problem or an opportunity in the system that needs to be dealt with. This may include a suggestion for how to solve the problem or take advantage of the opportunity.<br>*Human function* performed by the operating company. |
| 2 | **Validate the proposal** | The proposal is validated by a supervisor or manager before being entered into the database as authorised for further processing.<br>*Human function* performed by the operating company. |
| 3 | **Identify solution** | Potential solutions for the problem or opportunity are investigated and one solution is chosen. Pre-estimates of cost and risk may be made.<br>*Human function* performed by the operating company and the contractor. |
| 4 | **Refine solution** | Details such as the available resources, budget and criticality of the chosen solution are determined.<br>*Human function* performed by the operating company and the contractor. |
| 5 | **Define concept** | The concept for carrying out the modification is described in detail. Any requirements and the impact on ongoing system operations are also described. The final decision on whether to make the investment is taken.<br>*Human function* performed by the operating company and the contractor. |
| 6 | **Estimate cost** | Detailed costs estimates are prepared based on the description of the chosen solution and its impact on ongoing operations. This function applies to all phases of the modification project, with differences in the precision and level of detail.<br>*Human function* performed by the engineering and finance departments using information provided by the contractor. |
| 7 | **Assess risk** | The risk assessment (economic, process-related and safety) is based on the description of the chosen solution and its |

| | | |
|---|---|---|
| | | impact on ongoing operations. Particular note is taken of the criticality of the work. This function applies to all planning phases.<br>*Human function* performed by the operating company and the contractor. |
| **8** | **Decision to proceed to pre-engineering** | A kick-off meeting is arranged. The solution is opened for pre-engineering.<br>*Human function* performed by the operating company. |

These eight functions were described in terms of the six FRAM descriptors (input, output, preconditions, resources, time and control). For example, for the function 'define concept' the following descriptions were prepared (table 6):

**Table 6: The function 'define concept' with descriptors**

| **Descriptor** | **Function: Define concept** |
|---|---|
| **Input (I)** | Defined solution selected<br>Suggestion with criticality and possible solution registered in database |
| **Output (O)** | Concept study |
| **Preconditions (P)** | Solution selected<br>Budget allocated |
| **Resources (R)** | Contractor personnel<br>Engineering and maintenance personnel<br>Expert technical personnel within the company |
| **Time (T)** | Possible solution available<br>Criticality |
| **Control (C)** | Modification procedure |

After describing all the functions according to their characteristics, a consistency check was performed. The consistency check aims to ensure that each descriptor is produced (and used) by at least one function in the model. The consistency check enabled the background functions to be identified. Background functions are essential for work to be carried out and include for example, the provision of resources, competence, budget planning, etc. The exact nature of background functions depends on the system being analyzed. In this case, the background functions were identified through observations, interviews and procedures and are described in table 7

**Table 7: Background functions**

| | **Function** | **Description** |
|---|---|---|
| **1** | Provide resources (operating company) | *Organizational function*: provide and manage sufficient human resources for adequate system functioning in the operating company |
| **2** | Provide resources (contractor company ) | *Organizational function*: provide and manage sufficient human resources for adequate system functioning in the contractor company (depends on contract). |
| **3** | Manage budget | *Organizational function*: provide and manage sufficient financial resources for adequate system functioning. |
| **4** | Manage modification procedure | *Organizational function*: design and update procedures to support activities. |
| **5** | Evaluate criticality | *Operational system function*: label the problem or opportunity with an attribute. For example, if the modification is assessed as critical for production continuity or safety, it is labelled as such based on pre-established criteria. |

These background functions resemble the organizational functions identified in the study by Macchi, Hollnagel and Leonhardt (2009) who combined CPCs with research on the evaluation of safety-critical issues by Reiman and Oedewald (2009). However, in this case the organizational functions identified in the Macchi study were not appropriate to the analysis. For example, the authors identified a 'manage resources' function. In the current analysis this was divided into 'provide operating company resources' and 'provide contractor company resources' to account for the fact that resources had various origins, together with a 'manage budget' function to account for financial resources. In addition, the operational system function 'evaluate criticality' was added, as the criticality of a modification (in terms of safety and production issues) is an important part of the decision-making process that is not necessarily found in risk analyses.

## 3.3 The FRAM model

The foreground and background functions are shown in a FRAM model (Figure 6). Foreground functions are shown in grey and background functions in black.

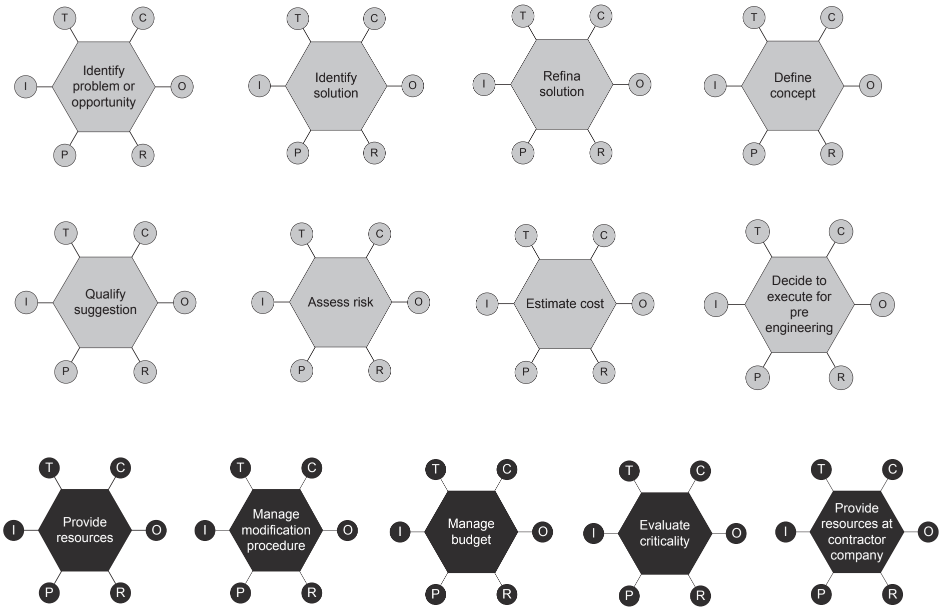


**Figure 6: The FRAM model for the planning phase of modifications**

This initial FRAM model shows all the *potential* couplings between functions, but not any *actual* couplings, which are the subject of the subsequent analysis.

## 3.4 Analysis of the Normal Scenario

The key to success for any modification project is that it is carried out on time and that cost and risk estimates are accurate. In addition, modification planning must take into account any other ongoing work on the installation, for example routine maintenance, other planned modifications, and normal production and operation activities. Modification projects form part of an overall work plan for the installation, which includes factors such as the availability of accommodation and transport (for personnel and equipment etc.).

The relationships between functions were based on the information provided by the function descriptors. The output of any function can be an input to another function. Taking the 'define concept' function as an example, inputs were 'defined solution selected' and 'suggestion with criticality and possible solution registered in database'. These in turn are outputs of the functions 'find solution' and 'identify problem or opportunity'. The fact that a solution exists (output from the 'find solution' function) is a precondition for the 'define concept' function.

## 3.5 Assessment of Potential Variability

Information about the potential variability of functions was gathered through observations of meetings and interviews. The description of potential variability is qualitative. In the analysis, potential variability in the output of each function was characterized as adequate, inadequate/inappropriate or unpredictable/missing. Where there was little performance variability and only small potential for interference from background functions, the output was characterized as 'adequate'. 'Inadequate' indicated that there was a greater potential for performance variability and interference from background functions, and when there was a lack of information on how the function was actually carried out, or the description of variability was unclear, the output was characterized as 'unpredictable'. The performance variability characteristics for the 'define concept' function are shown in Table 8. Similar tables were developed for all the functions in tables 3 and 5.

**Table 8: Characterization of variability for the 'define concept' function**

| Descriptor | Function: Define concept | Characterization |
|---|---|---|
| **Input (I)** | Defined solution selected<br>Suggestion with criticality and possible solution registered in database | Adequate |
| **Output (O)** | Concept study | Inadequate |
| **Preconditions (P)** | Solution selected<br>Budget allocated | Unpredictable |
| **Resources (R)** | Contractor personnel<br>Engineering and maintenance personnel<br>Expert technical personnel within the company | Adequate/inadequate |
| **Time (T)** | Possible solution available<br>Criticality | Unpredictable |
| **Control (C)** | Modification procedure | Adequate |

If any of the function descriptors I, P, C, R or T was rated as unpredictable or inadequate, the output (O) of the function was also assessed as unpredictable or inadequate, as unwanted variability in one function could transfer to any other function linked to it.

## 3.6 Identification of Functional Resonance

The fourth step of the FRAM analysis aims to identify where functional resonance may emerge. This involves identifying the ways in which the variability in one or several functions may spread through the system. Particular combinations of variability may lead to situations where the system is unable to safety manage events.

The initial scenario instantiated in the FRAM model and described here illustrates how the FRAM method can be applied to a safety assessment of the planning phase; it could be followed by a further set of instantiations to represent the subsequent installation phase. Other instantiations could introduce features of the operational environment such as staff shortages, a lack of other resources or unforeseen problems with the well or production system.

In order to identify potential emergent risks in the planning scenario, two environmental features were introduced into the FRAM model: 1) multiple concurrent modification proposals and 2) an ageing installation (which normally increases the number of modification proposals). The analysis of the entire FRAM model is too complex to be described here. Instead, the selected extract (figure 3) illustrates how the analysis is carried out and what the result may look like.

At the heart of Figure 3 are the two foreground functions ‘define solution’ and ‘define concept’ (shown in grey) and the relationships between them. In both foreground functions, the contractor is deeply involved in the preparation of proposals, preliminary concept descriptions and meetings and communication with the operating company. These functions also include preliminary risk assessments.

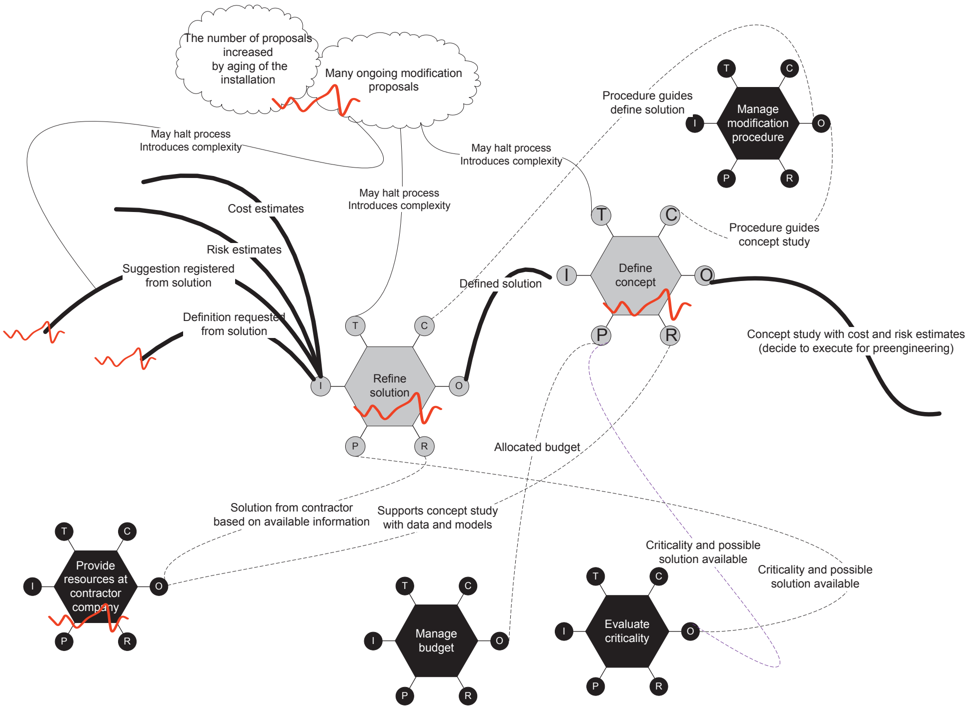


**Figure 7: Instantiation of the functions 'refine solution' and 'define concept' in the scenario of an ageing installation with multiple concurrent modification projects**

Figure 3 also shows background functions (in black) and the two environmental issues introduced to refine the instantiation (white clouds). Thick solid lines indicate the relationship between the output of one function and the input of another. Lines that are not connected to anything indicate an input or output to another function in the overall FRAM model (figure 2) that is not shown here. Thin solid lines show relationships that are the result of the two environmental issues introduced for the purposes of the analysis. Dashed lines show the relationships between foreground functions and background functions. Red zigzags indicate either variability in the function itself or the influence of variability from the input of another function.

The assessment of performance variability is based on the example shown in Table 8 and reveals several interesting results. Unwanted variability can be seen in both foreground functions. This problem relates to hidden or inaccessible information about the installation in question. Variability is strongly influenced by background functions that provide resources such as input from the contractor about similar modifications and information about the installation. In addition, both functions are influenced by the high number of modification proposals due to the age of the installation. Older installations that have undergone many modifications are typically underspecified and poorly documented. What documentation is available tends to be on paper and contained in drawings that have not been digitalized. Unwanted variability may also arise from the fact that the planning process follows detailed procedures that are remote from daily activities. 'Normal' work practices become habits that bear little relation to the specified procedures, and differing mental models of 'how' and 'how thoroughly' work needs to be done may develop in the organization. Another issue is that uncontrollable pressure in a gas lift in one well may impact other wells and the topside production system. This means that the entire production system needs to be taken into account in the risk assessment. Finally, other problems are created by the introduction of new employees who do not know the history of the installation. The combination of these factors can result in variability that may lead to unwanted outcomes in the planning phase. It is also likely to lead to delays which can put into question the decision to move into the pre-engineering phase.

It is important to note that the FRAM analysis helps to highlight both general variability in the process being modeled and where it is necessary to adjust to a specific situation. It is also important to focus not only on variability that may cause delays, adjustments, increased costs, etc. but also on variability that has an impact on safety. Moreover, it is important to ensure that the dampening of variability does not impede wanted variability and flexibility.

Figure 3 shows the instantiation of one part of the planning phase. In order to conduct a full risk assessment it is important to be able to zoom in and out of the overall model. In other words it should be possible to zoom in on a function and elaborate on the conditions that must be fulfilled in order to make it operable. It is also essential to be able to see the effects of functions on the whole system by zooming out of the model. This phase of the FRAM analysis depends on the description of functions in the model and (Herrera, Macchi and Hollnagel, 2010) emphasise the importance of ensuring that each function has been described in sufficient detail. This point is essential in order to arrive at an accurate risk assessment, to know where to dampen variability and to establish the relevant indicators necessary for monitoring.

## 3.7 Countermeasures to Dampen Variability

In general, improvements to safety and efficiency in modification planning result from an examination of 'work as done' rather than 'work as planned'. Ideally, it should be possible to identify the functions that are necessary for the safe and efficient planning of modifications, and to use them as the basis for a discussion about improvements. In this respect, the development of the FRAM model may be a helpful countermeasure, as it highlights the fact that each function exists in the system, and all aspects of a function can be related to other aspects of other functions.

Another effective countermeasure may be to make information about the system and the installation (models, drawings, historical data, etc.) visible and accessible to all personnel, and to encourage everyone involved in the planning and execution of modifications to work as a team, rather than two separate organizations. This is an issue that was addressed early on in the introduction of integrated operations in the petroleum industry (OLF, 2003) and should continue to be kept in mind. Modification planning would benefit from the sharing of updated and real-time information about the installation and its systems. In order for this to happen, barriers found in information and communication technology (ICT) systems must be removed while at the same time ensuring safety.

An important concern is to dampen variability arising from the number of other modification projects and the fact that modifications may be carried out concurrently. It may be useful to develop a FRAM model specifically focused on this scenario. It may also be useful to group modifications on the installation (or to specific systems of the installation) into a single project or modification program to provide a better overview and coordination of the situation.

# 4 Discussion

In order to use FRAM for risk assessment it must be possible to capture information about the human, technological and organizational functions of the system. A FRAM risk assessment requires that working practices are both planned and executed in real time and that information is available through observations and interviews. These factors suggest that FRAM is a promising risk assessment method for analyzing the planning of high-risk modifications in an operational system.

As it is unusual to carry out a risk analysis of planning or other non-operational work processes it is difficult to evaluate whether the FRAM method provides a better insight into risks than other methods, as there is little comparable data. Nevertheless, accident investigations have demonstrated that the planning phase of a project is important in ensuring safe operations. As an example, in 2004 several deficiencies in the planning phase of a well operation at the oil production installation *Snorre A* resulted in one of the most serious near-accidents on the Norwegian continental shelf (Brattbakk et al., 2004; Schiefloe et al., 2005).

Subsequent to the incident, the FRAM method was applied as a risk assessment method to the planning phase of the well operation (Phung, 2010).

Traditional risk assessment methods such as probabilistic risk assessment (PRA) characterize risks according to the magnitude (severity) of the possible adverse consequence(s), and the likelihood (probability) of occurrence of each consequence. As these methods rely on quantifiable issues and do not take account of issues that are not probable and/or have little impact, it is less likely that latent failures resulting from unwanted performance variability in the planning phase will be taken into consideration. These latent failures often combine with other issues and performance variability in the operational phase of the planned process, and eventually emerge as risks and hazardous situations. Major accidents can be the result of the combination of factors and behaviors that individually may have been regarded as quite normal and efficient if the result had been a success (Hollnagel, 2004; Hollnagel, Woods and Leveson, 2006; Hollnagel, 2009).

The FRAM risk assessment may reveal dependencies between functions or tasks that are normally missed. In addition to providing recommendations for measures that may dampen variance (these measures reduce the chance of a negative outcome of an interaction or action in a system and may also be termed human, organizational or functional barriers) the FRAM method aims to provide recommendations for monitoring performance and variability, and detecting undesired variability. As a result of the implementation of the method, performance indicators can be developed for every function and every link between functions.

Although FRAM as a risk assessment method (and an accident investigation method) is still under development it has been suggested that it may be a promising way to identify safety indicators (Herrera, Macchi and Hollnagel, 2010). As an accident investigation method, FRAM has already been applied to accidents and incidents in aviation (Woltjer and Hollnagel, 2007) and other settings. Experience has shown that FRAM is well-suited to the investigation of system accidents and that it provides a better understanding of events than traditional multi-linear methods (Herrera and Woltjer, 2009).

# 5 Conclusion

The study described here suggests that the FRAM method is well-suited to the investigation of complex sociotechnical operations and work phases in the oil and gas industry. This conclusion is based on the fact that traditional risk assessments rarely assess risk in normal working conditions (such as planning), although accident investigations have demonstrated that sociotechnical factors are very often found to be contributing factors to incidents.

This study also demonstrates that further work is needed if the FRAM method is to become a practical tool for risk assessment in the offshore oil and gas industry. This point particularly applies to the evaluation of potential variability and how this should be assessed. It is also important that the method is made accessible to risk analysts and safety personnel in companies; although it will probably be necessary to provide research support for the analyses while the method is under development.

In addition, efforts should be made not only to dampen unwanted variability in the system, but also to support desirable performance variability. In the study in question, this could take the form of making historical information about the installation available to everyone, and facilitating the exchange of real-time data between the operator and the contractor company. Organizational barriers should be lowered in order to provide support for the integration of employees who share the same goal; safe and efficient modifications. Although further development of the FRAM method is needed in order to become of practical use in a dynamic operating company, the method shows promise as a tool for the identification of latent failures and potential variability in the planning phase of high-risk operations.

# 6 References


Brattbakk, M., Østvold, L.-Ø., Van der Zwaag, C., and Hiim, H. (2004), *Investigation of the Gas Blowout on Snorre A, Well 34/7-P31A, 28 November 2004*. (Stavanger, Norway: Petroleum Safety Authority) <http://www.wellintegrity.net/Documents/PSA%20Investigation%20of%20Snorre%20Blowout.pdf>, accessed 1 May 2012.

Herrera, I. A., and Woltjer, R. (2009), "Comparing a Multi-Linear (STEP) and Systemic (FRAM) Method for Accident Analysis," in S. Martorell, C. G. Soares and J. Barnett (eds), *Safety, Reliability and Risk Analysis. Theory, Methods and Applications* (CRC Press, Taylor and Francis Group) 1: 19-27.

Herrera, I. A., L. Macchi, and E. Hollnagel. (2010). What to look for when nothing goes wrong? A systematic approach to monitor performance variability. Unpublished work

Hollnagel, E. (1998, 2007), "CREAM (Cognitive Reliability and Error Analysis Method)". <http://erik.hollnagel.googlepages.com/cream(cognitivereliabilityandaccidentana>, accessed 1 April 2009.

Hollnagel, E. (2004), *Barriers and Accident Prevention* (Aldershot, UK: Ashgate).

Hollnagel, E. (2008), "From FRAM (Functional Accident Resonance Model) to FRAM (Functional Accident Resonance Method)," Presentation at the 2nd FRAM Workshop, Sophia Antipolis, Ecole des Mines, Centre for Research on Risks and Crises.

Hollnagel, E. (2009), *The ETTO Principle: Efficiency-Thoroughness Trade-Off . Why Things That Go Right Sometimes Go Wrong* (Aldershot, UK: Ashgate).

Hollnagel, E., Nemeth, C. P. and Dekker, S. (2008), *Remaining Sensitive to the Possibility of Failure*. Resilience Engineering Perspectives, Vol .1 (Aldershot, UK: Ashgate).

Hollnagel, E., Paries, J., Woods, D., and Wreathall, J. (eds) (2011), *Resilience Engineering in Practice: A Guidebook.* Ashgate Studies in Resilience Engineering (Burlington, VT: Ashgate).

Hollnagel, E., Woods, D. D. and Leveson, N. (eds) (2006), *Resilience Engineering: Concepts and Precepts* (Aldershot, UK: Ashgate).

Leveson, N., Dulac, N., Zipkin, D., Cuther-Gershenfeld, J., Carroll, J., and Barrett, B. (2006), "Engineering Resilience into Safety-Critical Systems," in E. Hollnagel, D. Woods, and N. Leveson (eds), *Resilience Engineering: Concepts and Precepts* (Burlington, VT: Ashgate).

Macchi, L. (2010), *A Resilience Engineering Approach to the Evaluation of Performance Variability: Development and Application of the Functional Resonance Analysis Method for Air Traffic Management Safety Assessment*, PhD thesis (France: Ecole Nationale Supérieure des Mines de Paris).

Macchi, L., Hollnagel, E., and Leonhardt, J. (2009), "Resilience Engineering Approach to Safety Assessment: An Application of FRAM for the MSAW System," *EUROCONTROL Safety R&D Seminar*. Munich, Germany. <http://hal.inria.fr/docs/00/57/29/33/PDF/eurocontrol_Luigi-Macchi-29-Paper.pdf>, accessed 1 May 2012.

Nemeth, C. P., Hollnagel, E., and Dekker, S. (2009), *Resilience Engineering Perspectives: Preparation and Restoration* (Aldershot, UK: Ashgate).

OLF (2003), *eDrift på norsk sokkel - det tredje effektivitetspranget [eOperations on the Norwegian Continental Shelf - the Third Efficiency Leap]*, <http://www.olf.no/PageFiles/14295/030601_eDrift-rapport.pdf?epslanguage=no >, accessed 1 May 2012.

Phung, V. Q. (2010), *Bruk av functional resonance analysis method (FRAM) som et verktøy for å forutse og identifisere fremtidige uønskede hendelser [Using the Functional Resonance Analysis Method to Anticipate and Identify Future Incidents]*, Master's thesis (Trondheim, Norway: NTNU).

Reason, J. (1990), *Human Error* (Cambridge, UK: Cambridge Press).

Reason, J., and Hobbs, A. (2003), *Managing Maintenance Error. A Practical Guide* (Aldershot, UK: Ashgate).

Reiman, T., and Oedewald, P. (2009), *Evaluating safety-critical organizations – emphasis on the nuclear industry* (Swedish Radiation Safety Authority). <http://www.vtt.fi/inf/julkaisut/muut/2009/SSM-Rapport-2009-12.pdf>, accessed 30 April 2012.

Schiefloe, P. M., Vikland, K. M., Torsteinsbø, A., Ytredal, E. B., Moldskred, I. O., Heggen, S., Sleire, D. H., Førsund, S. A., and Syvertsen, J. E. (2005), *Årsaksanalyse etter Snorre A hendelsen 28.11.2004 Stavanger [Causal Analysis of the Snorre A 28.11.2004 Stavanger Event]*, (Statoil ASA).

Woltjer, R. and Hollnagel, E. (2007), "The Alaska Airlines Flight 261 Accident: A Systemic Analysis of Functional Resonance," in *Proceedings of the 14th International Symposium on Aviation Psychology* (Dayton, OH).

Paper 4

# Building Resilience into Emergency management

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**ABSTRACT**

Emergency management faces a changed reality in terms of possibilities and threats with use of new technology. Due to the ongoing changes in the operation of oil and gas production, different constellations of actors in a distributed system are built. This introduces opportunities for planning and operation. At the same time as new technology offers opportunities, the technology-enabled distributed network of actors generate challenges for emergency handling. The purpose of the study presented has been to look for possibilities for making emergency management more resilient by becoming a part of continuous risk and hazard management. The suggested three main elements that are important to consider in the development of future emergency management are 1) proactive emergency management through early risk anticipation; and emergency management's adaptation to new and future work practices such as 2) distributed actors and 3) new technology. Based on these results we suggest broadening the scope of emergency management to systematically include monitoring, anticipation, responding and learning.

**Keywords: emergency management, intelligent operations, petroleum industry**

**Abbreviations:**

| | |
|---|---|
| DSHA | Defined situations of hazard and accidents |
| HRO | High reliability organizations |
| IO | Integrated operations |
| NCS | Norwegian continental shelf |
| NOFO | Norwegian oil protection association for operating companies |
| NORSOK | Norwegian standards for the petroleum industry |
| NTC | Norwegian Technology Center |
| RE | Resilience engineering |

# 1 Introduction

Emergency management, as well as many other areas in society faces a changed reality in terms of possibilities and threats with the introduction of new technology and related changes in work forms as wells as organizational forms. In this paper we study how new technology and new work processes influence emergency management in the Norwegian oil and gas industry. Emergency management has to adapt to this development, which will offer both opportunities and challenges for improved handling of emergencies. *This paper studies how emergency management can adapt to these new technologies and ways of working in the Norwegian oil and gas industry, in order to improve detection of and handling of emergencies.* This purpose has been approached by an explorative study where early anticipation of risks; interaction between different actors; and information and communication through new technology' has been in focus.

We define emergency management as the total of activities (both administrative routines and informal processes) conducted in a more or less coordinated way to control emergencies before, during and after an event. This includes analysis; planning; training; handling; learning; anticipation; and monitoring. Our definition of emergency management represents a wider definition than what is found on emergency preparedness assessment in the NORSOK standard Z-013 'Risk and emergency preparedness analysis' (NTC, 2001:6), which is the mainstream best practice for planning of emergency management used at the Norwegian continental shelf.

The theoretical basis of the study is taken from the field of Resilience Engineering (RE) and High Reliability Organizations (HRO). Both perspectives are relevant for handling emergencies as well as representing a proactive approach to emergency management. RE looks for ways to enhance the ability of systems to succeed under varying conditions (Hollnagel 2009). This includes the ability to respond effectively to both expected and unexpected conditions; to monitor both threats and opportunities; to anticipate future developments that may affect the system's ability to achieve its goals; and to learn from past events, to understand correctly both what happened and why. The HRO literature gives input on how organizations develop a capacity to handle unexpected events and detect risk. The theory is grounded in studies of organizations that have demonstrated an outstanding capacity to handle fairly complex technologies without generating major accidents (LaPorte and Consolini 1991; Rochlin 1997). Important aspects from this research tradition are organizational redundancy and the capacity of organizations to adapt to peak demands and crisis (Weick 2001; Weick and Sutcliffe 2001; Weick and Sutcliffe 2007). In HRO theory, mindfulness points to a constant awareness and an ability in an organization to search for evolving practices and mechanisms to handle the unexpected through the principles of anticipation and containment.

The starting point of this study was the findings in a study by Skjerve et al. (Skjerve, Albrechtsen et al. 2008). This study showed that new technology and new work processes generate new causes of accidents and new relationships between causes in an Integrated Operations (IO) setting. The report stated that this impacts emergency handling, which implies that training scenarios should be revised when IO is introduced. Defined Situations of Hazard and Accident (DSHAs) for example gas leakage or falling objects, are used by petroleum companies operating on the Norwegian continental shelf to specify a selection of hazardous and accidental events, which are important input to emergency preparedness analysis (EPA) processes (NORSOK Z-013: (NTC, 2001). The study indicates that the content of existing DSHAs is not changed in a significant way by the new IT-based development. The study also reveals that new opportunities and challenges arise regarding emergency handling. One of the interviewees in the study illustrated this neatly by the following statement: *"New work processes and technology or not – the crises are the same*[8]*. ... The crises are the same, but the emergency handling is different in IO"*

[8] By 'crises' the interviewee refers to top events or defined situations of hazards and accidents (DSHAs)

A review of 16 investigation reports from the petroleum authority in Norway in the period 2007-2009, show that eight of them are related to possible or real major accidents and eight to possible or real fatal occupational accidents. We looked for findings concerning anticipation of risks and risk assessment, learning from earlier incidents or accidents with similar attributions, monitoring (ability to detect risk) and response of the hazard. These categories are in line with the cornerstones of resilience engineering (Hollnagel 2009). Deficiencies in risk anticipation and – assessment were found in 11 of the 16 reports (eight out of eight occupational accidents and three out of eight major accidents). Deficiencies in learning were found in five of the reports (all major accidents); deficiencies in monitoring were found in four of the reports (all major accidents). Emergency response (evacuation of personnel, rescue etc.) was described as sufficient in seven of the 16 reports (four occupational accidents and three major accidents) and insufficient in one report.

In the next section we present the background for the study related to the changes in work forms in the petroleum industry. We then describe the approach of the explorative study (observation studies of emergency training sessions and a workshop with industrial experts). The next section presents the results of the explorative study related to early risk anticipation, interaction between different actors, and communication during distributed emergency handling. This is followed by a discussion of the results, emphasizing how emergency management can become more proactive and how it can adapt to new technology. In the concluding remarks we argue for a more resilient emergency management by suggesting improvements in monitoring of normal operation and for anticipation of possible deviations from normal operations.

# 2 New work practices in the Norwegian petroleum industry

The need to optimize offshore oil and gas production, maximize overall recovery, while safeguarding cost, safety and environmental aspects is met by a change in work practice by actors on the Norwegian continental shelf. The change in work processes is enabled by digital infrastructure and information technology. The benefits of the development are several: better use of available resources, increased production, lower operating costs, longer field lifetimes and increased recovery of oil and gas (OLF 2006). The Norwegian government (whitepaper nr. 12 2005-2006 (Regjeringen 2002)) underlines that technological challenges are not the only issue within the industry. The focus is on new work processes; integration of information; and HSE challenges related to safety. The ambition is to make the work processes faster, safer and better, additionally to create enhanced value and safer operations through better dialogue across specialist disciplines and closer cooperation between employees onshore and offshore. The result is expected to be improved decision making through new ways of working utilizing real time information to collaborate across social, professional, organizational and geographical boundaries. ‘Integrated operations (IO)’ is the most common term used to describe this development.

Ringstad and Andersen (2006) describe general trends for new work processes in IO. One of the new trends is moving away from individual experts working alone in a sequential hand – over characterized work process towards real time simultaneous cooperation. In addition, the work can frequently be performed independent on where the operator is situated if the worker has access to the necessary real time data. The distributed as well as the co-located work is supported by advanced information and communication technology in its work processes as well as industry specific technology such as sensor technology that provide possibilities for distribution of real time data.

# 3 Approach

Within the theoretical framework of RE and HRO the research design of this study has had an open-ended approach and exploratory character often found in ethnographic studies (Hammersley and Atkinson 2007). Thus the sampling strategies were worked out and refined as the research progressed. In order to gather data; observations as well as a workshop setting have been used. Dingwall (Miller and Dingwall, 1997) points to the importance of using observation as a method in social research as it enables us to document behavior in natural settings. Workplace studies by Suchman (1996; 2007) have shown that one of the strengths of observations “in situ” is that many incidents are not unremarkable for the participants, making them quickly forgotten and thus difficult to describe verbally to the researcher.

We observed two emergency handling training sessions in two different companies. The first training session included a) loss of control of a well and a b) following oil spill. Three researchers, partly at different locations, observed the identification of the event in a morning meeting between the onshore operation support center and the offshore installation. The next step was the establishment of the 2$^{nd}$ line emergency organization and the following actions in the emergency handling center and in the well support center. 3$^{rd}$ line emergency handling was also partly present in the areas that we observed. In the second training session two researchers followed a training session for handling a) loss of control of a well with b) following oil spill and c) personal injuries. The 2$^{nd}$ line emergency handling onshore (the emergency handling room/central) and 3rd line handling at the company’s head office was observed. The results from the observations of the two training sessions were recorded in field notes in the sessions The field notes followed an observation guide that included the role of actors and groups, interfaces between actors, communication between co –located actors, formal and informal information sharing, use of ICT, as well as observation made on the transition from normal to an emergency situation.

The observations uncovered a need to discuss future challenges in emergency management across different organizations and professions. A workshop setting was considered as an appropriate method to get more information about emergency management from several of the actors in the Norwegian oil & gas industry. Farner (2008) describes the workshop as an efficient tool to collect data and get opinions from several stakeholders as well as an arena for coordination and interdisciplinary problem-solving. In order to jointly reach a new understanding in this setting he underlines the importance of making the participants active contributors and not merely passive listeners. To achieve this, the researchers took the role as facilitators. The role of facilitator for the researchers introduced the difficulties with reflexivity of the researcher in the results (Hammersley and Atkinson 2007). This means that the facilitator's attributes such as opinions, attitudes and social aspects will influence the group processes and thus the result just as any other participant's attitudes will have an influence on the other participants. The role of the researchers as facilitators in our observations was at all times overt, just as it was in the observations of the emergency handling training sessions in order to diminish the effects of our presence in the results. Emphasis for the facilitators in the workshop was put on opening up for discussions and dialogue between the participants by asking questions and summarizing the discussions, thus our involvement mostly influence the scope of what was discussed and focus on the future rather than the present situation for emergency management.

The overall question asked to the group at the beginning of the workshop was 'Which opportunities and challenges do you foresee related to emergency handling in the future?' The participants in the workshop were representatives from three operating companies, a contractor and consultants within the emergency handling field. The meeting lasted for six hours with informal discussions. The group of 19 participants was divided into two smaller groups during the day to make it easier for everyone to contribute to the discussions. The results were recorded by the researchers taking notes during both discussions and presentations

# 4 Results

Results from the two observation studies and the workshop indicate that there are possibilities for more efficient and earlier handling of possible hazardous deviations in the transition stage between normal operation and emergency handling. This acknowledgement is supported by the introduction of new technology, work processes and more integrated information. The main results are presented below in relation to *early risk anticipation, interaction between different actors, and communication during distributed emergency handling.* The results are relevant for opportunities that should be incorporated into the future of emergency management, as well as representing challenges that follows the introduction of IO.

## 4.1 Proactive emergency management through early risk anticipation

As the emergency situations that we observed were training sessions, the possibility to observe the transition from normal operation to emergency handling, as well as how deviances are handled in normal operation, was limited. The results presented in this paragraph on early risk anticipation stem mostly from the workshop though one observation was made during one of the training sessions. As part of the training scenario, which included a well operation that developed into an unsteady state, the onshore engineers were warned about a possible situation the night before, but the emergency was called off. In the following morning meeting, information about the development into a less steady state for the well was listed in the log that was shown on the screen during the meeting. As a part of the training session, it was an uncertain element whether this would be addressed in the meeting before the training situation was announced – in fact, the group seemed not to notice the disturbances. The emergency scenario was announced in the morning meeting and by this the training session begun. For this as well as the second observed emergency scenario, the co-located teams had an increase in collaboration as time passed.

The workshop participants stated that there was a need for more focus on detecting and responding to deviant situations at an earlier stage. The role of the recently established operation centers that (continuously) support the operations offshore was discussed; how these could be involved at an early stage and how training for better collaboration between these and the emergency preparedness room was an issue. Where to draw the line between 'normal operation' and emergency was also discussed. It seems as the industry generally has only the two states; normal operation and emergency; though some workshop participants also spoke of the transitional state between normal operation and emergency (i.e. a deviation state where normal operation was left but where the operation group would handle the situation, not the emergency team).

In the workshop it became clear that there are differences between operating teams and emergency preparedness teams according to the how risks are assessed. The ‘worst case scenario’ is normally not considered in normal operation, but it is the shared image of the situation for an emergency handling team. In addition it was argued that the handling of crises seem still to be either ‘on’ or ‘off’; the emergency handling organization is established by call in case of emergency, usually late in the problem solving process. How to train operation teams in risk consideration and assessment was discussed as a way of improving the risk assessment. It was even said that in the transition from normal operation to emergency, work was done ad hoc as there are no procedures for this. It was argued that offshore on site teams are more preoccupied with looking ahead and being prepared for the worst and that this behavior could be transferred to onshore as onshore groups become more involved in the daily operation.

## 4.2 Interaction between different actors

Risk anticipation between different actors was raised as an issue in the workshop, following the open question on what opportunities and challenges emergency management would face in the future. The challenges regarding interaction between actors are related to the increased number and complex map of actors involved in emergency handling in the industry due to changes brought on by IO. These actors are different in terms of responsibilities, interests, proximity to hazard and resources and thereby there is a need to focus on new forms of cooperation, coordination and awareness when planning and handling emergencies. Furthermore, it was identified that involvement of some of these actors at an earlier stage in normal operation and developing new ways of including these actors in emergency management could be a step in the right direction in detecting deficiencies or a drift from normal operation to incidents or accident situations. Figure 1 shows mappings of relations and sharing of information from the observation of one of the emergency management training sessions. A line indicates a relation, a one way arrow indicates the direction of information flow and a two way arrow indicates two- way information sharing.

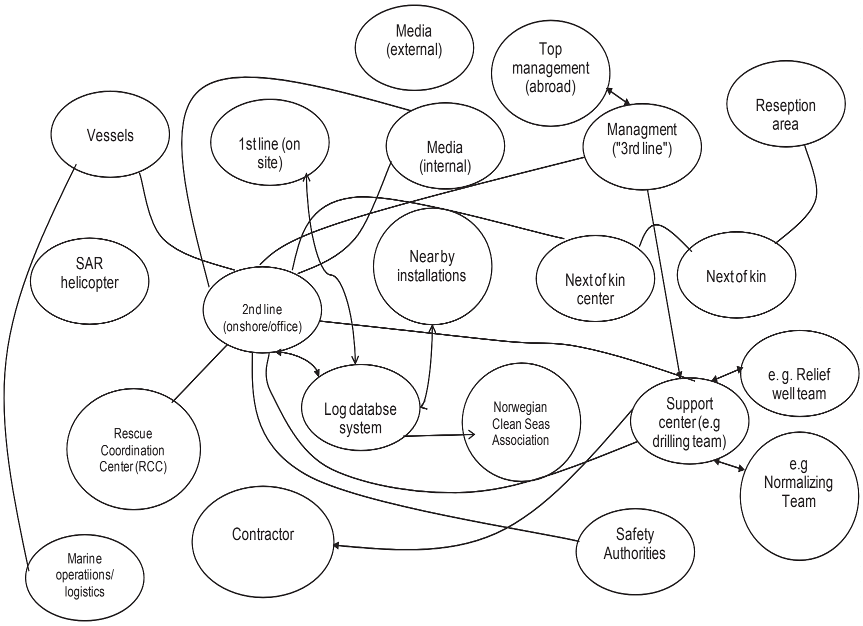


**Figure 8: An actor map from an emergency handling situation[9] (Tveiten, Albrechtsen et al. 2010).**

The actor map shows rather complex inter-relations between actors. In the evaluation after the emergency management training situations and also in the following workshop, it became evident that actors in emergency handling are not necessarily aware of this complexity or even of all the actors involved. It was further found that mapping of distributed actors was particularly important for the planning stage of emergency management as this creates an awareness of who should be involved and consulted in an emergency handling situation. The different actors should further be specified for each DSHA as well as a general map of actors for any unspecified emergency situation. This was also related to being able to *clarify the different roles and responsibilities* in a situation where there are many different internal and external actors involved. The DSHA study (see Skjerve et al., 2008 and Tveiten & Albrechtsen, 2010) suggested that the scenarios used for emergency training need to reflect this new environment of IO.

There are many interfaces between distributed actors to consider when looking at the operators' emergency handling, both within and across organizational

[9] The presence of each actor will depend on which situation of hazard or accident that is handled

boundaries. In the workshop it was said that there is a need to "draw the map all over again" due to the changes that have happened in the industry and get an overview of the different distributed actors involved in emergency management. The changes that need to be included in the mapping of the actors are both the internal actors in operation and emergency management. This includes internal company support teams and other resources available as well as external agents such as contractors, the Norwegian oil protection association for operating companies (NOFO) and other important actors.

In situations of emergency some actors may have different functions than within normal operation. Partly as a consequence of IO, there may be several expert teams present onshore in the office locations. In one of the observed emergency exercises, the Operational Drilling Center turned into a support team (drilling team) for the emergency organization. This team is occupied by solving the problem, e.g. to kill the flow from the well.

In the route of identifying the actors involved, the participants in the workshop put their emphasis on the recent increase in use of support centers onshore which consists of experts with competence in different areas of the production process. These support teams and -centers possess crucial information for emergency management, and it was suggested that their role in the emergency management organization should be assessed. This also includes the contractors support team(s) and what their role should be.

## 4.3 Communication and information during distributed emergency handling

Communication challenges in existing emergency management seem to be related to the increased number of actors and the large amount of available information. Sharing of information in real time plays an even more crucial part than before in coordination of activities at different vertical and horizontal levels in emergency handling. From the observations it was found that both poorer and richer forms of communication could be used, but that these have both strengths and weaknesses in emergency handling that needs to be considered further. Additionally, the reliability and integrity of the information shared and received in an emergency situation should be considered as important factors when reviewing the data, channels and tools used.

From the observations and the workshop it became clear that the log system is considered as an important tool for coordination as well as to gain awareness of the actions and how the emergency situation is developing. However, it was found in the observation studies that this log was not accessible for all actors, and there is a need to assess who should have access to different types of information and systems. Another important element is that there may be a need to protect some of the actors involved e.g., 1st and 2nd line emergency personnel from too much information and request for information from other actors. However, this needs to be balanced in terms of how much information the other actors need in order to be able to handle the emergency situation at hand.

When discussing issues regarding introducing new technology in the emergency organization it was found that the tools introduced has to be familiar and user-friendly to the personnel involved in the emergency situation. It was argued in the workshop that emergency management should not be technology driven but that the technology and tools used has to support the work processes in emergency situations.

# 5 Discussion

The main result from our study is that new work processes enable a more proactive approach to emergency management. Making emergency management more resilient increases the possibility to deal with deficiencies in risk anticipation, dealing with unanticipated events and emergency management's adaptation to new and future work practices. The discussion is further sectioned into three parts; proactivity in emergency management and deficiencies in risk anticipation; emergency management's adaptation to new and future work practices such as distributed actors and new technology.

## 5.1 Towards a proactive emergency management

The petroleum safety authority refers to the NORSOK Standard Z-013 as requirements for handling risks in the oil and gas sector at the Norwegian Continental Shelf (NCS) (NTC 2001). The requirements are according to traditional risk assessment procedures and follow the as-low-as-reasonable-possible (ALARP) principles. Defined situations of hazard and accident (DSHA) form the basis for the planning, and execution of the risk- and emergency preparedness analysis. The emergency preparedness plan is established in an installation's design and building phase and is executed e.g. for training and manning purposes throughout operation. The oil and gas companies rely on the NORSOK standard and the work carried out based on this standard for establishing their emergency management and for training.

Based on the discussion of the empirical results it becomes evident that the emergency organization should expand their operational time frame. Today, the onset of the emergency team is when the event has occurred. Indications of possibilities of such an event may exist but are handled as part of normal operation. The system recovery phase is handled by outside the emergency management team.

We suggest broadening the scope of emergency management in both directions as shown in figure 2.

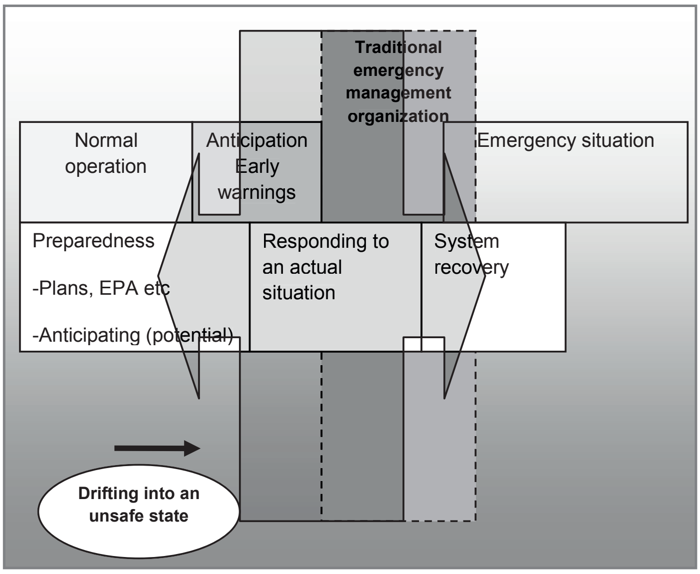


**Figure 9: Phases in an emergency situation. The position of the traditional emergency management organization is shown by a dotted line in the figure and the possible new onset of parts of an emergency organization is shown by the arrow.**

In figure 2, the dotted lined square shows the quite late onset of a traditional emergency response. The onset of emergency response comes after there have been attempts to respond to the actual situation. The perspectives for the emergency management team thus remains to rescue and evacuation of those exposed and to bringing the production systems etc. to a safe state. The square with arrows indicates that new actors and technology may contribute to an earlier onset of response and handling of the situation at hand and thus improve situation awareness for the emergency management team. Broadening the scope of emergency management implies to expand the set point and total time frame by emphasizing anticipation and monitoring. New technology such as real time monitoring and visualization enables this expansion. Also, the new work forms with use of support teams etc. support such an expansion. When support teams and centers are included in the emergency handling they ensure learning throughout the organization. It is likely that such an expansion will deal with the deficiencies in early risk anticipation, deal with unanticipated scenarios, and help adapting to new technology in work processes.

### 5.1.1 Deficiencies in risk anticipation

The read-through of the investigation reports referred to in the introduction in this article was that risk anticipation (mostly referred to as (operational) risk assessment in the reports) was insufficient in the majority of the cases. Several major system accidents in the recent years have revealed deficiencies in risk assessment and – anticipation (e.g. the BP Texas accident (Baker, Erwin et al. 2007) and the Challenger accident (Vaughan 1996)).

Adaptation is an important element in the RE perspective. The capacity to adjust and adapt comprises knowledge in terms of Anticipation (what to expect), Attention (what to look for), and Response (what to do). These three elements are not positioned such that anticipation precedes competence, which in turn precedes response. Rather, all three should be continuously be applied and kept active. Adaptation is a necessary means to face and cope with change and unexpected events (Størseth, Albrechtsen et al. 2010). The continuous process of adaptation implies that the level of vigilance in operation needs to stay high in all phases. In IO, the use of onshore support teams in normal operation has enabled a turn into a dynamic problem solving work process rather than an ‘expert-on-call in case of problems’ way of working. The handling of crises seem still to be either ‘on’ or ‘off’; the emergency handling organization is established by call in case of emergency, usually late in the problem solving process. In order to become more adaptive and resilient in the handling of operational problems, emergency management need to include the transition period from normal operation to the actual emergency handling by use of available resources such as the different support centers in a more coordinated manner. There is a need for a more proactive focus in emergency handling; to focus more on handling deviant situations and worst case scenarios at an earlier stage and involving experts, thus handling the situation before it escalates to a severe accident.

Following French & Niculae (2005) it may be argued that there is overconfidence in emergency preparedness modeling. They claim models are poorly calibrated for major accidents since they are by nature infrequent, thus insufficient pasts data to test the models.  The involved persons are drawn from other “day jobs” and have little experience of working in a crisis situation (with and assessing the import of the advice from their experts).This is true also in the oil and gas industry - the personnel that man the emergency centers are drawn from different parts of the organization.

### 5.1.2 Emergency management of unanticipated scenarios

Most emergency management models are based on a belief that the system is known or knowable, i.e. that cause and effect are understood and predictable or can be determined with sufficient data (French and Niculae 2005). Handling of major accident events are mainly characterized by systems or situations that are either complex (i.e. cause and effect may be explained after the event) or chaotic (i.e. cause and effect not discernible). Social, political and economic issues arise in these situations; this is partly due to several stakeholders involved with different perceptions of the situation. In these situations it is difficult to predict what is going on and what will happen (Weick and Sutcliffe 2001; 2007).

An emergency management plan will not be able to consider all aspects of a possible future danger or accident situation mainly because it is difficult to anticipate how a given danger or accident situation will develop. This means that the personnel involved in handling a situation has to have the skills, knowledge and creativity to somewhat improvise in a given situation. There may be different approaches to designing resilience into a system: (1) Resilience based on detailed predictions of hazard scenarios or causal chains, (2) resilience based on specific predictions of hazardous effect and states and (3) resilience based on dealing with a totally unanticipated scenario (Smith, Spencer et al. 2009). Smith et al. argue for a hybrid combination of the three approaches (the fourth approach) which means that an organization should be aim at identifying potential contingencies in order to ensure effective, customized response to such situations (first layer of defense), but that it is not possible to accomplish this for all contingencies. A second layer of response should be to identify contingencies at a less complete level of detail and to develop generic responses to these. For complex systems, it is argued, that a third level of defense is needed, one that makes it possible to detect and respond to novel and yet unanticipated scenarios. On the NCS it is usually not possible to detect even a second layer of defense in the written procedures and manuals for emergency management, though many accident and incident investigation reports, especially those that are carried out for major accidents, describe the accident scenario as partly or totally novel and not identified in detail in any risk analysis or DSHA. Investigation reports of successful handling of major accident scenarios often include a description of how the people at the sharp end apply a combination of layers of defense, that is; not only relying on detailed or more generic predefined handling of the situation (Brattbakk, Østvold et al. 2004; Schiefloe, Vikland et al. 2005; 2006)

## 5.2 Distributed actors

Integration of disciplines; technology and across organizational and geographical borders is one of the main changes in work practises in the industry (OLF 2005). The different actors involved have different responsibilities, rationalities, resources and proximity to hazard, which makes the map complex. Which actors who are involved in emergency management will vary according to the situation and the organization handling it. This makes collaboration and communication between different actors a challenge. This challenge of complexity is not only relevant for emergencies but is also relevant for maintaining safety in normal operations (Grøtan, Størseth et al. 2009).

On one side, new work processes by distributed actors in the petroleum industry is a challenge for emergency management regarding coordination, planning, analysis and training. On the other hand, it also represents a possibility for improved anticipation. More actors, including contractors, with different ways of interpreting situations imply that problems might be detected at an early stage (Weick and Sutcliffe 2001; 2007) as well as different understandings of phenomena enrich understandings of deviations and causes (Hale and Hovden. 1998; Bolman and Deal 2008). This can for example be onshore operational drilling centers that monitor drilling performance (Andersen, Sjøwall et al. 2009) and onshore drilling support centers that support several rigs with multidisciplinary expert knowledge (Wahl, Johnsen et al. 2009). Such centers also strengthen the principle of anticipation 'reluctance to simplify interpretations' (Weick and Sutcliffe 2001; 2007) since they have access to as well as dedicated time to study detailed real-time information about ongoing offshore activities. Most of the operators as well as contractors at the NCS today are using or plan to implement onshore operation and/or support centers, which will strengthen the ability to anticipate and monitor if used in a proper manner in emergency management.

According to a study by Skjerve et al. (2008) no changes in DSHAs as a consequence of new technology and work processes at the shelf have been identified, but new factors influence the build-up of; consequences of; and handling of events. As a result of integration of actors involved in emergency management and how they interact, emergency management planning face two challenges. First, all involved actors for different types of events must be identified. It must also be mapped out what the roles of the actors are and how they interact with other actors. The second challenge is related to risk analysis as an important input to emergency preparedness analysis – do adequate risk analytical approaches exist to express risk for complex systems? It is outside the scope of this paper to discuss the second challenge, which has been addressed by e.g. Grøtan et al. (2009) and Vatn (2010).

## 5.3 New information- and communication technology

As we stated in the last paragraph the sharing of information between actors within a distributed team is important and normally a challenge. Information technology can cope with some of the challenges in emergency management. Explicit knowledge (databases, models, information surfaces) can be used to make more detailed model based analysis and for complex and chaotic spaces where more judgment is needed. ICT can support this by collaboration technology (French and Niculae 2005). But there is a downside to the increased use of ICT, it leads to more complex and tighter coupled organizations (Perrow 1984; Perrow 1999) adding to the challenge in emergency management.

De Bruijne (2007) claims that the environment of many HROs in modern, western countries has undergone dramatic changes in the last decades, changing reliability organization into high reliability networks (HRNs). HRNs are distinguished from traditional HRO by an increased use of ICT, increased real time management and an increased interactive complexity. De Brunijne (ibid) stresses the importance of informal, rich interaction between operators across organizational boundaries in order to maintain the reliability in HRNs. This statement points to the essence of the challenges in future emergency management in the oil and gas industry. The concept of Integrated Operations is based on an increased use of ICT giving room for faster decisions in real time in an increasingly more complex system. When these decisions are made within complex systems with many actors from different organizations as shown in figure 1 , it is important that the information that is shared is easy to interpret and understand as well as that it is suited for the receiver. Richer information such as real images instead of text helps this by demanding less interpretation effort from the cognitive human system.

Increased bandwidth and new information and communication technology (ICT) is the main enabler for new work processes in the industry (OLF 2003; 2005; 2009). Our observation studies showed that collection and sharing of information among different actors have a central role in coordination of activities at different vertical and horizontal levels in the emergency handling situation. Workshop participants working at the sharp end emphasized that the demand of information must be balanced with the actual handling of the emergency situation. It must be avoided that request for information disturb the actual handling of the event. Furthermore, our observation studies indicate that use of rich communication channels and other ways of sharing information than the log system was absent. Paradoxically, the industry claims that richer communication and effective visualization of real-time information is one of the main new technology-based work processes (ibid). The reason for this technological underdevelopment in emergency management is probably related to a conservative mind-set in this field. Trust in technology is emphasized and emergency handling it is not an area where one explore new technology and work processes. However, in the future it must be assumed that emergency management must adapt and implement new technology. In a long-term perspective, use of rich communication channels and collecting and visualization of real-time information, becomes an established way of working in the other areas of operation. In such a situation it will be more efficient for emergency handling to stick with the technological solutions that are being used in normal operation.

To deal with this the challenge of trust in new technology in emergency situations, training should emphasize use of the same tools for co-located and distributed teams in training so that they are familiar with the tools that will be used in an emergency handling situation. Additionally it is important that all actors are able to view and observe the same information because this will lead to better communication and understanding of the situation.

Information and communication technology (ICT) must be carefully introduced into emergency preparedness training. This is showed by Woltjer, Lindgren et al. (2006) and Iannella and Henricksen (2007). There should not be a mismatch between the ICT tools used in training and those used in the actual work environment as this may lead to that the domain-specific skills do not transfer to real situations. They further go on to say that the skills may transfer but that that the skills are inappropriate and a source of confusion and ineffectiveness (Woltjer, Lindgren et al. 2006). Emergency management systems that are not used on a regular basis are unlikely to be of use in actual emergencies. Our findings support that the technology must be familiar to the user(s) and that the user must trust it which normally also include that the technology needs to be highly reliable.

# 6 Conclusion

We have presented the results from our study of future challenges and possibilities in emergency management in intelligent operation of petroleum production. The main result from our study is that there is a need to be more proactive in emergency management, a possibility that is enabled by IO concepts. In the discussion of the results we suggested three main elements that are important to consider in the development of future emergency management; 1) proactive emergency management through early risk anticipation; and emergency management's adaptation to new and future work practices such as 2) distributed actors and 3) new technology. It is possible to look at emergency management as a process that includes several phases – from early signs of something that may develop into an accident, to the direct handling of situations and consequences and the process of returning to a normal state. To cope with the challenges of new work processes and new technology, managing unexpected events and poor risk anticipation we suggest the following principles of resilient emergency management in integrated operations:

- The **first principle** is **monitoring.** This is part of normal operation, but it may turn into the first phase of emergency handling. Real time data and monitoring during normal operation improves the ability to monitor the emergence of unwanted development
- The **second principle** is **anticipation** which involves handling the early warning deviation and to foresee that this may turn into an unsafe state of the system if not handled. This principle influences the emergency preparedness planning and implies that risk assessment is an ongoing process rather than a static measure. Risk assessment needs to include new input such as mapping out distributed actors.
- The **third principle** involves **responding**. This principal is similar to the traditional emergency handling. However a proactive focus makes it possible to react to deviations before they develop into accidents. As a result it makes it possible to return to normal state before the emergency situation develops. If this is not possible a different phase of emergency management will start that resemble more traditional crisis management.
- The **fourth principle** is **learning.** As the system is back safe state there is a need to learn from the process and update the risk image of the system**.** Equally important is to learn from successful handling of events.

These principals are equally important in all phases of emergency management. In order to fulfill these principals the emergency organization in the petroleum industry need to consider changes in their structure, roles, use of technology and work processes.

Onshore teams that monitor and work with real time data introduce more people seeing more of the same things within the operation. Expert knowledge is often used in onshore teams. Their knowledge and expertise may imply reluctance to simplify and more sensitivity to the operations. This may move the focus of handling crises from just handling the top events. The implications of the changes will be changed scenarios for and roles within emergency management training sessions. In order to prevent distrust in new tools and unfamiliarity with new work forms and new actors, the use of collaboration tools and technology for information sharing must be especially considered in training sessions.

Other sectors such as energy supply, the financial system and transport systems face the same challenges with new technology and distributed organizations. The challenges with emergency management in other industries and especially at the societal level have been exposed to disasters and accidents in the last years, and seem to resemble the challenges that we see in our study. The results in this article may be equally important for emergency management outside the oil and gas industry.


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## References


Andersen, K., P. A. Sjøwall, et al. (2009). Case History: Automated Drilling Performance Measurement of Crews and Drilling Equipment. SPE/IADC Drilling Conference and Exhibition, Amsterdam, The Netherlands, 17-19 March 2009.

Baker, J. A., G. Erwin, et al. (2007). The report of the BP U.S. refineries independent safety review panel.

Bolman, L. G. and T. E. Deal (2008). Reframing organizations : artistry, choice, and leadership. San Francisco, Jossey-Bass.

Brattbakk, M., L.-Ø. Østvold, et al. (2004). Granskning av gassutblåsning på Snorre A, brønn 34/7-P31 A (Investigation of the gas blow out at Snorre A, well 34/7-P31 A In Norwegian only). 28.11.2004. Stavanger, Petroleum Safety Authority.

Bruijne, M. D. (2007). Networked reliability: from monitoring to incident management. ISCRAM Delft.

Farner, A. (2008). Verksted som verktøy / å planlegge og lede workshops (The workshop as a tool/ to plan and mange workshops).In Norwegian only. Oslo, Kommuneforl.

French, S. and C. Niculae (2005). "Believe in the Model: Mishandle the Emergency." Journal of homeland security and emergency management **2**(1).

Grøtan, T. O., F. Størseth, et al. (2009). Scientific foundations of risk in complex and dynamic environments. Reliability, Risk and Safety: Theory and Applications. Proceedings of ESREL 2009. S. M. e. Bris. Prague, Taylor & Francis Group.

Hale, A. and J. Hovden. (1998). Management and culture: the third age of safety. A review of approaches to organizational aspects of safety, health and environment. Occupational Injury: Risk, Prevention and Intervention. Feyer and Williamson. London, Taylor & Francis.

Hammersley, M. and P. Atkinson (2007). Ethnography : principles in practice. London, Routledge.

Hollnagel, E. (2009). The four cornerstones of resilience engineering. Resilience engineering perspectives; Preparation and restoration. C. P. Nemeth, E. Hollnagel and S. Dekker. Ashgate, Aldershot

Iannella, R. and K. Henricksen (2007). Managing Information in the Disaster Coordination Centre: Lessons and Opportunities. ISCRAM, Delft.

LaPorte, T. and P. M. Consolini (1991). "Working in practice but not in theory: Theoretical challenges of "high-reliability organizations"." Journal of Public Administration Research and Theory **1**: 19-47.

Miller, G. and R. Dingwall (1997). Context and method in qualitative research. London, Sage Publications.

NTC (2001). NORSOK Standard Z-013: Risk and emergency preparedness analysis, Norwegian Technology Centre.

OLF (2003). "eDrift på norsk sokkel - det tredje effektivitetspranget." (eOperation on the Norwegian Continental Shelf – the third efficiency leap) Retrieved January 1. , 2010, from http://www.olf.no/getfile.php/zKonvertert/www.olf.no/Rapporter/Dokumenter/eDrift-rapport%202003.pdf.

OLF (2005, 20.10.05). "Common network operation management for digital infrastructure offshore on the Norwegian continental shelf." 1.0. Retrieved January 1., 2010, from http://www.olf.no/getfile.php/zKonvertert/www.olf.no/Rapporter/Dokumenter/071030%20Informasjonssikkerhet%2C%20brosjyre_5788.pdf.

OLF (2005). "Integrated work processes. Future work processes on the Norwegian continental shelf." Retrieved January 1. , 2010, from http://www.olf.no/rapporter/category229.html.

OLF (2006). "Verdipotensialet for Integrerte Operasjoner på Norsk Sokkel." (The value potential for integrated operations on the Norwegian Continental Shelf). In Norwegian only Retrieved January 1., 2010, from www.olf.no.

OLF (2009). "Information security baseline requirements for process control, safety and support ICT systems." 5. Retrieved January 1., 2010, from http://www.olf.no/getfile.php/Dokumenter/Retningslinjer/101-

120/104%20Information%20security%20baseline%20requirements%2015.01.09%20-%20Rev.05-English.pdf.

Perrow, C. (1984). Normal accidents living with high-risk technologies. New York, Basic Books.

Perrow, C. (1999). Normal accidents living with high-risk technologies. Princeton, N.J., Princeton University Press.

Regjeringen (2002). Stortingsmelding 38 om olje- og gassvirksomheten. Oslo, Regjeringen. (Whitepaper on the oil and gas business from the Norwegian government. In Norwegian only)

Ringstad, A. J. and K. Andersen (2006). Integrated Operations and HSE - major issues and challenges. SPE Int. Conf. on Health, Safety and Environment, Abu Dhabi.

Rochlin, G. (1997). Trapped in the net. Princeton, Princeton University Press.

Schiefloe, P. M. and K. M. Vikland (2006). Formal and informal safety barriers: The Snorre A incident. Safety and reliability for managing risk. C. Guedes-Soares and E. Zio. London, Taylor and Francis Group. **1**.

Schiefloe, P. M., K. M. Vikland, et al. (2005). Årsaksanalyse etter Snorre A hendelsen (Cause analysis of the Snorre A incident. In Norwegian only) 28.11.2004 Stavanger, Statoil ASA.

Skjerve, A. B., E. Albrechtsen, et al. (2008). Defined situations of hazards and accidents related to integrated operations on the Norwegian continental shelf. SINTEF, SINTEF.

Smith, P. J., A. L. Spencer, et al. (2009). Layered resilience. Resilience engineering perspectives, preparation and restoration. C. P. Nemeth, E. Hollnagel and S. Dekker. Ashgate, Aldershot. **2**.

Størseth, F., E. Albrechtsen, et al. (2010). Resilient recovery factors: Explorative study. Safety Science Monitor.

Suchman, L. (1996). Constituting shared workspaces. Cognition and communication at work. Y. Engstrom and D. Middleton. Cambridge, Cambridge university press**:** 35-61.

Suchman, L. A. (2007). Human-machine reconfigurations : plans and situated actions. Cambridge, Cambridge University Press.

Tveiten, C. K., E. Albrechtsen, et al. (2009). Defined Situations of hazard and accident related to integrated operations on the Norwegian continental shelf Reliability, risk and safety. Theory and applications. R. Bris, C. G. Soares and S. Martorell, Taylor and Francis**:** 2183 - 2190.

Tveiten, C. K., E. Albrechtsen, et al. (2010). New opportunities for emergency handling in the intelligent energy organization. Proceedings SPE Intelligent Energy. Delivering Value - Creating Opportunities, Utrecht, the Netherlands.

Vatn, J. (2010). Can we understand complex systems in terms of risk analysis? Unpublished work.

Vaughan, D. (1996). The Challenger launch decision : risky technology, culture, and deviance at NASA. Chicago, University of Chicago Press.

Wahl, A. M., S. O. Johnsen, et al. (2009). Resilience in distributed teams. A field study of drilling and well operations in the Sub Surface Support Centre, StatoilHydro, SINTEF.

Weick, K. E. (2001). Making sense of the organization. Oxford, Blackwell.

Weick, K. E. and K. M. Sutcliffe (2001). Managing the unexpected. Assuring high performance in an age of complexity. San Francisco, Calif., Jossey-Bass.

Weick, K. E. and K. M. Sutcliffe (2007). Managing the unexpected. Resilient performance in an age of uncertainty. San Francisco, Calif., Jossey-Bass.

Woltjer, R., I. Lindgren, et al. (2006). "A case study of information and communication techology in emergency management training." International journal of emergency management **3**(4): 332-347