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Resilience in well operations through use of collaboration technologies

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Preface

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Abstract

The thesis studied resilience in drilling and well operations at an oil company operating on the Norwegian continental shelf, with a major focus on the onshore drilling support function in the case company. Drilling for oil and gas involves significant risks, according to scientists, authorities and the industry itself. The risks of offshore oil extraction have also been manifested through major accidents like the Deepwater Horizon. At the same time, the industry faces challenges like less reservoirs and rising operating costs. The development of new technology for collecting and transmitting data and new ways of working emerged about a decade ago and is often referred to as Integrated Operations or simply IO. The changes made new ways of working over distance possible, which were said to have produced numerous advantages that would lead to improved productivity and profitability as well as HSE. Some scientists however have warned against possible negative risks associated to Integrated Operations that should be accounted for. At the same time, within the safety management science Resilience Engineering has evolved as a well acknowledged theory for building resilient organizations. However, the literature on Resilience Engineering is rather new, and some authors have called for more empirical studies of resilience in practice. To perform a study on resilience in practice in an IO environment, the following research questions were formulated:

- How does collaboration technology and integrating of operations influence resilience?
- How can resilience be engineered in an IO environment?

A case study design was chosen, and the case was delimited to compass the selected case company's drilling and well operations units with the organization's onshore drilling support center as the core object of study. The qualitative research methods semi structured interviews of key personnel at the case company and observation of work practice were used for data collection. In addition some documents were used.

The study started off by investigating how the case operates, and in particular how they utilize collaboration technology and work over geographical and organizational borders. Specifically, the focus of attention was to identify the risks and challenges in drilling and well operations and how the organization operates in such an environment. The data collection then focused on how the organization manages risks and what factors contribute to resilience. Relevant literature was reviewed in order to identify characteristics resilient organizations. The data collected at the case company were then compared with the literature study and the organization's resilience was then sought to explain.

The analysis resulted in a set of recommendations that was seen as key contributors to resilience for the case, and may be useful recommendations for organizations in other relevant contexts. The suggested steps towards a resilient organization are:

- Organize the workers into teams of experts in collaborative open space offices
- Make sure employees have experience from relevant work practice
- Have organizational processes that facilitate collaboration in place
- Use analytics on historical and realtime data extensively
- Have knowledge databases with lessons learned and best practices
- Invest in new technology and workplace facilities
- Create positive attitudes towards change
- Encourage curiosity and employees' interest in their field of expertise

Contents

1 Introduction

1.1 Background

The World's demand for primary energy is projected to increase with 1,2% per year, or 36% between 2008 and 2035 according to the International Energy Agency (IAE 2010). Fossil fuels account for more than half of the World's primary energy demand and the IAE (2010) expects/projects rising demand over the coming years. Despite rising commodity prices and carbon taxes, oil is expected to remain as the dominant fuel in the global primary energy mix to 2035. Much of the proven and unexplored reserves are on deep water, in the Arctic region or in unconventional forms like bituminous sands. Drilling for oil in such areas is set to play an increasingly important role as the more easy accessible reserves is being depleted. Natural gas will also play a central role in meeting the energy demand due to the size of reserves and the environmental compared to other fossil fuels. The petroleum industry alone produces 25% of Norway's economic output and accounts for half of the nations export (OLF 2010). With rising commodity prices and energy demand, exploration of hydrocarbons on the Norwegian continental shelf is likely to continue for the next few decades.

Several of the major accidents during the last 30 years happened on petroleum installations and illustrate some of the safety challenges in this type of industry. One of the most famous/well-known is the Deepwater Horizon accident in the Mexican gulf in April 2010. But there have also been serious accidents in the North Sea like the Piper Alpha disaster in 1986 and a few serious incidents with major accident potential like the Snorre A incident in 2004 and a number of well integrity incidents on the Gullfaks C installation in 2009-2010.

Expanding the life time of maturing fields is one option for rising oil supply. Producing oil from maturing field is becoming increasingly difficult (NPF 2011), and represents a challenge for the Norwegian petroleum industry. Integrating operations across organizational and physical borders through use of new technology and ways of working may improve profitability/lifetime and is expected to be utilized at a greater scale in the coming years (OLF 2005). New technology and work forms may change the way organizations behave and the risks they face (Grøtan et al 2010). It seems that drilling for oil and gas will not have decreased importance in the near future and the application of new technology and changed work practices that come along with integrating of operations may play a central role in petroleum activities.

Drilling for oil and gas has for decades been regarded high risk activities, which has recently been evidently illustrated by the Deepwater Horizon disaster. High energies in combination with demanding conditions/environments have resulted in advanced ways of producing oil. As technology and operations develop, organizations grow in complexity. Understanding the systems and managing the risks becomes increasingly challenging. In the petroleum industry, technological advances through new software and tools made it possible for companies to employ new measurements, analyses and ways of communicating in their operations. With the new technology and changed ways of working, organizations could be more integrated with internal and external units. The intended results are improved profitability and safety, but some authors have warned against unexpected and unwanted effects. Resilience Engineering has developed during the recent years as an approach to understand how safety is brought about and how resilient organizations can be built and maintained. Resilience is used increasingly in other disciplines as well to encompass the dynamic and adaptive characteristics of modern systems that more classic mechanistic thinking does not cover. An interesting area of study for this master's thesis was to study resilience in a modern organization, like one engaged in drilling and well operations.

1.2 Aim and purpose

The general purpose of this thesis was to perform an empirical study of resilience in a system that operates in an IO environment. More specifically it was to study actual use of new collaboration technologies in drilling and well operations, and how risks and uncertain situations are managed in practice. The aim was to study the impact of the use of collaboration technology may have on resilience in high-risk activities. Finally, a goal was to try to develop recommendations for handling these risks based on the case study and the literature review. Organizations operating in a similar context might use the findings from this study when designing a resilient organization.

1.3 Research questions

The problem statement that was decided before starting up the work on this thesis was specified by research questions. During the research process these research questions were specified further as the data collection and the literature study progressed. The research questions for this thesis are:

- How does collaboration technology and integrating of operations influence resilience?
- How can resilience be engineered in an IO environment?

1.4 Research design

To get elaborate descriptions of how collaboration technology is used in practice and how organizations actually work/perform drilling and well operations, it was decided to do a case study. Finding a case company that operate on the Norwegian continental shelf and use collaboration technologies in their operations would give the possibility to get raw data from people familiar with the matter that works within the field every day (not only close to the matter). At the same time there would be an opportunity to do observations of work practice. Having direct access to the work system that is daily involved with well and drilling operations was important in order to investigate how resilience is brought about in practice and what factors that lay the foundation for safety in such context. Selection of the case was done by contacting one of the operating companies on the Norwegian petroleum industry. Data collection was done by interviews and observation. Documents were also used as input to the data material and as preparation to interviews and observations. Before the study began literature on resilience, safety management and sociotechnical systems was read and during the research process more literature that was found relevant was reviewed.

1.5 Clarifications and boundaries

This study focused on organizational factors, and their interplay with technology. The case is a system including drilling and well operations. Included in this type of activities are in addition to the drilling itself (where the wellbore is extended) casing, cementing, completion and slot recovery. Often the term “drilling” is used in a general way for activities performed before a well is set in production. This thesis deals with activities in the phases before a well is entering the operational phase plus other operations the same work system is conducting. The activities are commonly described as drilling and well operations. The terms resilience and Resilience engineering are defined and discussed in a separate section, and are used throughout the report. Safe and efficient operations are also used in this report as a synonym to resilience, especially in connection with the interviews as this was regarded as more common expression that the interviewees fully understood.

2 Theory

This chapter starts with elaborating use of integrated operations and the use collaboration technology in the petroleum industry, and presents relevant theories related to resilience like sociotechnical systems, safety management and organizational change.

2.1 Use of collaboration technology in the petroleum industry

A development during the recent years in the petroleum industry characterized by utilization of new technologies, work forms and work processes is often called Integrated Operations (IO). From the beginning of the 21st century oil companies started to deploy sensor data transferred from offshore to onshore installation by broadband/high speed cables enabling use of real time data and more remote operations. Collaboration between onshore and offshore facilities could now be improved through deployment/application of communication channels like video conference and internet/computer instead of the more traditional channels telephone, fax and radio communication. This lead to both that human resources onshore could be utilized better and personnel could be moved onshore and continue their functions from onshore centres. This is called the first generation of IO.

Tighter integration of external units within and outside the operating company progressed in the second part of the last decade, and was named the second generation of IO. Involvement of stakeholders and expert resources from contractors as well as other departments inside the company characterizes the recent development of IO. Integration across geographical borders, disciplines, departments and companies through use of new technology, work processes and work forms is a well known description of this development. Team based, interdisciplinary and multidisciplinary work is now more common in modern petroleum activities. Video conferences instead of physical meetings, which often require extensive travel, are increasingly employed in the industry and people are becoming more familiar with this type of communication and work form. Use of computers in communication (e.g. e-mail) as well as for information processing (e.g. interpretation of sensor data in onshore centres) is also more common.

Outsourcing and specialization are main characteristics of today's business world. Engineering companies are for instance massively/highly involved in the engineering and construction phase as well as maintenance and new build operations. Then there is the delivery and installation of equipment. Financial advises, geological surveys, reliability analysis, environmental assessment - the list is long with external consultancy services that usually are outsourced/hired in. Companies are specializing more and more, which results in integration/involvement of contractors in the operations to a higher degree. Even though some of the biggest oil and gas companies own/cover several upstream and downstream sections, many operations and parts of them are done by external companies.

Many different types of data are collected during the drilling process. Flow and temperature, vibrations, torque and drag, rate of penetration, pore pressure, and hook load are examples of data that are presented to an onshore center realtime or with a small delay of a few minutes (Rommetvedt et al 2007). The personnel onshore use this information in their work supporting the offshore operations in different ways. The application of analytics – mathematical and statistical analysis on data sets – is playing an increasingly important role in drilling and well operations. Decisions during operation can be made based on recommendations from the analyses. Another application of realtime data is modelled of the wellbore and its constituents through 3D visualization.

Integrated operations may produce both desired and undesired effects. A study in risk assessments in the Norwegian oil industry found that factors like loss of human competence through downsizing, new roles and responsibilities, changed working environment, increased vulnerability and dependency on technology, and different situational context between offshore and onshore may affect the major accident risk (Weltzien 2010), but it was not unambiguous whether IO influenced safety risk positively or negatively. Letnes et al (2008) found that both the collection, interpretation and utilization of the realtime data were a problem for the execution of the remotely operated drilling process. The involved actor did not have a total and shared overview of the process and the relationships between different actors as well as the connections between different parts of the process and how they influence each other. Better collaboration and integration of the drilling actors were recommended in order to better utilization of the new technology. This would lead to new modes of working and changes in roles that should be accounted for in the change process.

The survey indicated that the workers expected that improved operational decisions will lead to improved HSE due to faster and improved communication. Few of the interviewees thought eDrilling would lead to positive changes in their daily work processes, but not have a big impact. Trust in the technology and the reliability and quality of data were among the success factors identified for implementing of eDrilling. A study investigated the effects on safety IO may have, and found no new Defined Situations of Hazard and Accident stemming from the introduction of IO (Skjerve et al 2008). However, changes in the contextual factors could have an impact on the DSHAs casual chains. For instance new ways of communicating may influence accident precursors and increased ICT dependency may change how events develop.

2.2 Theoretical background/framework

2.2.1 Resilience

Flexibility, strength, adaptability, durability and ability to bounce back are listed in the Oxford Thesaurus of English as synonyms to resilience, while vulnerability and fragility are among its antonyms. In the field of biology and ecology resilience is commonly defined as *"**the capacity of a system to continually change and adapt yet remain within critical thresholds**"* according to Carl Folke at Stockholm Resilience Center. Peterson et al (1998) write that ecological resilience is a measure of the amount of change or disruption that is required to transform a system from being organized around one set of processes and structures to being reorganized around another set of processes. In psychology, resilience is the capacity to withstand high level of stress and cope with crises. Brudal (2006) writes that resilience is an *inherent ability connected to restoring, maintaining and improving the capacity to withstand stress and crisis*. This adaptive capacity can be divided into three main factors, namely flexible attitude to change; focus on coping with the situation rather than trying to change the external factors; and creative thinking to come up with new ideas and solutions to a problem. A few people keep the spirit up and maintain a good life in spite of severe injuries or highly traumatic experiences. Psychologists call them resilient.

In search for a general definition of resilience Folke (2010) loosely defines resilience as the capacity of a system to deal with change and continue to develop. This capacity refers to both withstanding shocks and disturbances and to using such events to rebuild and renew itself. Crisis is a catalyst for innovation and development rather than degradation and breakdown. Resilience has three main features; persistence, the ability to withstand stresses and remain within critical thresholds; adaptability, the capacity to learn and adjust its functioning to meet the changed conditions/requirements; and transformability, the capacity to undergo more fundamental changes like restructuring in order to exist functioning. Two underlying principles for resilience theory are the one of couplings between humans and nature that make up a socio-ecological system and the one of self-organizing systems with feedback loops, so called complex adaptive systems.

In organisation theory Horne and Orr (1998) defines the term resilience as a fundamental quality of individuals, groups, organizations, and systems as a whole to respond productively to significant change that disrupts the expected pattern of events without engaging in an extended period of regressive behaviour. They furthermore list seven «streams» of resilience behaviour within an organisation that alone and in combination contribute to resilience. The seven are community, referring to the relationships between the people and cultural factors in an organization; competence, i.e. skills and knowledge to meet internal and external demands; connections, characteristics of the relationships in the system; commitment, the ability to work together; communication, sharing of information; coordination, the organisation's coordination of efforts to reach common goals; consideration, the understanding and self-correction to achieve harmony in the organisation.

Hollnagel (2010/11) defines resilience as "the intrinsic ability of a system to adjust its functioning prior to, during or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions", and emphasizes that resilience refers to something that a system does rather than what is has. Resilience theory within safety science developed during the last 5-8 years as *Resilience Engineering*, and is presented in a separate section.

2.2.2 Sociotechnical systems

The idea that organizations consist of both social and technical system and the interaction between the human and technology is vital for the functioning of the organization is the fundamental idea of sociotechnical systems theory. The socio technical school emerged in the last half of the 20^{th} century, probably having its origin in the early nineteen fifties around the social research group of Eric Trist and Fred Emery at the Tavistock Institute in London. In the years following the Second World War, the British economy was characterized by low productivity and little capital available for investments and the government made grants to research projects on better use of human resources at the Tavistock Institute (Trist, 1989). One of the projects studied work groups in the coal-mining industry, and led to the discovery of the effectiveness of self-regulating work groups. Small groups worked autonomously and adapted better to technological than work system built on principles of bureaucracy and Taylorism. The groups showed high productivity, low absenteeism, few accidents and high personal commitment and the outcome of the studies was the birth of a notion – sociotechnical system. This perspective is used for the understanding the interactions between the social and the technical system and for designing the work, often referred to as fit between human and the machines (Klev and Levin 2009). One main principle of sociotechnical theory is that there are both linear and non-linear interactions of technical and social factors that make up the organization. The other main principle is that optimization of each aspect alone will lead to sub optimization, and therefore joint optimization the core feature of sociotechnical system theory. The main principles of sociotechnical theory can be summarized in four categories (Walker et al 2007).

- *Responsible autonomy.* Giving smaller groups responsibility and authority improve their performance.
- *Whole tasks.* Putting responsibility for the whole work tasks on the group or individual worker helps for the commitment and feeling of responsibility plus it ensures that a variety of skills are used which is good for individual development and maintenance of skills.
- *Meaningfulness (interdependency)*. If one's work has significant impact on others, sociotechnical thinking assumes that one strive to do the tasks as good as possible and in that way supports the others in the work system – in other words joint optimization takes place.
- *Adaptability*. Human redundancy increases flexibility so that groups can adjust their functioning, and complexity drive systems to adapt to its environment.

As will be seen in the following sections key features from sociotechnical systems theory is found in several other theories. Human resource management, safety management and organizational development and change management have links to the sociotechnical systems theory. The principles are applied in many purposes like work design, process development, change management, knowledge management and accident investigation. In human resource management motivation, job enrichment and other job performance increasing factors (Bolman and Deal 2004) play a significant role.

2.2.3 Organizational learning and change management

Levin and Klev (2009) writes in their book C*hange as practice* ("Forandring som praksis" in Norwegian) that *change management* is a field within management science that has a great amount of literature, but many of the books written within this field are not scientifically grounded. There are lots of best selling books that presents a solution to successful change processes that are decoupled from scientific based knowledge which is problematic from a scientific point of view, Levin and Klev argues. Instead they take on an academic approach by applying both theoretical and practical knowledge, where for instance empirical data from research projects conducted by the Norwegian labour organisation and the employers' organisation and theories like Argyris' action science are among the main sources. Their perspective is that change management is a subset of leadership and is about arranging for good change processes. This is done by arranging for locally development processes and managing the resources and capacity needed for effective changes and development processes. One can prepare and arrange for successful organizational change and development processes, but everything cannot be planned and end results cannot be fully predicted. It is the actors involved in the process that determines the end result through their actions and their interactions with the environment. Change processes must therefore be continuous in order to realize the desired changes.

Levin and Klev consider organizational change as a learning process. Work practise has developed through learning, and new practises must come from learning processes. Practises or routines are a result of its members' actions and knowledge, and all the actions and interactions that take place is what make up the organisation. These established routines are not only rooted in some of the individuals but shared by people in the whole organisation. For organizational learning to take place the organisation's members must take part and contribute in the learning process. Otherwise learning becomes individual and not collective. A core principle in learning processes in organizations is the collaboration between those needing the change, the problem owners, on the one hand and the facilitator, consultant or team/change leader, on the other hand. Common arenas for communicating the needs and implications of a change are important to involve all affected and "democratize" the process. Organizing for democratic change processes has the advantage of motivating the individual workers, *make sure that top-down instructions/decision resulting in destructive forces/tensions among the employees do not take place*. Such common arenas are also very important in creating common reflection and learning.

An organizational development process typically consist of three main phases: the initiation phase with search for problem clarification, reflections around approach and aim of the development; the start-up phase with involvement of the individual worker, starting with tasks that show rapid results; and the learning phase where commune reflection around the solutions and suggestions for improvements and new solutions creates a learning spiral.

It is common to distinguish between two types of learning within an organisation. One type is single-loop learning where improvements are sought within the frames of established routines. When attempting to improve results simpler corrections are made by using the same means. The established goals, values and routines are not questioned; instead only simpler corrections of current practice are made. On the contrary, fundamental assumptions are questioned in double loop learning. The question is not only "are we doing the things we do right" but also "are we doing the right things". By raising more fundamental questions, the double loop learning may result in completely new practices and assumption. Single loop learning on the other hand typically leads to adjustment of the way of doing things while the more deeply rooted assumptions, goals and values remain unchanged.

Knowledge is playing a central role in any development process. Acquiring, sharing and maintaining knowledge becomes increasing important in today's knowledge intensive working life and ***knowledge management*** has developed as a branch of organizational science. Knowledge may be in different forms. Explicit knowledge can be easily transferred in written and verbal forms and stored in media, and is often thought of as fact based written knowledge. It has the advantage of making the knowledge available to other through some type of media, and the user of for instance written material can make his/her own interpretations and use it in the way the want. As distinguished from explicit knowledge, tacit knowledge is difficult to transfer by writing it down or verbalising it. This kind of knowledge is not immediately available for others and is “hidden” in skills and habits. One may be unaware of the tacit knowledge on has, or does not understand that it is valuable to others. It is therefore not easy to share without close cooperation with the people that hold the knowledge. *Knowing how to do* things is a common expression for practical knowledge and is a type of tacit knowledge. Levin and Klev (2009) presents two ways of spreading practice based knowledge at the workplace adapted from Schön (1983). First there is reflection with the employee about what is done *during* the execution of the work and reflection of what has been done *after* the work has been performed. Second there is a type of reflection that takes place in an organisation development process where a group – consisting of for instance employees, managers and change facilitators – reflects on current work practice in order to develop new ways of working. Since much of the knowledge within an organisation is tacit and difficult to transfer, finding ways of sharing experience based tacit knowledge may be of increasingly importance.

Organisations that are learning new practices on an organizational as well as on the individual level are often referred to as learning organisations. Senge (1990) presented five theories for how to become a learning organization. The discipline of *personal mastery* says that individuals need to have vision for work and focus energy on learning. *Mental models* are about the understanding of the organization, and are closely related to the action science. In order to develop a common commitment, *building a shared vision* is vital. During the learning process, collective learning in a team is effective since taking advantage of *team learning* make the team more knowledgeable than the sum of each of its members. Taking systems dynamics and interactions between the actors into account, Senge presents *systems thinking* as the fifth discipline that integrates the other four.

This section is rounded off by discussing competence. While knowledge is an important part of competence, being competent in a field also requires skills. One must have the ability to utilize knowledge and to do so certain skills are required. Skills can like knowledge be attained through formal and informal training, but one could in general say that skills usually need more practice before it is learned whether it is cognitive or physical skills. Competence is regarded as a source for flexibility and less uncertainty when it comes to handling the challenges ahead (Levin and Klev, 2009), and is in several theories mentioned as an important feature for safe and efficient operations.

2.2.4 Uncertainty management and work system design

Managing variations and disturbances are the core tasks of a work system according to Grote (2009a). Internal and external variances affect the system’s performance, including its safe functioning, and there are different strategies for how to cope with variances. The approaches for managing uncertainties have different strengths and weaknesses depending on the internal characteristics of the system and its environment.

The degree of procedures and standardization versus the degree of flexibility and autonomy links the principles of work process design to the principles of resilience engineering. The idea of loose coupling was proposed by Weick (1976) as a way to allow for flexibility and situational adjustments while at the same time adhere to routines and standards. Decentralized autonomy and centralization of norms and values are the core principles behind loose coupling. This balance between central and local control is the basis for Grote's (2009) theory of managing uncertainties in organizations. The two approaches minimizing of uncertainties and the coping with uncertainties need to be balanced. In the minimizing approach disturbances are to be avoided, and this is done so by central planning and standardization. The coping approach, on the other hand, sees disturbances as an opportunity for use of competence and making changes to the system. Here the individual worker or team is given autonomy to deal with situations that occur. The minimizing approach is a type of feed-forward control and the coping is a type of feed-back control. She rejects the assumption that full control can be achieved by minimizing uncertainties and central planning. Limits of planning and central control should be acknowledged and focus should be moved more in the direction of local control through decentralization of autonomy. Grote et al (2007) called for further research on this topic, namely how loose coupling can be put into practice and what role organizational routines play in achieving loose coupling in such environment.

Grote (2009b) also points at another problem that may be relevant for IO, namely the limits to control in automated systems. As systems gets more automated the need for human supervisory control increases. But more complex systems make it harder for human to understand and control the processes. More automation usually allow for less practising of skills and less familiarization with the system and its behaviour. Since every automated system is a sociotechnical system, humans have been involved in both developing and operating the system and the technological factors should therefore not be analysed without also taking the M's and O's into account. Human and machines should be viewed as fundamentally different and complementary, performing together in a joint cognitive system (Hollnagel and Woods, 2005). System design should therefore focus on supporting human strengths and compensate for human weaknesses. Grote points at limited control and accountability for the individual operator of a system as a result of more automation. And more complex systems along with higher demand of productivity and cost effectiveness is often tried solved with more automation. Increasing complexity in today's systems may therefore actually limit control.

The KOMPASS method, developed by Grote et al (1999), is a method that can support solving the problems in the two above discussed topics. It seeks to promote work system design that handles uncertainties stemming from the system's own operations and from the environment and. The method may also support design of systems particularly exposed to new technology that needs to handle technological risks. The foundation of the KOMPASS method is sociotechnical systems theory. The starting point is the work system which is an open, dynamic and goal-oriented system consisting of human, technological and organisational elements. In contrast to many human is seen as a resource that contributes to safety rather than safety risk factor. The system has primary task where inputs are transformed to outputs and secondary tasks of preserving and developing the work system. Internal factors like work conducted by individuals or machines and equipment as well as external factors like inputs and outputs are sources for variances and disturbances. Any deviations from plans that do not interrupt the system significantly are variances while deviations that lead to interruptions of the work process are disturbances. As described earlier handling uncertainties is seen as vital for a system's functioning.

Assessment of variances and disturbances in the system is therefore at the core of the KOMPASS method. Local managing of variances is assumed to prevent variances from developing into disturbances or system failures. The analysis of work system task completeness, independence of the system, fit between regulation requirements and regulation opportunities, polyvalence of the members, autonomy of the groups, and boundary regulation by superiors. The individual work tasks are analysed with respect to task completeness, planning and decision making requirements, communication requirements, opportunities for learning and development, variety, transparency of work flow, influence over work conditions and temporal flexibility. The overarching aim is to assess the system's capability to manage uncertainties, in both the short and the long run. It is assumed that the requirements the work puts on the worker should be challenging and rich enough to stimulate and motivate the individual while at the same time not too demanding so that awareness and readiness may be suppressed. By having polyvalence, independence, transparency, autonomy and temporal flexibility the work system can be able to cope with the variances and disturbances locally.

2.2.5 High reliability organisations

HROs handle complexity and risks by corrections and reconfigurations by the humans. Organizational redundancy, mindfulness and the ability to reconfigure spontaneously are three main characteristics of HROs (Dekker et al 2008). Mindful organizations are sensitive to risks and improbable events and are able to detect errors and contain them at an early stage. When the high reliable organization detects that a demanding situation or crisis is developing, it changes rapidly into a more flexible and resilient mode. A key contributor to this is organizational redundancy, which consists of both structural and cultural factors. Overlapping competence, overlapping tasks and the possibility to directly observe each others work are among the structural factors. And willingness to share information, to provide feedback to co-workers and to reconsider decisions that have been made are important cultural aspects of organizational redundancy. Functional decentralization, i.e. task that are decomposed and delegated to smaller work groups which has necessary autonomy, is a main characteristic of many of the organizations studied by HRO researchers. The people working in such HROs share a belief that operational safety is achieved by constantly anticipating events that may cause harm and continuously preparing for future surprises. An organization that shares this belief is curious, open-minded and inviting doubt (Dekker and Woods 2010).

2.2.6 Resilience Engineering

The ability to adapt effectively and safely to pressures, variations and disruptions is what to Resilience Engineering is about (Dekker et al 2008). This new way of thinking takes as a starting point that safety is not about the absence of errors, but rather about the presence of some kind of adaptive capacity. By identifying and enhancing positive capabilities that help an organization to cope with changes and disturbances without suffering from break-downs or accidents, the organization can create safety. Resources and capabilities within the organization need to be weighed up against the sources of risk. Knowing what risks it faces and being able to anticipate risks that may occur are very important, but also a continuous discussion about risk and revision of the risk picture is necessary in order to achieve resilience. This thinking regards safety as something that must be created and recreated. Capacities that contribute to resilience therefore need to be developed and maintained. To do so the right resources must be available, but they must also be used efficiently so that they are not wasted.

It is the people that create safety through their involvement in building and operating the systems. The Resilience Engineering thinking view systems as inherently imperfect that need to be managed by people rather than perfect designed systems that need protection from unreliable human. Past success are not taken as guarantee for future safety and even though the present safety situation may look good resilient organizations keep a discussion of risk alive. New and different perspectives are welcomed and people that want to “pull the brake” because they are concerned about safety being traded for production pressure are encouraged and rewarded to do so. Resilience Engineering takes on a systemic perspective where dynamic interactions across different scales result in far more complex behaviour than the sum of each behaviour in isolation. Small changes from simple parts can create major impact to the whole system. Today's organisations are living and dynamic, not stable and linear. Resilience Engineering tries to account for this by putting emphasis on adjustments of natural varying performance instead of corrections of single errors, and sustainability instead of stability.

By looking at successes and failures as the same type of phenomena stemming from natural variability, Hollnagel (2006) together with other safety scientists like Woods, Leveson, and Dekker introduced a rather new perspective into the field of safety management. Normal functioning is characterized by variability, and by learning to reinforce and strengthen variability that produce successes and dampen unwanted variability a system can be more resilient. Organizations that seem to posses these adaptive abilities can be described by four points (Dekker et al 2008, pp 3):

- Past success is not taken as a guarantee of future safety.
- A discussion of risk is kept alive even when everything looks safe.
- They bring in different and fresh perspectives on things and stay curious and open minded.
- They make investments in safety even when everybody says that they can not, and courage people to say no to trade chronic safety concerns for acute production pressures.

Woods (2006) presents buffering capacity, flexibility, margin and tolerance as the key characteristic of resilience. Disruptions can be absorbed or adapted to by the system so that breakdown is avoided if sufficient buffering capacity is in place. Flexibility is about the ability to restructure and respond to external changes or pressures. If a system is operating too close to its limit, pressures and variability may cross its performance boundary and therefore a certain margin is needed. When pressures exceed the adaptive capacity the system can still avert full degradation by having enough tolerance. The characteristics mentioned in the following are by Hollnagel (2011) summarized as the four cornerstones of resilience engineering.

Natural variability produce potential problems and risks and a system needs to ***address the actual*** situation during operation. The ability to respond to variances that occur is one of the key characteristics of a resilient system. Variances may develop into disturbances and even break downs if no proper response is initiated. Ready-made responses can be made for known risks but some situations require the system to adjust the response to the given situation. What kind of response to implement depends on what type of risks one has to deal with and of the organization's capabilities. Predefined rules for what type of response to implement for given risks and when no response is required can be made. Organizations often have procedures about what assessment and decision process that is required for risks with different significance. While internal procedures and external regulations define much of the to risk response, people in the organisation are the key to effective implementation of a response together with other resources like time, availability of tools and equipment, technological solutions, infrastructure and so on and so forth. After detecting risks the system assess the nature of the risk and available resources in the organization and then come up with solutions. People in the organization in interaction with the technological systems identify and assess solutions to a problem and design the action plan before the response is put into action. Risks may differ with respect to a number of properties, and consideration on how many resources to allocate to the different risk factors and ranking of alternatives also need to be done. Economic and practical considerations are often made by the ALARP principle, meaning that any risk labelled red have to be reduced to at least yellow and in the yellow area risks are reduced as far as reasonable practicable.

For already identified events, responses can be planned in advance so that it can be rapidly initiated. Even if no situations are identical, types of responses or guidelines for responses to different types of events can be developed and be helpful. Depending of the severity of the event the system's response can lead to minor or more large-scale changes. These changes can be temporary, and after the situation has been solved the system can return to normal operation – but making changes based on learning from the experience after the event. In any way it is important that the responses to an event is not to resource-demanding compared to the severity of the situation because resources should always be used most efficiently and available for dealing with other threats or opportunities. A flexible design of the system together with flexible use of available resources responses are therefore important requisites for the ability to respond. In the case of crisis, however, a full transformation of the system may take place. During crisis the system usually goes into a state of readiness for a period and the system may undergo fundamental changes in order to continue functioning.

The system does not know what is going on and what to do without ***addressing the critical.*** It needs the ability to flexibly monitor its operations and its environment. Knowing what to look for is essential to be able to respond to changes that occur in the near future. An important tool in these processes of detection and interpretation is indicators, which are elaborated more in the next section. Detecting that something is happening or has happened is the first step to make a respond. Then the event must be recognized and assessed or rated before the respond can be planned and finally executed. Sometimes the time pressure can be high and the detection and design phase of a response must be very short. This requires a system to have the right technological system in place to monitor its operations and to have the right people to interpret signals and warnings during operation. Both the humans and the technical systems must be able to detect the significant risks that occur and direct their attention to the relevant signals and indications. Since time is a scarce resource and being proactive is preferred to being reactive, detecting things that is about to occur or may occur give the system time to respond before the risks manifest. Monitoring in order to expose risks that may occur in the near future is closely related to the ability of anticipation.

By also ***addressing the potential*** the organization can be proactive and know what one can probably expect in the future. The ability to anticipate changes make the system able to perform safe and efficiently without major interruptions. Finding out what risks to expect from future operations and be ready to initiate adjustments. Knowledge and understanding about the system and its operations/environment. Addressing the potential is more about irregular than regular which is a monitoring. A risk assessment is an important for identifying potential risks. But it is hard to make complete descriptions of systems today (Hollnagel 2010) – and most established methods for risk assessment are developed for simpler and tractable systems – it is necessary with other ways to address potential risks. Deep understanding of the system among the employees is important when imaging possible risks and future system states. And if the knowledge about the system identified is shared and potential risks are communicated within the organization, the anticipation capability may improve. To list some of the most central anticipation properties, risk awareness, imagination of future situations, regular revisions, knowledge about the system and its environment, and sharing of information, are among them.

A lot of the anticipation also take place by the individual in a way that is informal way and not very visible to others.

And finally there is the ability to learn from experience. During operation the organization should not only focus on current situation and operate in accordance with established practice but also ***address the factual***. By knowing what has really happened and learn the right/relevant lessons from past experience the system can accommodate adjustments and improvements. Looking back may provide a very useful source of information and put the present situation in a bigger context. Historical data has the advantage of providing information specific to the context the organization has operated within and may be very valuable when preparing for future activities. Deeper analyses can be made since it is possible to have access a greater data material and one can easier process and combine data. When looking for trends and combining data to a bigger picture it is important to be aware of the specificity and validity of information. Too old data may not always represent current situation and too big data material may not always be specific enough for the objects that one is trying to learn about. Addressing the factual is an important premise for the other three abilities, knowing what to expect, what to look for and what to do.

As the practical discipline resilience engineering is, finding ways to enhance the ability to succeed under different conditions and situations is a main occupation/goal/task in engineering resilience. Investigating what goes right and why rather than what goes wrong is one important principle for adjustment of performance. To find out how the necessary adaptation and change of a system's functioning takes place is at the core of resilience engineering. Such adjustments can be reactive, concurrent and proactive, meaning they take place after, during or before a situation occurs. These three types of actions or responds are connected to the four cornerstones, where interventions and improvements happen both before during and after – all with the objective of achieving resilience.

2.2.7 Safety performance indicators

Indicators are often used as to measure the current state of a system or a process, or its future development. A safety indicator indicates how safe a system is or how well the safety management system is doing. It is common to distinguish between lagging and leading indicators.

Indicators that give information about past performance are often called lagging, while indicators that provide information about future performance are called leading. The distinction is not clear cut as it depends on what underlying model one uses. Leading indicators provide according to EPRI (2000) information about developing or changing conditions and factors that tend to influence future human performance. This is pretty much in line with leading economic indicators that intend to predict future economic trends. Many different predictors, which each of them may have large data material, are used by economists to forecast how the economy is developing – either the direction alone or also quantifying the amplitude of expansions or contractions in the economy (Lahiri and Moore 1991).

Incident statistics can be viewed as lagging indicators as they lag behind the occurrence of the events, but may also give information about the performance of the safety management system and/or incident precursors and can therefore according to Hopkins (2009) be viewed as leading indicators. If one for instance uses a bow-tie model as the underlying safety model, indicators that measures pre-identified accident precursors are lead indicators while indicators that measure incidents and accidents are lagging. Learning from experience may be effective for improving future safety performance. Measures of safety activities are in general defined as leading indicators since they measure process or inputs essential to achieve safety or reach a desired outcome (UK HSE in Hopkins 2009), and measures of failures are lagging indicators since they reflects when safety has not been achieved or a desired outcome has failed. Kjellén (2009) defines leading safety performance indicators as indicators that change before the actual risk level has changed.

Three types of safety indicators are presented in a safety indicator report by the Swedish Radiation Safety Authority (SSM 2010). The three categories are feedback, monitor and drive indicator. A feedback indicator measures the outcomes of a sociotechnical system, i.e. the result or consequence of a process or activity. Examples are number of incidents, ratio of components failing under inspection, amount of procedure violations and availability of safety instruments. Monitor indicators measure the functioning of the system and reflect the capacity or potential of the system to perform safely. Examples are measures of current situation like quality of procedures and policies, compliance with safety rules, personnel's skills, and present work load of workers. Drive indicators measure prioritized safety management activities, i.e. they reflect the control measures that manage the sociotechnical system. Processes that influence the activities are typically drive indicators. Examples include hazard identification processes, procedure for update of documentation, maintenance programs and practices for communication of safety issues.

To assess resilience, at least quantitatively, may cause difficulties as the concepts and are quite new. More practical examples of resilience and development methods for measuring resilience is according to Hollnagel (2011) important for developing the field/discipline of resilience engineering further. As RE challenges the traditional ways of thinking about safety, indicators of resilience and methods for assessing resilience needs to be developed. Hollnagel (2011) suggests a number of indicators for each of the four cornerstones. In general an indicator should be concise; well defined, reliable and valid; objective, i.e. independent of who the user or interpreter is; sensitive to change, i.e. it must be possible to see the indicator changing within a reasonable time span; lagging, current or leading; practicable, must be able to derive concrete actions from it; easy to use. The list of indicators Hollnagel presents are grouped by the capabilities of responding, monitoring, anticipating and learning.

In most modern industries a business' environment changes continuously and creates problems of ***monitoring***. Being able to perceive and interpret those changes is a key ability of a resilient system. At the same time, its own performance must be monitored. Indicators are then what is needed, be it lagging, current or leading indicators. Leading indicators are preferred since they indicate future changes, while lagging indicators in general measure past performance. But leading indicators require a model of safety and how the system functions to define cause-effect relationships and leading indicators may represent correlations rather than causation relationships. Therefore current and lagging indicators are often necessary to monitor system performance. A problem of lagging indicators though is that larger statistical material, which increases statistical reliability and validity, usually implies either longer measure interval or larger sample. The first case creates a problem of including old performance that does not reflect current state, and the second creates a problem of including other systems or industries in the sample that are not necessarily representative for the system itself. Finally, traditional indicators based on counting errors and accidents give little valuable information about future, especially if the incident rates have already come down significantly. However, as Hopkins writes, process safety parameters like leaks and pressure that often are defined as lagging can be useful; both because they indicate the state of the safety management system and because they are countable and rather easy to measure.

	Responding	Monitoring	Anticipation	Learning
	Event list; event list for prepared responses adequate and complete?	Indicator list; how have the indicators been defined?	Expertise; “in-house” and available?	Selection criteria; principles of what to investigate?
	Background; on which basis is the list of events made?	Relevance; is the list be up-to date and revised, and on which basis it is revised?	Frequency; how often are threats/opportunities assessed?	Learning basis; learning from both failures and successes?
	Relevance; is the list be up-to date and revised, and on which basis it is revised?	Indicator type; single or aggregated measurements? how is the mix of lagging, current and leading?	Communication; how well are expectations about future communicated?	Data collection; formalization of collection, analysis and learning?
	Threshold; when are responses activated, and what does the decision depend on?	Validity; how is the validity indicators established? are they based on a model?	Assumption about future; Assumptions and model of future?	Classification; categorization of data?
	Response list; how are responses selected, and what are they based on?	Delay; what is the duration of the lag?	Time horizon; what are the time horizons?	Frequency; continuous or discrete process?
	Speed; how fast can a response be initiated, and how soon is it operating effectively?	Measurement type; are the measurements quantitative or qualitative? Reliable?	Acceptability of risks; when are risks unacceptable, and is this distinction clearly expressed?	Resources; adequate resources?
	Duration; how long can the response last? how fast can resources be restored?	Measurement frequency; how often are measurements made?	Ethology; what is the assumed nature of future events?	Delay; how fast is reporting, analysis and learning done
	Resources; adequate resources available? how much is assigned to prepared responses?	Analysis/interpretation; what analysis and interpretation are needed? how are results communicated and used?	Culture; risk awareness embedded in the culture?	Learning target; which level learning takes place, and who is responsible
	Stop rule; clear rule for stopping response and returning to normal state?	Stability; are the effects permanent or temporary?		Implementation; how are lessons learned implemented
	Verification; how is the readiness to respond maintained and verified?	Organizational support; are there appropriate resources for inspection and follow-up?		Verification/maintenance ; verification of the learning process and maintenance of what has been learned

Table 1. Indicators of resilience; list of probing questions for the four cornerstones of Resilience Engineeringf. List adapted from Hollnagel (2011)

3 Scientific methodology

The scientific methodology used to approach and answer the research questions is outlined in this chapter. A description of the research process is provided so that the reader can evaluate the trustworthiness of this study. Transparency may also make it possible to test the validity and reliability of the study, for instance through replication. The chapter is rounded off by discussing the research process in the light of criteria for social research.

3.1 Description of the research process

The whole research process started with identification of an interesting problem area. Based on the project assignment in the preceding semester investigating the relations between integrated operations and resilience engineering – especially the use of collaboration technology in a dynamic and complex environment – seemed like an interesting area of study. From literature in the project work as well as from earlier lectures resilience in practice seemed relevant to study.

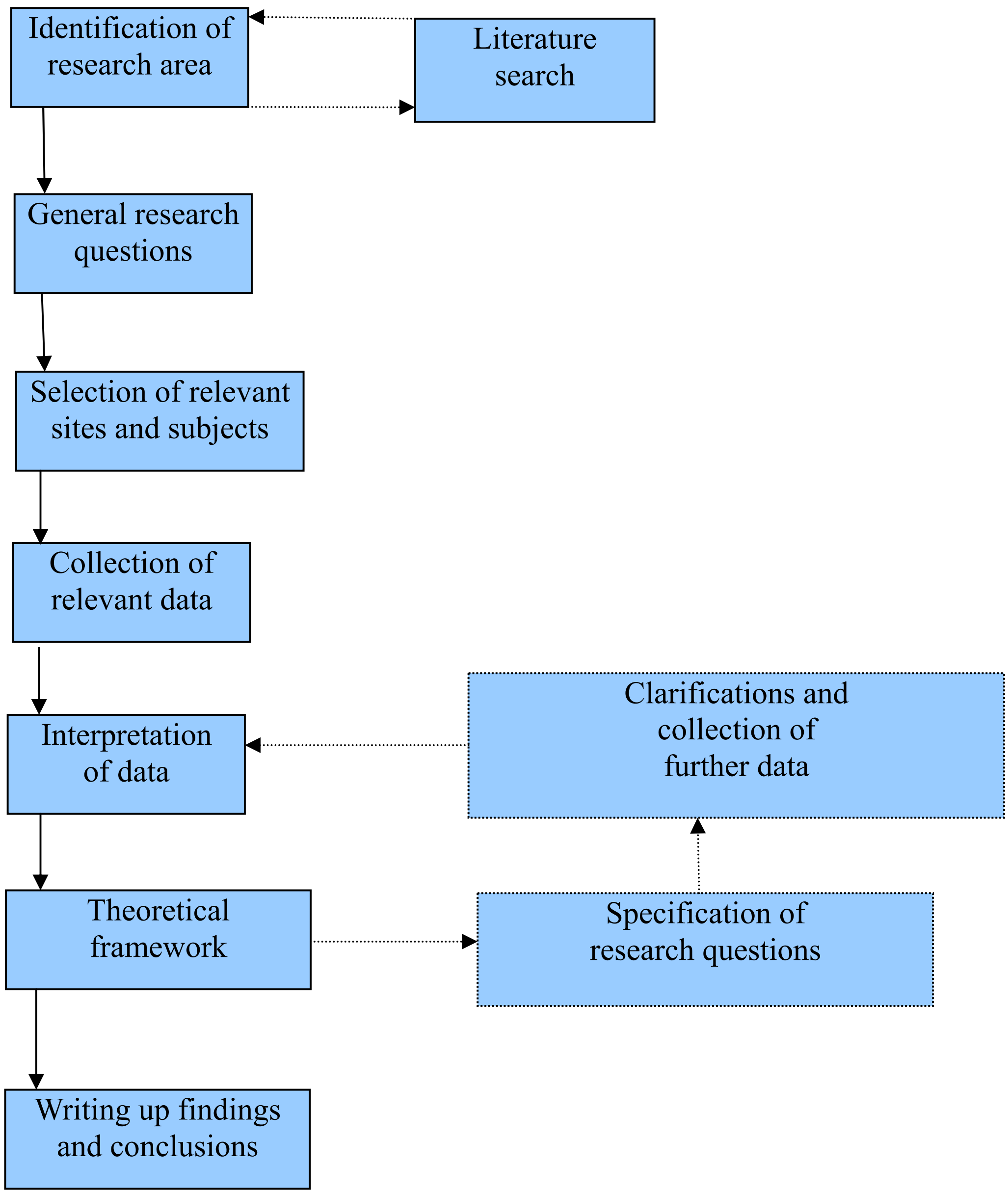

Figure 1. The research process of this thesis.

The case was selected among the major oil companies that operate on the Norwegian continental shelf. Together with the thesis advisor, a couple of companies that had introduced Integrated Operations were identified. Companies were then contacted and one of the companies responded positively whether to be used as a case in this master thesis. The selected case company was regarded as very relevant for the area of interest, and provided both access to personnel for interviews and the possibility to do observations in the onshore support center. As with all case studies (Bryman 2008) the case is unique and the findings in one study may not apply for another case. However the oil companies use much of the same technical and organizational solutions for a number of reasons. For example, they need to apply to the same regulations, their contractors also provide the same services to other companies and employees work for different companies during their careers.

This thesis uses empirical data collected from the case organisation during the research process as its main data source. Most of the interviews and observations were conducted in the onshore drilling support center, which was the focus area for this thesis. The data was collected by qualitative, semi structured interviews and by observation of work practice. The observations were done by sitting in the open workspace offices and watching the workers during daily work and attending to meetings, while the interviews were conducted face-to-face at the case company and the service companies' offices. Some documentation, for instance an organizational chart and HSE procedures, were also provided as support to the other data sources.

As the observations were not typically active participant observations but rather passive observations, the observation was more a structured than an ethnographic technique. The observer took on a researcher role rather than a participant role, even though some questions were asked to the employees who then described aspects of their work to the researcher and sometimes also demonstrated tools they use in their work. Demonstrations of for instance well design, well paths or reservoir models in 3D were also done in some of the interviews. An observation guide was developed based on the research questions and can be found in the appendix. Duration of the six observations lasted 10 minutes in average, ranging from 5 to 15 minutes. Observation as method for data collection has advantages over survey methods that it studies actual behaviour and is not influenced by the interviewer in the way interviews are (Bryman 2008). Of special interest was team work and communication across geographical and organizational borders, and much time was spent in the onshore support center together with the realtime data engineers and the drilling optimization engineers. Three meetings were also observed; morning meeting, simultaneous operations meeting and onshore support evaluation meeting. In all meetings, the researcher was present in the room without asking questions or taking part in the discussions. During observation of individual's performing their work, the researcher got the possibility to ask questions and get clarifications and deeper descriptions on the work. The underlying aim for the data collection was to get rich descriptions directly from subject matters experts and get direct observations of a work system in a well and drilling environment.

Fifteen qualitative face to face interviews of 30 minutes in average, ranging from 15 to 60 minutes, were conducted. The interviewees were employees possessing different roles within drilling and well operations in the case company and its contractors, with a focus on the onshore organization. One of the interviews was with an offshore employee, but some of the other interviewees had worked offshore earlier in their career. Twelve of the interviews were directly focused on answering the research questions, while three aimed at getting an understanding of the organization's systems and processes. These three interviews were done early in the research process in order to get a better understanding of the organization and helped designing the interview guide for the other interviews. A review of relevant literature within resilience, safety, integrated operations and sociotechnical systems laid the foundation for the interview questions which can be found in the appendix. The interviews were semi structured, which means they were performed by asking the interviewees questions from the interview guide and letting them answer the questions without strict following the interview guide. During the interview the informants were asked for clarifications when needed, otherwise the interviewer focused on recording the answers and not interrupting the informants. With semi structured interviews more questions may be answered in the same answer and the order of the questions may therefore be different from the interview guide. Before the interviews time was invested in reading about drilling and well operations in order to get a better grasp of how such operations are and to be familiar with some of the jargon and technical terms.

The data from the interviews were recorded in written form during the interviews, and data from the observations were recorded in the same way. After each interview the recorded data material was transcribed electronically on a computer. Due to anonymity reasons the data was only available to the student and the thesis advisor, and data represented in the report are made anonymous.

After all transcription was done the data was analyzed. The results were compared with literature, and as new things came up more literature was reviewed. Bryman describes this as a process common in social/qualitative research. The interview results were presented with as little interpretation and processing as possible due to correctness reasons, i.e. reflect the correct meaning of the responses. The answers were grouped in four main categories related to the research questions with the purpose of systematizing the results, and the factors extracted from the categories were grouped according to their characteristics in order to provide a more visual and structural representation to the reader. A description of the system based on observations, interviews and documents in the beginning of the chapter was intended to provide the reader with insights in the processes in drilling and well operations as well as addressing some of the research questions. Finally the collected data was analyzed with respect to factors identified in the literature review. Also here further examination of literature was done when analyzing the data.

The findings were summarized and discussed in the light of relevant theory. Triangulation was performed by comparing the findings with what literature says and what other research projects found. At the very last stage of this thesis work the limitations of this study were addressed and reflections around implications for industry and further research were made.

3.2 Criteria of qualitative research

Criteria for evaluating the quality of the research are discussed in this section. The research performed in this study is assessed against common criteria for social research.

Reliability and validity

Systematic and consistent collection and processing of data described in the previous section was done for the promotion of validity and reliability. Review by others, mainly the thesis advisor and the advisor at the case company's, and transparent process is meant to ensure reliability. Typically for qualitative research is the strive towards a “true” representation of the real life situation (Bryman 2008). Therefore getting empirical data from people working with the subject on a daily basis, big oil company, extensive use of collaboration technology was one of the main goals for this thesis.

Internal reliability is about the consistency between the data collections throughout the process and inter-observer consistency is about how consistent the observer is over time. Only one interviewer performed the interviews and they were conducted over a period of one week. But still changes in the way data were recorded and transcribed may have taken place and the interview data were reviewed with the purpose of detection and correcting that.

When a measure is measuring what it is intended to measure, it has measurement validity. Reactive effects taking place when the people being observed change their behaviour when they know they are being observed may influence validity. If there is variability in the way observers record and administrate the observation schedule the results may be unreliable and therefore not valid. Ensuring that the measure actually addresses the focus of attention is another criterion of validity, and whether the collected data actually were relevant for the research questions was discussed with the thesis supervisor throughout the research process.

Trustworthiness

Reliable and valid data are regarded as important criteria that secure trustworthy results (Bryman 2008). By using more than one measurement method and comparing the results may advance convergent validity, which implies that a set of data may be consistent with data found by other means. Triangulation encompasses use of multiple methods, sources of data and theoretical perspectives. In this thesis a number of different well acknowledged theories were used and as described different methods and sources for data collection were used. Collection and interpretation of data may therefore be checked out against each other, and conclusions may be more trustworthy.

Transparency and replicability

The description of the research process in this chapter aims at ensuring sufficient transparency so that the study can be replicated by other researchers. The validity of the results from this specific context can be tested by using a similar case within the same industry, or one might use a case from another industry to test whether the findings are transferable and apply in that type of environment as well.

3.3 Limitations and alternatives to the chosen research design

The aim of the interviews was to find out what people working daily/familiar with the matter think. What are the risks, how are risk handled, what is the role of collaboration technologies and how can resilience be engineered. One alternative might be to base more of the data collection by observations (and in particular participant observation). Another alternative might be to perform a survey on a bigger sample. An advantage of doing interviews is that one ensures that the research questions are addressed. In combination with observations it would be possible to study actual behaviour not only the informants' own views and descriptions. A survey can reach a greater number of respondents and thereby give the opportunity to do more quantitative analyses. Cause effect relationships might then be established with greater statistical reliability compared to qualitative methods. However the literature review found no well established method or framework for quantitatively assessing resilience. Good quantifiable indicators and measures of resilience seemed to be difficult to find and therefore the alternative of having a more quantitative approach was rejected. Since the main goal of this thesis was to examine how an organization operates in a specific context and how resilience may be achieved, interviews and observations were selected as methods for data collection.

4 Results

This chapter presents the results from the data collection, starting with a description of the case organization (the study object) and its operations followed by a presentation of the interview results and rounding off by analysis of the collected data. As described in the previous chapter data was collected from three main sources; observations of work practice, interviews of relevant employees and review of documentation. The interview results section presents data collected in interviews only, while in the other sections all sources are used.

4.1 The drilling process

A short description of the drilling process and its associated processes are presented here. This section seeks to explain how the case company employs collaboration technologies and perform their drilling and well operations and is based on observations of work and interviews of employees.

The different stages and activities in a drilling project are shown in figure 2 and discussed in this section. Each of the main functions involved in drilling are presented in order to give the reader an overview of the case. Familiarization with the case and attaining knowledge about offshore drilling were a major element of the study as well in order to get understanding about the system and be better prepared to carrying out this study.

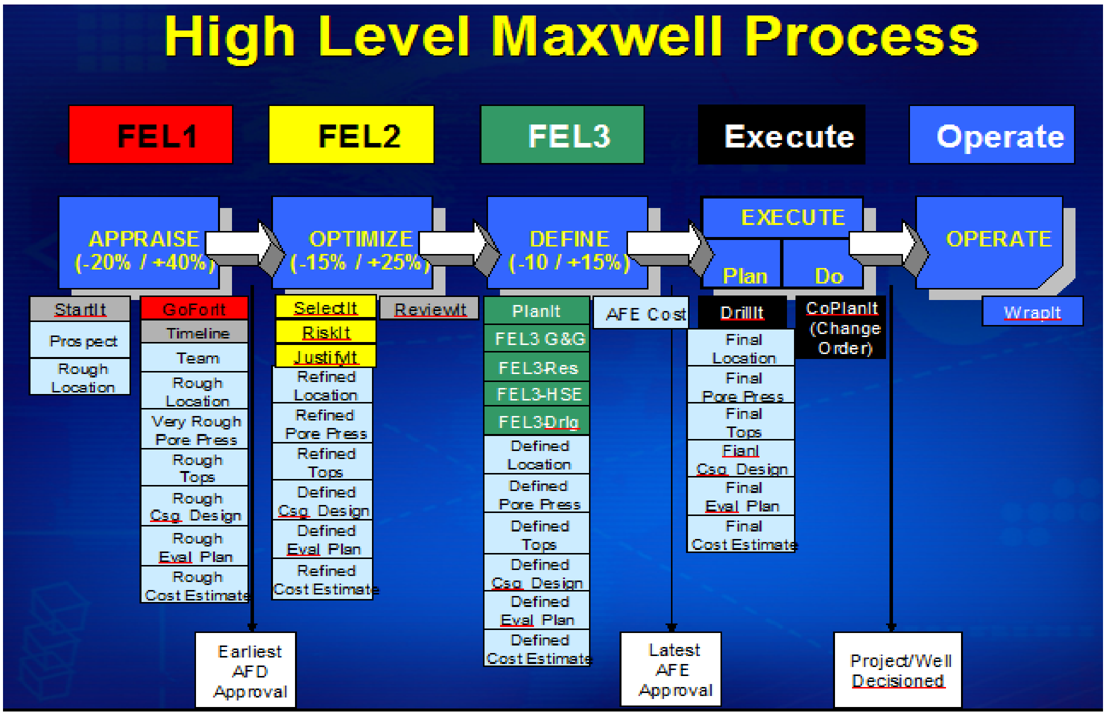

Figure 2. The processes of drilling a well.

4.1.1 Main actors involved in the process

At the very early phases of oil exploration the geologists survey the area by measuring gravitation and the earth's magnetic field to get an initial (simpler?) map of possible deposits of oil. Fields that are promising based on information from similar areas and the early surveys are explored more deeply through the use of seismic surveys. This type of survey makes it possible for the ***geologists*** to map the formations by interpreting sound signals that are sent from a source on a ship and then reflected from different layers in the reservoir depending on the wave characteristics and type of formation. Compared to earlier surveys, this gives much more detailed and reliable information about the geological conditions below the surface.

Before even planning a well, geological surveys are made based on seismic data. Geologists use the data available to create a geological model of the reservoir. Seismic data and other data related to geological conditions are filtered, interpreted and put together in a geological model. ***Reservoir engineers*** – who are more concerned with the existing reservoir itself and the operations that have taken place there – create the model of the reservoir together with the geologists. This model consists of geological structures of the field including possible oil and gas reservoirs. The subsurface group identifies zones in the reservoir were hydrocarbon finds are probable based on the model, and the most promising zones and possible ways to reach those zones are then analyzed. Factors like cost, safety, practicality are considered when identifying target zones and possible well paths.

Early planning phase proceeds the early concept phases and consists of more detailed planning of the drilling phases. Here the reservoir management from the subsurface group meets the drilling management from the well operations group. A meeting of planning and reviewing the costs takes place in every drilling projects. The team goes through every sections of the well in both drilling, slot recovery and completion. Risks and possible problems are discussed here and dealt with more in detail in planning meetings and risk assessments later in the project.

A well planner receives target zone and a suggested well path from the subsurface group. Software showing the geological and reservoir model is used to evaluate the well path and plan it in detail. Based on this information and governing requirements from the operating company while at the same time adhering to requirements from the authorities, the well planner plans a well path. In mature oil field there might be several other wells – “active” or “dead” – that must be taken into account when making the new well plan. Collisions with other wells may cause serious damage to life, environment and property and there is a key focus to avoid such incidents.

The planned well path is decided upon after a dynamic process of design, review adjustment and approval where different actors are involved. Drilling engineers, geologists and reservoir engineers review the plan and give feedback related to the geological conditions. Most of these activities take place in the proximity meeting, where the well planner presents the planned well and parts of the path where extra care needs to be taken. Especially in mature fields there may be several areas where the planned well path is close to existing or old wells. As there is uncertainty associated with position of the planned well, extra attention is needed. The exact position of the old wells may also be uncertain, and this is mathematically modeled in order to produce uncertainty ellipses around each well. Alternative actions in case of drilling too close to neighboring wells or other well bore positional problems are normally agreed in the proximity meetings.

After planning of the well path, the well operations are planned more in detail. First the different phases of the well operations are addressed with respect to among other things resources, cost and risks. The outcome from these planning meetings is used as input in the coming risk assessment and planning activities.
Some of the functions in drilling that were earlier located on the platform have been moved to

onshore. Workers are now able to work remotely through use of realtime data, collaboration technology and new work processes. This also enables other workers to be more integrated than before, supporting offshore with technical and expert support. The case company has introduced several elements of what is called *Integrated Operations*.

The rig crew is operating the wellbore, handling the drilling equipment and doing maintenance. The team is lead by the drilling supervisor, often referred to as the company man, which has an office at the rig and is responsible for contact with onshore organization as well as with organizing the well and drilling activities on the rig. The tool pusher leads the drilling contractor team that carries out the drilling program. Maintenance personnel, driller, assistant driller and rig floor workers – often called roughnecks – make up the drilling rig crew.

The driller interprets signals from the well, with a primary function of following the drilling plan, and ensuring well bore stability, and is responsible for taking the correct actions in case of an emergency. There are many different sensor data from surface used during drilling and well operations: Hook load, surface torque, pump pressure, flow rate out, fluid temperature in and out, mud density out, tank volumes. Sensor data from downhole used during drilling and well operations: vibration measurements, downhole pressures and temperatures, down-hole (in some cases) WOB (weight on bit) and torque, directional measurements, formation evaluations measurements (gamma ray, resistivity, neutron density, etc). Much of the data not only from the surface sensors, but also down-hole is transmitted to the onshore in real time. To help the driller interpret the signals, teams of engineers monitor and interpret data and provide different kind of support to the driller. In general the driller is very much focused on the surface data, and some down-hole information.

Drilling support functions are located in the operator's locations onshore and at other contractor's offices. Support functions onshore have different roles. One group is monitoring and following the offshore operations on a continuous basis. This is done by monitoring real time data displayed on monitors and live video streaming from the drill floor. Planning of operations in the near term and reporting of operations to the operating company's drilling representative are main tasks for this realtime data engineers. Some proactive planning of the operations are done by this team, but they are mostly concerned with monitoring and interpretation of realtime data flowing continuously from the rig. The data is assessed and the calculations form a basis for recommendations to optimize the drilling process. The most critical parameters like gas, pit volume and position of drilling tools(??) are main focus for this team, while other parameters are analyzed more in detail by other teams. Contact with offshore crew is done through continuous radio communication, telephone calls and e-mail messages. Which communication tools they use depend on the situation; for instance recommendations and reports are delivered by e-mail, and smaller messages and requests are done by radio communication or phone.

The drilling contractor also has a support function in an onshore center that are collaborating with its rig crew and the operating company's onshore center. Their main task is to perform drilling according to the section plan, i.e. implement the planned drilling activities and ensure compliance. Follow up of rules and regulations take up much of this team's time. By taking care of much of the administrative tasks they give the rig crew more time to focus on the operational tasks. Many of these administrative tasks need to be coordinated with the operating company. The contractor's visit the operating company's offices at least twice a week, and they attend to regular meetings like RiskIT and section plan meetings. The communication with the rig is done in the same way as for the operator's onshore-offshore and using the same type of IT systems and software.

Another group in the onshore support center is working on **optimizing** the drilling operations. This group is monitoring and analyzing the drilling process and is focusing more on parameters and are analyzing them deeply. Both the software and the humanware, the engineers working in the optimization team, is outsourced to a contractor. But all in the drilling optimization group have their workplace in the operating company's offices; they sit in open landscaped offices in the onshore support center, by the side of the realtime data engineers. Since monitoring realtime sensor data is not their main tasks, but rather more specific analysis the optimization team do not follow the ongoing operations on the big screens like the realtime data engineers. Instead they do different types of in-depth analyses on their computers like pre-job assessment, learning from past experience and helping with diagnostics and analysis of present situation in the well. A few of the well optimization people are also following the drilling operations real time and analyzing the data from the rig, but their main focus is on specific parameters. Special analysis is done on the parameters and the analysis result and recommendation is communicated to the drilling crew on rig, usually by mail.

Parameters the drilling optimization use in their analysis are for example temperature, gas volume, torque and drag forces, pipe pressure, pore pressure, fluid viscosity, flow rate and vibrations. A visual representation of drilling parameters like the optimization engineers use in their work is illustrated in figure 3. The figure shows predicted drag forces during trip out and trip in, i.e. the operation of removing the drillstring from the wellbore and running it back in the hole, and actual values from realtime sensor data at different depths. These predictions are used for modeling revolutions per minute (RPM). Too slow RPM, in other words a low spindle speed, may cause too high pressure on the drilling tool. From the chart one can also see the correlation between the estimated and actual values. The chart to the right shows the well path's inclination.

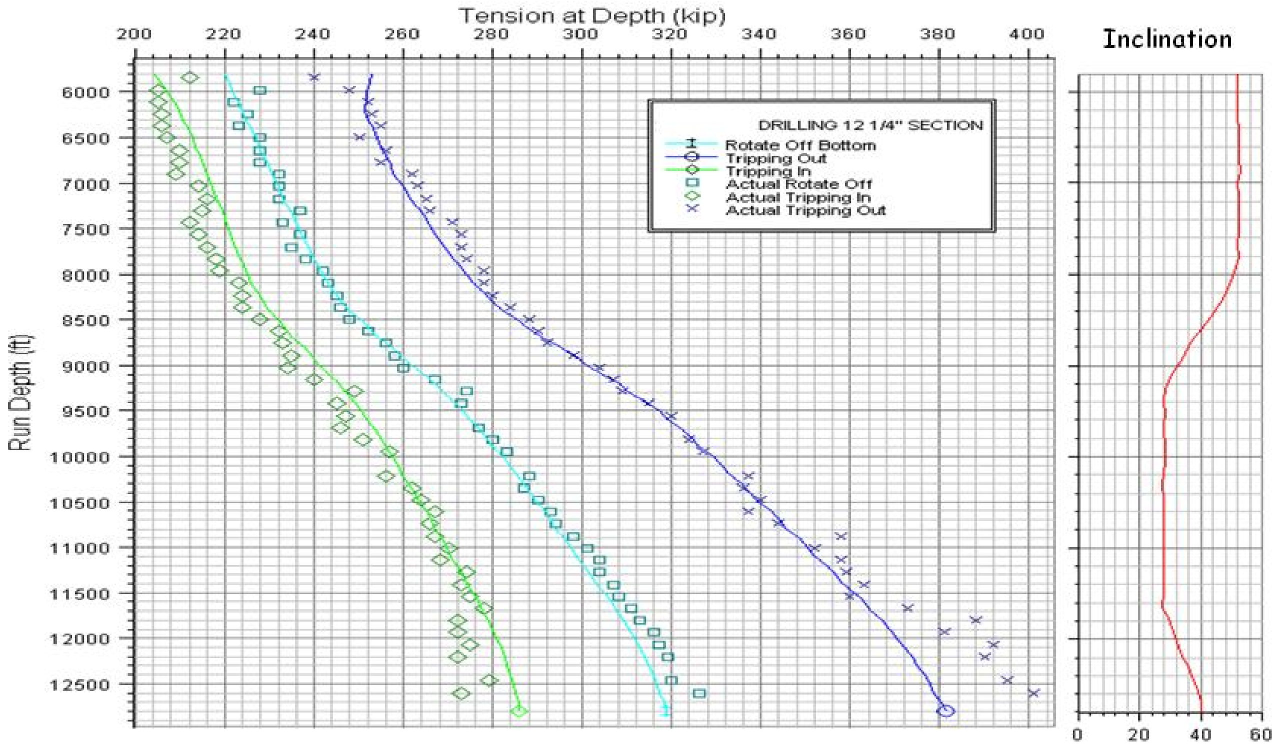

Figure 3. Drag chart.

Historical data and evaluations that are made available in so-called post run analyses are used as sources for data. Comparing data from the ongoing operation with post run analysis and looking for trends and similarities are typical done when analyzing a given situation. In addition recommendations and learning from past experience are used as guide for future operations. This is valuable when planning a new well and when designing the changes in the plan during operation. Recommendations and procedures for managing some of the known problems are available. Such guidelines have been developed after special analysis of how the event occurred and how it was handled. This was reported to be useful for the drilling team since they provide specific advices and insights about that type of event. But even if a procedure is based on neighboring wells where similar equipment was used, the informants underline the fact that every situation is unique. Human judgments before taking action and monitoring during execution always need to be done.

It is interesting that it can be seen that most interventions from onshore are concerned with drilling itself (extension of the well bore), followed by planning. The Data engineers were also mostly involved in drilling, but other activities such as trip in, trip out, casing running, cementing, etc were also a focus area.

An ***offshore coordination meeting*** with all relevant actors is conducted on the rig every morning before the offshore-onshore morning meeting. Coordination of the day's operations, important areas to focus on and which information to communicate to onshore organization are the main content of this meeting. By holding this meeting, the involved actors get the information they need for the operations, and in addition the need for them participating in the morning meetings is reduced.

At 8 am every day the ***morning meeting*** with the offshore crew is held in the onshore office. A team from the onshore organization consisting of the onshore drilling supervisor, the drilling superintend, drilling engineers, geologists and reservoir engineers from the subsurface group, well planners and people from the onshore drilling support center is gathered in a collaboration room and communicates with the rig via video conference. Personnel taking part from the offshore organization is the drilling supervisor – often called company man since he is usually the one representing the operating company in the drilling operations at the rig – and a driller and the tool pusher. When the drilling is outsourced, the contractor's onshore drilling support center also connects to the video conference and takes part in the meeting. The contractors support people was little active in the meeting during the observations, and were mostly observing. They were located/showed in a smaller box in the uppermost right corner on the onshore screen view while the rig room covered rest of the screen. The tool pusher and the driller were mostly paying attention and it was the offshore drilling supervisor that was speaking most of the time when he was informing the onshore team. Update on recent and present activities at the rig and information about the plan for the coming day(s) was provided the onshore people. During the meeting there were some questions and comments to what the company man told from people in the collaboration room. Most of this input came from the meeting lead since he was the one going through the topics to be covered and was responsible for conducting the meeting. Typically things that were covered during the meeting were clarifications on anomalies from the drilling operations and deviations from plan, expression of needs for support or resources, discussion about challenges in the present and coming activities. First the company man informed on safety issues, in this case flow rate and hook load. Here for example, the drilling superintend and the drilling engineer commented on the flow rate. Then they were going through operations where topics like corrected mud loss, deciding whether to log or not, plans for how to conduct cement testing, information on flow test and pressure tests that had been performed, and so on and so forth. Logistics was covered in a separate section, were for instance transportation was informed upon, and finally personnel were changes in crew and new shift was communicated to the onshore team.

The ***drilling engineer*** performs tasks related to planning the drilling process other than planning the well path itself. Using the characteristics of the planned well as a starting point the drilling engineer decides on for example what casing and type of mud to use. Regulations, internal steering documentation and practical things are taken into account when selecting for instance casing size and depths. Tools and equipment required to drill the given well are then selected. Availability and practicality/cost of equipment and other resources needs to be taken into account in this planning phase. Finally a schedule is made and put together with the other planned items in the well plan. Throughout this process the drilling engineer is in contact with several other people within the organization and from external contractors. For instance the proximity meeting and the Risk IT process involves actors from all parties and the drilling engineer has a lot of coordination and planning tasks. They also follow the operations but more on the section plan level. Daily drilling reports and the morning meeting are main sources for follow up of the daily operations.

4.1.2 Risk management activities

Before the start up of a drilling operation, or other operations like slot recovery, well intervention, completion and P&A (procurement and abandonment), possible risks that may occur during the future operations are assessed in a formal risk assessment process in accordance with the company's steering documentation and the relevant laws and regulations. After the section plan is approved the risks are analyzed more in detail in this risk assessment process, which is centered around a separate meeting with representatives from both drilling and reservoir management and the involved contractors. By discussing and going through known possible risks and identifying new risks the team identifies risks for this project in a document called **RiskIT**. Risks factors are ranging from risks associated with equipment and materials, specific designs or technical solutions to weather and geological conditions or planning and operational factors. An identified risk stemming from for instance problems with some kind of tools and equipment may be reduced by implementing specific procedures for human intervention as a safety measure, or for instance problems due to geological factors may be dealt with by redesign or using other equipment. The risks that have been identified and assessed are presented in a risk matrix. Reduction of unacceptable risks is done by applying the ALARP principle, i.e. the risk’s consequences and probabilities are reduced by defining mitigating safety measures and/or reducing exposure. Risks in red area are unacceptable and must be reduced, green are generally tolerable and those in yellow are reduced as low as reasonable practicable. A drilling engineer from the operating company leads the risk identification meeting, but the drilling superintend is always deeply involved in this risk assessment process which is reviewed and approved by the drilling operations director.

A ***section plan*** is a document for the actors involved in drilling that describes the activities and resources in the project of drilling a well. This document is governing the work for the drilling team, from platform management, driller and tool pusher on rig to drilling supervisor, drilling engineer, well planners and drilling support engineers onshore. Governing documentation and check lists is identified and listed in a table. Processes and actions that should be implemented in order to achieve the project’s goal is then listed and described in the table. Main risks connected to the activities are identified and linked to the RiskIT document.

A number of formal safety activities take place before the individual jobs. Section plan is gone through offshore before starting the operations. RiskIT is also part of the preparations for the jobs, together with the job safety analysis. The ***job safety analysis*** (SJA) is a structured preparation of the job with identification of risks, assessment and reduction of the risk, design of safety measures performed before the job. Checklists are used for identification of risks and procedures. A main purpose of the SJA is knowledge and awareness about the job and its associated risks. The SJA focuses on the individual job and its related safety issues, while more systemic risks and factors concerning simultaneous operations are dealt with in other HSE activities. At the level under the

SJA lays the ***work permit system*** and the pre job meeting. Before any work is started, it must be approved through the work permit system. What to be done, who to perform the work, which facilities and equipment to use and when the work will be done are subjects being examined in the work permit. The purpose is to ensure that the work is conducted safely and without conflict with other jobs on the site. Every workers involved in a job go through the tasks and related safety issues with the supervisor in the ***pre job conversation***. The team is informed about risks and procedures identified in the SJA. Parallel to the activities mentioned, there are two other the ***personal safety involvement*** (PSI) where safety issues are addressed and ***risk area map*** where the different risk factors are mapped geographically on a rig map. Another initiative the company undertakes is a risk observation, a systematic observation technique where risks related to the jobs and how to work safely are examined. Increasing risk awareness and safety training is the risk observation's purpose, and the desired outcome is employees being able to detect risks and give warnings.

Observations, both positive and negative, are documented by the workers after each working day and stored in an archive. These observations may be events that had potential for causing risks, actions that contributed or suppressing safety or conditions on the rig that affected safety.

The operating company conducts a self assessment of the operational integrity in their drilling operations. Assessment of the level of integrity of different categories like management, health and training are done and given a score on a 10 level scale. Before the start-up of every drilling program, a score of 7 must be reached before drilling or well operations can begin.

After action review is conducted after a drilling project is finished. First a team of onshore and offshore drilling personnel and management goes through the MOPS – a summary of the drilling activities with comments – and evaluates time usage, discusses problems and successes during the drilling, and finally summarizes lessons learned and actions to be implemented in future projects. The lessons learned from the last week's operations are used as input in the next well's RiskIT/risk assessment.

Activities that are planned to be performed simultaneously are assessed according to the operating company's procedure in a special risk assessment process. The installation's HSE supervisor leads a meeting called simultaneous operations meeting where – depending on the activities – representatives from the organization's units involved are presented. For instance representatives from project management, modifications, technical safety, offshore operations, onshore operations, construction, drilling and well intervention from the operating company and representatives from the contractors involved on the operations concerned take part in the meeting. Examples of activities can be modifications on the installation, different types of maintenance work, well service jobs and testing of equipment. The assessment is performed as a hazard identification process where possible risks, problems and conflicts are identified and discussed for typically 8-10 different categories of activities to be performed over a period of typically two months ahead. Area of location, communication issues, equipment, maintenance, lifting operations, logistics, safety and not doable/possible simultaneous activities are examples of categories. The risks and potential problems are expressed as questions, which are answered through an assessment by the team during the meeting. Clarifications about the activities and their influence on each other are discussed before mitigation measures for handling the risks are identified. All the information is documented and presented in a table. The outcome of the assessment is communicated to units and personnel in the organization which work is affected by the simultaneous activities.

To better grasp what kind of problems may occur happen during drilling and well operations, some typical incidents are presented here. Cayeux (2007) divides incidents in drilling into five main categories in purpose of well simulations. Tool failure, well control problems (mud losses, lost circulation, kick, blow-out, formation collapse), stuck pipes, collisions and position of well in the pay zone. Tool and equipment downhole or at surface can fail in different ways during the drilling process and may cause incidents. Mud loss, formation influx, lost circulation, blow-out and formation collapse are characterized as well control problems. When a pipe is impossible to move in one or several directions, it is called a stuck pipe. Mature fields consist of a big number of wells which can lie close to the planned well path. Old shut in wells and production wells represent risk for collision. Uncertainty in the wellbore position combined with uncertainty in the geological model of the reservoir makes it difficult to hit target zone.

Another challenge is the changes in the reservoir due to the drilling and oil production activities may complicate the drilling of new wells. Gas and water is injected respectively above and below the pocket of oil in order to pressurize and maintain the volume so that the oil production can be kept up for a longer time. Other interventions that remain in the reservoir are the old wells. Many of them are shut-in but the way the have been shut-in and secured/closed varies. The older ones may for instance represent other risks than newer wells. One of the authorities' main goals for industry is to longer the life span of the oil fields, and as drilling and operating wells in mature fields gets increasingly complex, this may represent a challenge for the industry – also with respect to safety.

4.1.3 Use of sensor data and collaboration technology

Sensor data is transmitted and stored both on the rig and in the operating company's databases onshore. These data can then be accessed by people involved in drilling at different levels. Specific applications are used to utilize this data for different actors. For instance people doing well planning and anti-collision analyses use other software than people involved in reservoir modelling. One of the company's goals is to integrate the tools and applications even more so that the same data and the same models can be accessed in the same software. The operating company has integrated the software that manages the geological models with the software that manages well path plans, enabling the models and plans to be automatically updated in both applications. Data can then also be imported into the same model from two applications.

Many different types of data are collected during the drilling process. Flow and temperature, vibrations, torque and drag, rate of penetration, pore pressure, and hook load are examples of data that are presented to an onshore center in real time or with a small delay of a few minutes. Data transmitted from rig is represented in different ways. The engineers monitoring the realtime data on a continuous basis see the data as graphs on the screen. Big screens are installed in the onshore support center so that everyone working in this office location can follow the operations realtime by watching the incoming data on the big screens. Live video from the rig floor is showed on the same big screens. In addition to that the data is represented on the computer/desktop screens, and depending on their function, personnel in the onshore center can have different screen views.

Mainly raw data are sent from the sensors to the onshore database system. Only a few parameters are adjusted or represented in another way. For example well-bore positional data is sent onshore to apply magnetic model corrections to the azimuth, sent back offshore corrected, and also stored onshore in a definitive database. In general the engineers want the data to be unprocessed when they access them. In this way the engineers know the dataset have not been modified and can do their own analysis on the set. When data are corrected should it should be informed upon, either as a standard note if the adjustment is of a regular type or as a special notification in case of an exception. Datasets and analyses from current and earlier operations are stored with explanations and notifications so that they can be used correctly at later projects.

Data can be accessed through different applications depending on the type of data and the intended use. Geologists use different software for accessing seismic data and formation core sample tests, well planners use software for planning the path. The operating company is aiming at integrating the software systems to such an extend that different types of data from different sources can be imported into other software or they can be viewed in the same applications. Redundancy is another issue that needs to be dealt with. Databases offshore and offshore are duplicates, and serve as backup for each other. The drilling technology contractor has a third backup in the database at their offices.

The engineers that are constantly following the offshore operations communicate with rig crew through radio communication (UHF). The onshore support room and the people sitting there, often use this system for both the communication between rig personnel and the communication offshore-onshore. Some information is more convenient to communicate in written form and is usually sent by e-mail. Sending information over e-mail is typically the channel optimization engineers use when they send over their recommendations and other information concerning optimization.

Telephone is frequently used and can be the most adequate channel for communication, but more and more of the regular communication is done through the use of video conference. Meetings are held with several people from both the offshore and onshore organisation, and video conference is a communication channel frequently used. Interviewees regard video conference as a useful and well functioning tool. The software as well as the hardware have improved a lot in recent years and is now of good quality, and especially HD video conferencing has been an important improvement. Video conference was one of the core ideas for integrated operations and the informants tell that it is widely used and meet their needs to a great extend. But still many of them explicitly say that it is still something completely different to meet people face to face. Much of the personal relationships aspects like the confidence and trust that develop between people when they meet are lost when video conferencing replaces traditional communication.

4.2 Interview results

Relevant personnel involved in the drilling and well operations were interviewed during visits to the operating company's and the contractor's offices. To get an overview of the work system the interviewees were initially asked to make a description of their function and work tasks. The collaboration with other in the work system and tools used for collaboration was also dealt with. They then described characteristics of drilling for hydrocarbons and operating oil wells, focusing on challenges related to safety. Factors influencing safety and the role of integrated operations, with its weaknesses and possible improvements, were then examined. The interview guide as well as transcripts from the interviews can be found in the attachment.

4.2.1 Challenges in drilling and well operations

First the interviewees described drilling and well operations from their perspective. Characteristics specific for well operations and challenges with respect to safety were the main focus in this part of the interviews.

	Role	Answers
1	Drilling optimization engineer	- Variations occur all the time. «Every hole is different» - Main factor: Be able to see that something is happening, and alert the driller - Reliant on (less redundant) technological infrastructure - Much is still put on the hands of the driller, which is the most prone to single operational/human errors - Human errors happen, they are not completely avoidable but rather normal and one should acknowledge that. When more people see the same and work together, single errors and misinterpretations/misunderstandings can be detected and corrected.
2	Onshore drilling support coordinator	- May be noise in the signals that must be corrected/adjusted. No standards, but based on common sense. Misinterpretations may occur. - Things never go exactly according to plan in drilling, and both events during drilling and uncertainty in the geological models cause variations. - Working with people one does not know, like substitutes or personnel from contractors, may cause inadequate communication due to social barriers.
3	Drilling optimization engineer	- Understand what the driller needs. Can be difficult without offshore experience - Many rules of thumb, reliant on experienced workers - Keeping up with software - Tendency to get stuck in the data rather than looking back on past experience/relevant projects and try to see trends and the big picture - Mismatch between sophisticated tools down hole and old measurement techniques on rig floor - A dynamic labour market may cause loss of knowledge and the need for more training - Offshore crew sceptical to IO. Still a little “Big Brother-atmosphere”
4	Well integrity engineer	- Little collaboration with drilling team during drilling, is more «taking over» a product from drilling crew. - Downhole safety valve leaking is a main focus area
5	Drilling support,	- A driller has many tasks to do, the drilling itself (sinking of the bit) is only part of the process. Many requests and disturbances requires attention

	drilling contractor	- Limited offshore experience among onshore personnel
6	Sub surface, well planning team leader	- Not all are present in the meetings where important decisions are made - High pressure zones due to water injections. This problem is growing in maturing fields - Have to plan many years ahead when planning a new well path, otherwise sub optimization may take place
7	Drilling support engineer	- Great uncertainty in the geological models - Unexpected high pressure (kick) - Unexpected loose/fragile formations - Can be hard to concentrate when disturbances, like when many rigs are communicating and many requests/contacts - Drilling a very dynamic system, with high degree of interdependency. One cannot optimize one part without taking into account the effects on the whole system
8	Drilling supervisor	- Dependency of technical equipment - Many young employees and many soon to retire - Both safety, cost and practicality need to be taken into account when planning and implementing drilling - Many variances, lots of unknowns and changes happen constantly
9	Integrated operations advisor	- Bounded/constrained by present facilities, old offices little suitable for "collaborative workstations/working environment" -
10	Evaluation meeting, onshore drilling support center	- Conversion of data and accessibility/usability/usefulness of data in database - Data quality, mud density in particular - Make all software solutions applicable with the company's systems and match the needs of our users - Drillers and offshore generally does not want "to be bothered" with more sensor data - Systematic errors in some data, like mud weight, not automatically corrected. Need to be corrected/adjusted manually - Offshore engineers sometimes do not know how to use certain data - Some problems with databases that are the changing variables and entities
11	Drilling optimization engineer	- Right interpretation and understanding. Many anomalities have explanations that need to be known for post-run analysis - Analysis of drilling data is an experience based field. Much can be learned from studies and books, but the main source of competence building is through experience from professional work. - Can be huge loads of work when several rigs are requiring support (e.g. facing problems, deviations from plan). Has to prioritize where to help first and who that has to wait (backlog).
12	Drilling engineer	- Changes and adjustments happen all the time, especially during drilling and completions, but that's why it is so interesting to work here - There will always be uncertainties from operation and one must acknowledge that as normal. "We're humans, we do mistakes" - Availability of tools and personnel, internal as well as from contractors, is also a source of uncertainty

Table 2. Factors representing challenges in drilling identified by informants.

The interviews indicate a wide range of factors that may cause challenges faced during drilling and well operations. Conditions downhole were by nearly all respondents mentioned to be uncertain and a source of surprises and risks. Software, measurement tools, well construction and design, drilling equipment – in other words technological factors – are other group of factors that may make well operations uncertain and risky. Finally actions made by individual employees and factors related to the organization as well as the individual appears to cause variability and uncertainty. Problems related to the geological conditions in the reservoir need to be solved at different stages in the drilling project. Interviewees explain that one seeks to avoid identified possible problem areas, but all of them are not avoidable.

Today's technology is not able to foresee all challenges and provide solutions to them. Many informants point at the uniqueness of every whole as a key factor. Historical data from similar wells may not always provide sufficient information in order to solve a given situation. Understanding the geological processes and being able to assess the situation correctly is regarded a difficult task and a combination of expert knowledge, individual skills, information from measurements and collaboration seems to be necessary preconditions for successful interpretation and assessment. Some of the physical processes in the reservoirs occur because of the changes activities from oil exploration and production have made. Pumping up hydrocarbons affect the pressure in the reservoir and may change the behaviour of the formations and fluids in the reservoir. Water and gas injections may affect this further/additionally.

Actions made by humans influence the reliability and variability of the operation of the system as well as the conditions that again affect future operations. Informants in general regard variable human performance as normal and a fact of life. All the factors described in this section may influence each other. Interviews indicate that internal as well as external sources both on rig and shore all play a significant role in affecting the whole system. For example decisions made during operation were, by some informants, said to be influenced by decisions made in the planning phase. During drilling, the rig crew was on the one hand dependent on assessments and support from the onshore center in order to perform their work, while the onshore team's work depended on the needs and requests from offshore. Accessibility and reliability of the data was according to a number of the interviewees dependent on design and quality of the software and infrastructure, which again was dependent on the acquisition and maintenance of the technical systems. One informant emphasized that “drilling is a very dynamic system, with high degree of interdependency”, and that one “cannot optimize one part of the system without taking into account the effects on the other parts.”, suggesting that a holistic approach is necessary to avoid sub optimization.

The main factors mentioned as challenges specific for drilling and well operations are summarized in the table below. The answers are grouped into people, processes, and technology, by a PPT diagram. As one can see there seems to be more factors related to human and technological resources were interviewees see a challenge.

People	**Process**	**Technology**
Situational awareness and understanding	Very dynamic and interconnected system; cannot optimize one part	Handling complex environment/reservoirs and mature fields
Human variability (human errors a fact of life, dependency on human operators unavoidable)	Many variances normal; plans need to be adjusted	Uncertainty in measurements and models
Social barriers; working with other teams	Relevant actors present when important decisions are made	ICT dependency
Many simultaneous tasks on drill neck; need support	Collaboration; routines and practices	Data quality; reliable data, no systematic errors
Understanding of the physical processes		Software and hardware that fit needs
Have the right knowledge; relevant work experience		Enough measurements

Figure 4. PPT diagram for challenges for safe and efficient operations; factors specific for drilling and well operations.

4.2.2 Key factors for safe and efficient operations

After identifying drilling-specific factors that influence safety, the informants then were asked about key factors that contribute to safe and efficient operations.

	Role	Answers
1	Drilling optimization engineer	- Data need to be reliable and of high quality - Being able to understand what is really going on. Look at the right data, and interpret them correctly. - Have more people that work together, look over each others work, complement each other - Reliable (redundant) and user friendly IT systems so that one can work uninterrupted and efficiently - Clear communication rig-onshore and within onshore center; what actions are implemented/status of operations and sharing of assessments
2	Onshore drilling support coordinator	- Experience based knowledge to understand what the sensor data means and know which changes in trends that are normal and which that need deeper investigation - The social relations to people you work with is important
3	Drilling optimization engineer	- See that something is happening and alert - Curiosity - Being able to understand what support the driller needs - Being able to grasp what is going on offshore - Willingness to share ideas and knowledge. Dare to expose ones assessments and conceptions to other
4	Well integrity engineer	- Have good overview: all documentation in place and updated - Be ahead of the curve, don't get backlogs of tests and maintenance work - Regular, frequent meetings important in order to be proactive and don't lag behind - Has the necessary (formal) authority and backing to shut down a well when they assess a situation to be significant
5	Drilling support, drilling contractor	- Experience from offshore is vital - Need to have enough time to support rig - Procedures and work practices that facilitate "safety thinking". E.g. individual talk with supervisor and employee on rig before the job where possible risks and how to work safely are the subjects
6	Sub surface, well planning team leader	- "Competence, more precisely experience is a core skill/ability for a geologist". "Actually experience from the specific oil field is the most important"
7	Drilling support engineer	- The tasks are very demanding, requiring high competence. A minimum of 10 years as real time data monitoring engineer - Holistic approach necessary in order to cope with dynamism and prevent sub optimization
8	Drilling supervisor	- Experience very important because you gain both relevant knowledge and the confidence to do the proper actions - Be able to sort out the important factors to focus on as there are too many variables to monitor. Impossible to control everything - Necessary to rethink during drilling operation. There are so many variables

		and it is impossible to control everything and account for every situations.
9	Integrated operations advisor	- Sufficient reliability and quality of data so that one has trust the data - Fit between technological solutions and user needs
10	Evaluation meeting, onshore drilling support center	- Systematize knowledge gained and provide advices and procedures for different types of problems - Be able to focus on the global situation and optimize the whole drilling process. Analyse the situations more deeply and compare with knowledge and past experience rather than focusing on the present situation only - Have enough measurements - Review what data we need and what we do not need
11	Drilling optimization engineer	- Past experience used and helpful, but present situation always taken into account. - The drilling therefore dependent on given situation and the raw data from formation and fluids are always analysed and compared with the specific well/equipment in order to attain «true» assessment/understanding. F.ex BHA equipment can be quite different from well to well, and might again influence sensor measurements of vibration. - Tools have different characteristics and load limits (tolerable time/length of exposure/stress, not only peak value) and therefore other critical parameter values must be used.

Table 3. Factors representing challenges in drilling identified by the informants.

In order to deal with the challenges and problems when drilling and operating a well, the informants listed several factors. On the individual level expert knowledge seems to be vital. Especially knowledge gained from work experience and ideally from the specific reservoir was said to be important. Further the interviews indicate that the ability to be able to see what is going on and understand what support the offshore crew need is of huge importance. Work experience from offshore and certain personal skills seems to be key contributors in achieving this. The ability to interpret data correctly was by several interviewees attributed to a certain degree to experience and competence. Having many people working together were said to result in two important things. Firstly the fact that people can focus on different data and draw attention to other may increase the potential for getting the right assessment of the situation. Secondly by having more people see and evaluate the same thing, one could improve chances of detecting errors or coming up with better solutions. In order to make decisions on real time data, some of the informants stressed that ensuring good data quality or at least being clear on the uncertainty of data, was needed. As can be seen many of these key factors for resilient operations are related to the challenges listed in the previous section.

The interview results are also here grouped in the categories people, processes and technology and shown in figure 5. The factors concerning experience, training and competence development that are connected to people are closely related. The interviewees suggested contributors to safety that are related to both people, technology and the organization's processes.

People	Process	Technology
Enough offshore experience among onshore employees	Replacing old procedures and making use of new technology	Data quality; accessibility and redundancy of data
Training and education	Processes for sharing of plans, reports, lessons learned	Knowledge database
Curiosity, interest in the field	Risk assessment; performing and updating	User friendly interfaces
Competence development; discussions with co-workers and mentoring	Simplified documentation processes	The right ICT tools; HD video conference, (realtime data) monitors, 3D visualization tools
Autonomy and support from superior	Involve all relevant actors at different phases of a project	Sharing of data and integrating IT systems
Willingness to adopt new things	Review processes	More sensor measurements
Focus on the most important things	Management of Change	
	Work practices that facilitate collaboration and sharing of information	

Figure 5. Key factors for safe operations identified by the informants.

4.2.3 Strengths of current organization

Moving from general questions about well operations and safety, the interviews then drew attention to the effect of integrated operations and collaboration technologies. First they were asked to come up with positive effects of integrated operations and potential that lies in collaboration technologies.

	Role	**Answers**
1	Drilling optimization engineer	- More people with different expertise and strengths see the same data, - Supports rig team with deeper analyses
2	Onshore drilling support coordinator	- Easier to work together, involve human resources - Tight integration of operating company and drilling technology contractor - Varying work load make allocation of resources to other tasks possible - Supports the driller with analyses (numerical values) that the driller cannot perform due to other tasks on the rig. - Collaboration technology is functioning well and is widely used
3	Drilling optimization engineer	- Lots of data available for analysis and decision support compared to traditional drilling operations. - Easy to bring together people with different knowledge, understandings and perspectives. - Current organisation gives opportunity for making different analyses and looking on different data - People have become familiar with IO, both the software and the tools, and use it more and more
4	Well integrity engineer	- Good communication possibilities with rig personnel.
5	Drilling support, drilling contractor	- Gives driller more time to focus on jobs offshore - Better work hours/cycles
6	Sub surface, well planning team leader	- Visualization tools useful when presenting models across disciplines - “The whole process of conducting a drilling project is team work” - “All the team work and the fact that people are working together, watching each other, giving feed back prevents single human errors and narrow thinking (“Skylapper”)”
7	Drilling support engineer	- Open space workplace facilitates collaboration, but can be hard to concentrate when many rigs are communicating with data engineers (radio communication) - A number of communication channels/tools available, usage dependent on situation - Part of a whole team of experts, where many views are presented to the drilling team
8	Drilling supervisor	- Easy to contact people and interact once you get to know each other - A number of communication channels available, can be used accordingly to need - Knowledge sharing across the organization: interactive training network - Dynamic process makes adjustments from involved actors possible
9	Integrated operations advisor	- Situational awareness, everyone has a common picture of the situation - Good collaboration and communication allows improved access

		to competence, and expertise.
10	Evaluation meeting, onshore drilling support center	- Historical data available for comparison with realtime data - Procedures for dealing with significant/difficult but well-known problems - Software has improved a lot, and people are familiar with it now
11	Drilling optimization engineer	- Huge databases with data from previous operations very valuable for analyses - Sharing of the experience and specific projects aimed at optimizing future drilling all contribute to successful runs - Knowledge gained in post run analysis is extremely valuable in future planning - Lots of money saved from support from, as the contact ADT-offshore leads to faster and better operations/work. Problems and delays (abruptions) are very costly. - Drilling data analysts have different preferences and qualities and can complement each other.

Table 4. Factors regarded as the organization's strengths identified by informants.

The current organizing of the drilling and well operations has according to the interviewees several benefits. The smaller team of drilling supervisor, tool pusher, driller and assistants on the rig can focus more on the execution of the operations. A greater team of people onshore provides operational support like problem detection and drilling optimization and take care of many of the administrative tasks like documentation and follow up of regulations. In several interviews the offshore drilling team's need for such support was emphasized, and the interviews suggest that the opportunities for that support are a strength of the current work system. By having a team of experts following the ongoing operations and analyzing the incoming data, more problems could be detected before they occur and errors can be corrected, some interviewees suggest. Specific analyses of previous runs were by a number of informants said to be valuable in future operations. The measurements that are done downhole, the processing and storing of the data as well as the application of the information all seemed to contribute to successful runs. Several informants highlight application of this information in the form of advices, analyses, recommendations or procedures as useful for the group working with drilling and well operations.

Techniques and tools for measurements have developed hugely during the last decade or two and give many opportunities for improving drilling and well operations, according to the interviewed persons. They told that both realtime support and post-run learning may have significantly improved as a result of access to more and better data. By integrating its operations the case company can facilitate sharing of knowledge and more collaboration, the interviews suggest. Additionally, contractors doing smaller jobs which are also part of the system, could also benefit from the sharing of information and use of collaboration technologies in their work.

As can be seen from the interview data many of the strengths identified in this section may meet the challenges listed in the previous section.

4.2.4 Organization's weaknesses and room for improvement

Finally the interviewees were asked about weaknesses in the current organization and possible improvements they saw.

	Role	Answers
1	Drilling support engineer , operating company (ADT)	- More and better communication; alerts, analysis of current drilling process, experience transfer and learning.
2	ODC coordinator	- Establish informal communication offshore-onshore; meet people face to face and facilitate discussions and experience transfer - Tighter integration with drilling contractor
3	Drilling support engineer, operating company (ADT)	- Better data quality; more consistency and accuracy - More knowledge sharing - Use more accurate measurements on rig and systematic correction of tool related factors that affect drilling parameters - Easier searchable database - Personnel offshore should meet onshore support personnel and share needs and ideas
4	Well integrity engineer	- More integrated with people from drilling
5	Drilling support, drilling contractor	- Many shifts, many people to train; better continuity and less turnover would be favourable - Simplify rules and external requirements
6	Sub surface, well planning team leader	- Make sure all relevant involved actors are present when decisions are made
7	Drilling support engineer, operating company (ADT)	
8	Drilling supervisor	
9	Integrated operations advisor	- Facilities that are more suitable for new workplace designs, more easily convertible to modern collaborative work offices - Willingness to try new solutions and adapt to new ways of doing things
10	ODC meeting	- Better interface (less bugs) for support engineers - Better merging of databases, merging of reports
11	ADT	- More use of analysis and recommendations during operation

Table 4. Factors regarded as the organization's weaknesses identified by informants.

There were also some limits or disadvantages to this organization and this interview study indicate that some improvements could be beneficial. Not all data and other resources seem to be fully utilized. More sharing of knowledge and being better to use the analyses from the optimization engineers were mentioned as possible improvements. Interviewees from both the operating company's support center and drilling contractor indicate that more and tighter collaboration could be beneficiary. One explicitly point at meeting the rig personnel face to face as a possible initiative that could reduce barriers against collaboration. Other highlight offshore experience as a possible problem in the future as fewer employees than before work offshore during their carriers. Regular video conference meetings with onshore engineers and offshore drilling team with discussions around the well operations and the team collaboration could improve collaboration, one suggested. Another pointed at regular meetings via video conference with people offshore as valuable in order to establish a good communication pattern – in this case between rig and the offices on land – and prevent that work is lagging behind. The morning meetings seem to serve other purposes, as they here go through a predefined agenda rather quickly and there are quite many people present. However there is also a separate meeting which is often run after this meeting, which is much more detailed in nature.

In an evaluation meeting, people from the onshore expert group indicated a need for even more measurements. Even though they expressed doubt in whether the offshore team was willing to or able to utilize more data from downhole or input from shore, the engineers said they wanted more data so that they could improve/optimize operations.

4.2.5 Gap analysis

A simple gap analysis is presented here in order to provide a more visual presentation to the reader of which areas that meet the requirements and where improvements should be made. This type of analysis may also indicate where the potential for improvement is greatest, and may help in prioritizing resources when considering where to put most effort. Based on the interviews, the different factors are assessed whether they are over, at or below average by comparing the actual and desired level. Since the data were not collected by quantitative methods, for instance by asking respondents to evaluate factors against a numerical scale, the factors is assessed here qualitatively on a simple three step scale. Factors that were clearly mentioned by many as a strength of the current organization fall into the category “good” that indicate a desired level with only smaller room for improvement. Factors that were mentioned by some interviewees as a strength, and maybe mentioned as an area of improvement by others, fell into the category “satisfactory” which means it is sufficient but not as good as desired. The factors that were mentioned as a weakness were assigned the lowest value “tolerable”, which indicate they are not regarded a strength and have the most potential for improvement. For factors assessed as “good” urgency for improvement seems to be low and these factors may be important contributors to resilience that the organization should strive to maintain.

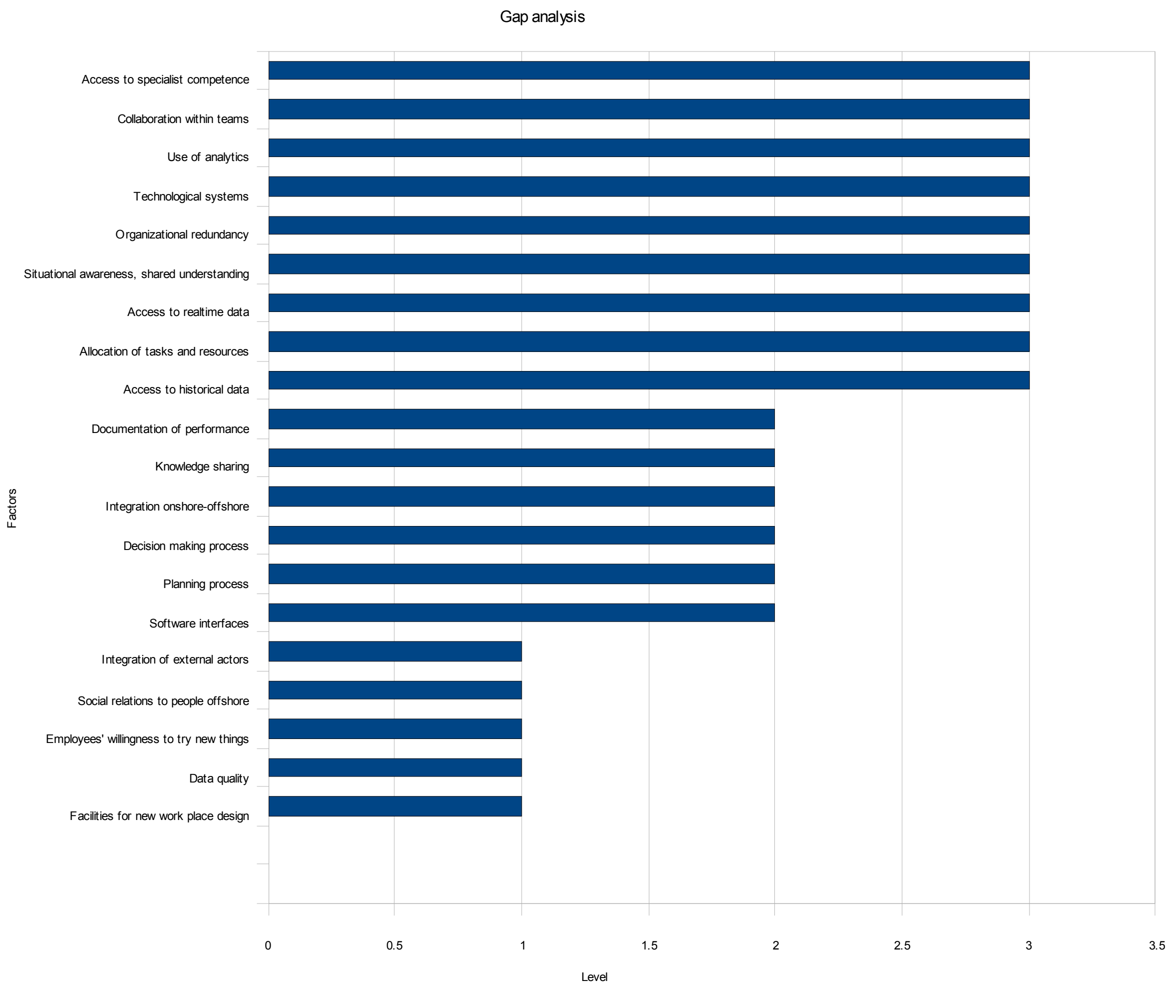

Figure 6. Gap analysis.

As can be seen from the diagram the organization seems to perform best at collaboration within teams, access to specialist competence, access to data (realtime and historical), use of analytics, situational awareness and situational understanding, allocation of tasks and resources, and human redundancy. Knowledge sharing, documentation of performance and lessons learned, planning and decision making process, software interfaces and integration of offshore-onshore are areas that the interviewees seem to regard as good but not as good as desired. Areas with the most potential for improvement seem to be data quality, relations to people offshore, integration of external actors and the work place facilities at the company's offices. In general the interviewees mentioned more factors strengths than weaknesses. The discussion chapter addresses the organizations strengths and weaknesses as well as the challenges in wells and drilling operations and the key factors in operating safe. As only the empirical data are presented here, the underlying conditions and the possible implications of the findings are discussed in the next section.

4.3 Resilient abilities

One of the aims for this thesis was to address how resilience is achieved in well operations through use of collaboration technology. Data gathered from the interviews and observations are in this section analyzed by using theory of resilience engineering – using the four cornerstones monitoring, anticipating, responding and learning. The indicator list, adapted from Hollnagel (2010/11) presented in the theory chapter is used as a reference along with the general principles of Resilience Engineering.

4.3.1 Monitoring

The operations are monitored in several ways. As described in the introduction, a team of engineers follows the drilling operations from an onshore center. Real time data and data logs from daily operation are sent to databases onshore. The main parameters like temperature, flow, depth, rate of penetration, torque and drag forces, and gas volume are presented on monitors in the support room. There data can be viewed at both computer monitors and the big screens. For all the parameters, the engineers look for critical values and significant changes in values. Such changes indicate that risks are emerging unless they are being controlled or there are natural explanations of the changes in values. The engineers alert the rig crew and assess the situation whether intervention is needed.

A group of the onshore engineers in the contractor's support center follows the realtime data of the main parameters and does not do in-depth analyses of trends. Their main task is to support the driller and serve the rig crew with warnings and advices. When they detect that problems are occurring they send out warnings and when they see trends in the data that indicate interventions are advantageous they send advices on what actions they recommend. Drilling technology engineers that make up rest of the onshore support group focus on specific data and do deeper analysis on the data material. These specific analyses and recommendations based on historical and realtime data serve as operational decision support and guidance to the offshore drilling crew. What kind of analyses the onshore support engineers do vary with what needs and requests the rig crew and personnel in the onshore organization express. Depending on the situation they can – and in stressful or critical situations must – prioritize tasks and flexibly allocate their resources.

Drilling contractor's onshore support engineers are more concerned with supporting the tool pusher/drilling supervisor role and have more direct contact with the driller. They are “the driller's second pair of eyes”, as one of the support engineers put it. Sensor data is displayed in the driller cabin, but due to many tasks and requests for the driller to pay attention to monitoring support is needed. Some rigs have real time data engineers offshore, but the case company has moved this function to onshore support center and the contractor's onshore offices. Observations of the contractor's support center showed monitoring on a continuous basis from the onshore center and communication when requested. Follow up of plans, rules and regulations were a major area of focus for the onshore engineers. Administrative tasks are taken care of by this team rather than the offshore drilling team. Using the same software and watching the same parameters as the contractor's onshore team, this team supports the drilling team on rig in monitoring the operations in addition to following up plans and ensuring resources are available. However this support center has a slightly other interface, which they regard as more suitable for them.

Drilling engineers, the drilling superintendent and the drilling supervisor onshore also follow the daily operations but focus more on daily progress and the big picture. Watching progress in drilling compared to section plan is a key task for the drilling engineer. The drilling superintendent and the drilling supervisor have leader responsibility and monitor the operations from a higher level, for instance through status reporting in the morning meeting where the drilling supervisor leads the meeting. Monitoring realtime data is not the main focus for the superintendent and the supervisor, but rather to watch progress in the drilling and well operations on a less continuous basis. Daily drilling reports, morning meetings, logs and operational reporting from rig during the day are where this group get their main input.

For every installation there is a HSE supervisor who follows the operations with respect to safety. He/she is alerted when well control situations or other anomalies occur. In case of deviations from plans that may affect safety, the HSE supervisor is getting involved. If operations need to be performed with exceptions from safety rules or regulations, HSE is involved and counter measures are implemented together with an application for exception to the authorities. The assessment of whether an event is an incident concerning safety is specified through or through individual assessment of the workers. If an employee feels that a situation is unsafe he/she notifies, and if it is regarded significant the operations are stopped. Such warnings may come from the driller, the real time data engineers or the well integrity engineers. The driller as well as the well integrity group has authority to terminate the ongoing operation if safety. HSE indicators are monitored and the status is evaluated on a regular basis. Many of the indicators are more of a lagging type, for instance HSE incidents statistics. Some are of a more proactive nature like training of personnel and surveys about the safety climate.

A specified set of indicators from realtime data used during operation seemed to be little established. The interview data indicate that detection of events and assessment of situation are mostly based on human interpretation of the realtime data. For example changes in gas volume or certain trends in WOB seemed not to be automatically subject to alerts and actions. Instead it appeared that detection and assessment depended on onshore support engineers and offshore drilling crew. An automatic detection system based on predefined scenarios might be helpful. Automatic systems like this need to be reliable and the indicators must be valid, i.e. the cause effect relationship between precursor indicators and events must be established in order to prevent false alarms. A number of the interviewees point at human interpretation and individual assessment of every situation as vital in drilling operations. The interviews suggest that many variances occur in drilling and therefore if automatic systems should be used engineers will still need to check the validity. On the other hand, a discussion in an evaluation meeting indicated that more predefined scenarios and associated procedures could be made, and perhaps this is a step towards an automatic monitoring support system. Indicators should be evaluated during drilling project and before applying them in a new project, since every well is unique, like one informant expressed himself, and statistical validity in one context may not be valid in another.

Interpretation of the data is vital for understanding what has happened, what is going on and why. Several interviewees highlight that monitoring is to a great deal about getting the right interpretation of the right signals. Competence, specifically experience from drilling and preferably from the specific reservoir, is important in order to have the ability to monitor well and drilling operations.

To sum up, different persons and teams serve different functions in monitoring the ongoing operations. This due to differences in competences and areas of responsibility, but it requires communication and sharing of information to be functioning. Leading indicators for use in continuous monitoring seemed little established, but the monitoring of realtime data was by many interviewees said to function through human interpretation and organizational redundancy. Automatic systems might be helpful tool in monitoring the operations if one is aware of limitations and possible pitfalls and complemented with the right “humanware”.

4.3.2 Anticipating

Signs, cues and recognized patterns in the data received do not only give valuable information about the present situation and immediate responses. They also enable the organization to anticipate things that may occur in the future and prepare for coping with possible risks. As described in the previous section, physical signals like vibrations and sounds as well as signals from the real time data on the monitors give opportunities for detecting risks. Recognition of phenomena and situations that are about to occur may indicate that risky events or situations are developing. When pre warnings of such events are recognized, resources can be allocated so that monitoring can be increased and responses prepared. Interviewees tell that data engineers from the onshore support center as well as from the drilling contractor's onshore center can direct their attention more towards specific activities and give the rig extra support if needed. They said that the organization of the work and the facilities make it possible to put aside other work tasks for a period of time, representing some buffering capacity. By having this opportunity the engineers can focus their work on problems they suspect may happen and prepare solutions to cope with the possible challenges.

Besides the information that continuously flows from the sensor situated down whole in the given/present well, data from similar wells are used for anticipation purposes. The experience from past drilling operations gives important input to planning and preparations of the future drilling operations. Data logs, daily reports, specific reports from analyses, recommendations and learning from incidents provide useful input to the planning, drilling and operation of future wells. The collecting and storing of this information for later use is described in the following section on learning.

Support engineers compare trends and patterns from current data with historical data. When recognizing a possible problem the optimization engineers search for historical data on similar successful runs and things to watch out for. Combined with their tacit knowledge – and often after consulting colleagues – they make recommended guidelines for handling the coming operation and deliver it to the realtime support engineers and/or driller. Interpretation of the data is a key here to understand current situation and anticipate risks. Informants tell about a number of factors and phenomena that influence each other that are not – and perhaps cannot be – written in procedures or guidelines. Several phenomena have natural explanations, they say, like conditions down hole that may explain a certain change in one parameter. Well specific design may vary significant from well to well and modifications made during the well operations may lead to changes in the values that need to be accounted for. Such changes would normally indicate risks, and interpretation and situational understanding therefore are important when addressing potential risks.

Even though the support center onshore fulfill the anticipation function to a great degree, the driller and the offshore drilling team still play a role in addressing potential problems, the interviews indicate. The practical experience gained from offshore work enables the driller to interpret signals and cues and anticipate upcoming events.

Geologists and reservoir engineers in the subsurface group base much of their work on knowledge gained in earlier drilling projects. A geologist expressed that knowledge attained from projects in the same oil field is the single most important factor for successful planning of a new well. Even though sophisticated models and tools are developed for reservoir management/drilling operations and huge amounts of literature on offshore hydrocarbon reservoirs and oil production exist, the knowledge of the individual employee and the organization as a whole are vital in the process of planning for drilling. Before drilling into a new section, the sub surface group seeks to identify specific problems to look out for. This is done when planning a well by comparing actual well path with data from previous wells and identifying possible problem areas. Solutions can then be designed based on lessons learned from similar operations. For instance different types of problems with different formations or areas with water injections and high differential pressure can often be anticipated, according to one of the interviewees. When drilling close to neighboring wells they also pay attention to specific issues and prepare different solutions in case they face problems. Uncertainty in the positioning of old shut-in wells are accounted for when planning new wells along with procedures for guidance in sections where one is drilling in close proximity to neighboring wells.

Although prediction of outcomes may seem difficult to make for drilling and well operations, the case company put effort in anticipating future activities/events. Engineers say that by perceiving and interpreting trends in the sensor data they can identify what is going to happen in the near term. Good general knowledge about the system and in particular knowledge about similar situations and events may then enable engineers and the driller to foresee possible problems. The identified problems and events can be combined to detailed scenarios. Based on experience the onshore support team can develop procedures/plans for handling the identified scenarios. Like the ability to address the actual, different teams and individuals contribute to the ability to address the potential. What data and tools different teams use vary depending on their function and area of focus. One also sees collaboration across teams through the involvement of people from different teams/departments, which was also indicated by the interviewees as important.

4.3.3 Responding

Informants explain well operations as a dynamic process with great variations. Physical processes below surface as well as interventions on the reservoir represent sources of variability and uncertainty. These variations may be of varying amplitude and are – depending on detection and interpretation – being assessed and responded to by the system. The monitoring of the drilling process and anticipation of events make the system able to catch signs of risks and make alerts. When alerts are made, procedures and assessment of the situation determines the response. The operating company has steering documentation that defines how the response is carried out and which goals and rules that apply for a number of identified/given situations. This steering documentation is based on their internal knowledge and on the industry's best practice. Experience from past operations, requirements from authorities and internal goals together form these predefined rules and procedures. After years of experience in offshore drilling and with a sector known for its strict and well functioning safety regime, the actors in the industry have learned to cope with risk factors and challenging environments. Rules and guidelines have therefore been developed to handle such problems. Some requirements are detailed and strict, for instance acceptance/threshold values for drilling parameters or how to perform function testing under a well control situation, but a great part of the rules and procedures actually allow for some degree of individual assessment and situational adjustment. Because of all the variations one has to rely on individual worker to a great extend, according to the interviewees. But since there are more people seeing the same data and doing different analyses a respond does not solely rely on single persons. By looking over each others work and discussing the solutions with the colleagues the onshore support center tries to function as a whole team of experts. By complementing each other in the sense of where they draw their attention and what knowledge the individual possesses while at the same time helping and correcting each other, the team can both handle a range of jobs and put extra focus on single tasks, the interview study suggests.

At the sharp end on the rig sits the driller, steering the well bore from the drilling cabin. While data engineers offshore and offshore together with the driller make up the first line of monitoring, the driller's function can almost be described as the utmost/solely first line of response. The driller can respond on warnings from his individual detection and assessment of signs from drilling parameters which are represented on screens in the driller cabin. He can also respond to signals received from other sources like sensing physical signals, e.g. sounds and vibrations. An offshore team consisting of driller, tool pusher and offshore data engineers monitors and interpret information they receive and initiate responses when required. Due to many different tasks for the driller to perform, his attention is drawn to other places much of the time. Information in the form of warnings and recommendations from engineers in the onshore support centers are the other main source for response that seeks to complement the rig crew. Since little can be steered remotely from shore, the response function of the onshore organization is therefore to translate information to action plans. As described in a previous section, engineers onshore do a variety of analyzes and provide advices and recommendations during operation. Many of those recommendations are within the decision latitude of the rig crew and can be implemented immediately, rejected or put “on wait” for more assessment. Governing documentation determines as mentioned where rules to comply with are defined and where there is room for individual assessment/decisions/actions. Other parts of the onshore organization have authority and responsibility to decide on when to respond and what actions to initiate. The drilling superintend is the person onshore responsible for daily drilling operations and is involved in all major decisions that concern drilling.

With many people involved in the same project the system may have good opportunities/premises to initiate and carry through responses. Even though the reporting and documentation seems to be extensive, the were some indications in the interviews that documentation of ready made responses were less than it could be. Procedures for best practices for more of the known/identified type of events may be developed, according to an interviewee. With even more post run analyses and learning from past operations a foundation for prepared responses can be laid. However this preparation and initiation itself – both the prepared ones as well as the more improvised ones – require that resources like ICT, drilling tools and human resources are available.

4.3.4 Learning

Information attained in the interviews clearly indicate that learning from past operations and utilizing the lessons learned are key to successful drilling of a well. This learning takes place on individual and organizational level, and are both formal and informal. Interviewees tell about the importance of learning on the job and being able to make good use of that knowledge. Once again they emphasize that work practice is the most valuable source of knowledge.

Real time data is stored in databases and can be accessed at a later point in time which allows the workers to check data from previous operations and do new analysis on the historical data. An important part of the optimization engineers’ job is to document their findings from pre-run and post-run analyses. By documenting the parameter values from a given situation and the recommendations they made together with the outcome and lessons learned from the run, that information can be used later projects. Interviewees point at data from the wells in the same area as the most similar and relevant, and therefore documentation of previous operations are seen as very valuable. Special analysis from specific wells may be combined with analysis from other wells, and one may obtain learning across projects and time periods.

Post run analysis is performed by drilling optimization engineers after a run. Data collected from real time sensors and logs from down hole are analyzed. The data are compared with the goals and plans for the run and with data from similar runs. When the analysis is performed one can, according to the interviewees, extract valuable information for use in later runs and for other wells. By documenting the lessons learned and sharing that information, one lays a foundation for successful runs in the future. In addition to the reports and procedures that are available, the knowledge of the individual employee also plays a significant role. Firstly, much knowledge from the engineer that is not explicitly written down is useful when applying the procedures and lessons learned in future runs. Secondly, when performing future post run analysis this knowledge can be utilized and give even better documentation of lessons learned. Through collaboration and utilization of the workers’ knowledge the organization may improve the learning process, like one of the interviewees stated: “with collaboration, these projects often result in serious improvements”.

Like the post run analyses and the drilling reports, HSE reporting provides a valuable source for learning. Risk identification, risk management, HSE events and performance of HSE measures are processes that aim at learning about the system and its future operations, and include documentation. These processes themselves may contribute to the individuals' tacit knowledge and the documentation contributes to the organization's written knowledge. According to some interviewees, HSE reporting is extensive due to i.a. strict regulations and is seen as a useful tool for learning. Observation related to safety issues are reported manually and stored in an archive. Both negative observations and positive can be reported by the workers on the rig. Learning from successes is one of the main principles in the Resilience Engineering thinking and if used properly this may be a valuable source in the search for improvement. Even though the observations are stored, they are hand written and not stored in a searchable database. This makes sharing across geographical borders difficult and may be a barrier to learning. Incidents on the other hand, are reported by people and stored in a database, a reporting system commonly used in the whole industry. The data stored here are used for making statistics and evaluating HSE performance.

Specialization of workers seems to lead to expert knowledge among the individual employees. Team work seems to facilitate polyvalence among colleagues, and collaboration across organizational borders and disciplines seems to contribute to sharing of knowledge within the organization.

4.4 Resources and performance conditions for resilience

The literature study found other factors connected to resilient organizations. They may be seen as abilities of the system, characteristics of a resilient organization or preconditions for resilience. In this section the collected data are analyzed with respect to those factors that may be seen as premises for resilient capabilities.

Flexibility
The group of engineers that follows the operations and supports the rig team with analyses and advices seems to have a rather high degree of flexibility with respect to organization of their work and allocation of their resources. They can draw their attention to problems that occur and in this way allocate resources to urgent things. During normal operation they have the flexibility to focus on areas they feel there is a need to monitor or do analysis. This is particularly true for the optimization engineers. Both the offshore team and the onshore support team need to be flexible in order to deal with the dynamic nature of drilling and wells operation, interviews suggest.

Sharing of knowledge was according to the interviewees a source for building polyvalence and organizational flexibility. Since the employees worker with the same data and collaborated tight they were said to develop common competence. For instance knowledge about an oil field and how to perform work tasks like sensor data analysis can be learned collectively in teams. By having a team working on the same projects, more people can have a good overview of the present operations. In case of a problem it may be an advantage to have more than one person familiar with the present situation. Engineers in the onshore support center still do much work individually which may maintain and develop their specific expert knowledge. In this way working in teams may promote organizational redundancy as well as taking advantage of making good use of differences in competence areas. The individual worker would still possess his own unique experience and skills, and in a collaborative environment the potential for building redundant knowledge and at the same time complementing knowledge, informants pointed at.

What may limit the degree of flexibility is the irreversibility of many of the activities in a project. Costs are to a great degree bounded early in a drilling project. After start up of the operations the design solutions may be too risky to change. Another source of inflexibility are situations where one may experience stuck pipe.

Competence

People working within drilling, often engineers, are well educated and many of them may have experience from different positions and companies. But the specific knowledge from drilling operations was regarded important and educational background with respect to profession and institution is less important. For example drilling support engineers may have background from mechanical engineering, petroleum engineering or physics. This is visible in the organization where the employees come from different engineering disciplines and have studied at different universities. A typical background for an engineer working with drilling in the onshore organization is education within geo-petroleum, mechanical engineering or physics and work experience from the company or other companies for a number of years. Some of the more experienced have also worked in other companies, different places in the world and have held other positions within drilling than now. Almost all have experience from offshore, some from onshore drilling and some have worked overseas. Interviewees point at offshore as important, but there is a tendency that employees spend less time offshore than earlier. Some rotation takes place – for instance once a year – and there are arranged/organized common training courses for the whole organization. Most of the informants were of the opinion that going offshore is little attractive and the modern work life is mainly situated at onshore locations.

Autonomy

The driller was said to be autonomous since he is performing the drilling ("styrer spakene"). Within regulation from steering internal documentation and legal rules the driller performs the drilling job and utilizes recommendations and advices from people offshore and onshore. Several interviewees mention the authority the driller has to stop operation when he believes safety is threatened and he has the formal and informal backing to do so. The support center is given responsibility to give expert analyses and advices. They can organize their work self and do analyses where they see needs. But still there are governing rules to adhere to and requests from offshore periodically determine their work flow.

Collaboration

Most focus in this thesis was put on the team of engineers located in the onshore support center, supporting drilling and well operations with analyses and advises. Engineers sitting in the same office, an open workplace environment, seemed to collaborate tight. As they worked with the same type of problems, often on the same project and even cooperating on the same specific analysis – they seemed to naturally support each other with feedback and tips. Sitting in such an open-plan office made it feel normal to ask the colleagues for help and feedback, the interviewed engineers said, since both the physical constraints and social barriers are broken down in such an environment. Collaboration with other parts of the organization, for instance with people the sub surface group or well intervention was less frequent. This was said to have natural explanations since their work is less connected with those groups', but also structural and social barriers were mentioned as reasons for less collaboration. Another factor contributing to collaboration was the regular, formal meetings that take place between actors and groups. Video conferences with people offshore and meetings with personnel from other onshore teams was not only an arena for discussions and sharing of information, but it was also reported to increase in communication between the formal meetings. Many of the informants point at knowing people and having established a social relationship with the other person increase degree of collaboration with that person because of social aspects like trust. Communication outside the formal arenas also depended on the access to communication channels for the actors. People offshore that have access to internet and regularly check e-mail may more likely to collaborate with employees onshore as several interviewees regarded e-mail as a good channel for communication; access to video conference equipment may increase communication and improve quality as it is more similar to real meetings face to face, interviews indicate; and the continuous radio-communication and video transmission from rig to shore leads to high degree of collaboration across borders. To sum up, factors restricting collaboration were reported to be lack of social relations, lack of formal meetings, insufficient technological tools, structural and physical barriers.

Resources

One may look at competence as one type of resources. In order to adapt to changes and manage risks the system would need other resources as well. The need for human interpretation in drilling indicate that a certain availability of human resources is necessary for coping with varying work load and time pressure. However, too big buffer of resources may waste resources that could be used different.

5 Discussion

This section discusses the results in relation to the research questions. The chapter is structured into sections of main points from this study; from characteristics drilling and well operations, to the case company's way of utilizing collaboration technology and handling risks, and to core principles from theory. The findings are discussed in the light of relevant theories, and reflection on strategies for engineering a resilient organization is made. The section is rounded off by discussing possible recommendations for how to engineer resilience in the context of the selected case.

5.1 Discussion of results

Risk, complexity and the relation between safety and productivity

Drilling and well operations seems to be characterized by complexity and uncertainty. At different stages in the process of drilling for oil and gas the people working in such environment face situations with uncertainty about the outcome, and sometimes the understanding of the given situation is subject to uncertainty. Informants involved in early phases of a project describe a number of aspects that are uncertain at early stages and may influence risks later in the project. Almost all of the informants mention that during operation physical processes in the reservoir can hardly be fully anticipated and unexpected events occur frequently. Besides that the whole system seems rather complex with many actors, and all may affect risk in some way. It should be emphasized that the variability and uncertainty from conditions downhole and human interactions does not constantly produce unexpected outcomes, but compared to less complex systems the variability and uncertainty is significant. This is visible when one look at the high number of changes in the project plans, the reported need for human interpretation in order to understand sensor data as well as the number of accidents and well integrity incidents in offshore drilling.

Risk in this thesis is broadly defined as risk for unwanted outcomes, and the consequences range from work injuries and health aspects on the individual level, to major accidents causing damage on life, property, environment and immaterial assets as well as incidents causing emission of hydrocarbons to the environment, operational disruptions and production delays on the organizational level. As described in the previous chapter, there are a number of incidents that can cause potential accidents depending on the nature of the event and situational factors. So for every problem or unwanted event, there are potential effects on safety risk. If unexpected problems occur and strategies for handling such problems have not been outlined at an earlier stage, there is less preparedness. When resources unexpectedly have to be allocated elsewhere, an organization's ability to respond may be degraded. The point here is that safety is interlinked with other of the organization's goals like profitability and environmental sustainability. If costly measures that improve safety are implemented one place, cost cuts done other places could reduce safety and vice versa. Interconnections between actors and between decisions made at different points in time were described by several interviewees as an important aspect for operational performance. People involved in well planning were aware of their impact on others, for example the way decisions they make early in a project significantly affect operations later. The overarching goal for early phases is to reduce uncertainty and risk as much as practicable possible in order to avoid incidents, cost overruns and other consequences later in the project. But the informants acknowledge that risks cannot be reduced to a level where they are negligible. Risks will always remain and have to be handled at later stages.

Detection and early warnings in an uncertain environment

The need for early identification of potential risks and ways to manage the risks is illustrated by the way the interviewees describe the nature of well operations and drilling. One of the key aspects of Resilience Engineering is to look for the unexpected and be prepared for regular as well as irregular threats and opportunities (Dekker et al 2008). This is the ability to expect and be prepared for the unexpected. Another central principle within RE is that many modern sociotechnical systems are intractable, and variability is a natural phenomenon. The interview data indicate that variations occur frequently and are unavoidable in today's drilling and well operations. The informants did not propose any solutions/ideas about how to eliminate variations and uncertainty; many of them emphasized that it is impossible to do so, and it might even be counter productive. Because it may be difficult to assess the situation exactly during the operations, and even harder to anticipate the next step strict planning without taking the uncertainties into account would not be a good solution. When one is not always planning for the best case, one could imagine that in every uncertain situation it may lay opportunities for upside risks as well. A situation may actually be safer than first thought or an operation may turn out more successful than anticipated. Following strict routines where certain types of situations are managed the same way and may not be best in that case. If one focuses solely on things to avoid, one may forget the positive risks. And being exposed to positive risks can be more effective than avoiding the negative risks, at least the smaller ones. The Resilience Engineering perspective views that failures and successes are two types of the same underlying processes. Variability is unavoidable, and so are errors. By dampening what leads to unwanted variability and strengthening what causes successes, performance is improved. Errors should not be sought eliminated; they are rather a result of natural variability and actually provide valuable information about the system. This is what the case company seems to do. The teams onshore and offshore collaborate to cope with variability and gain knowledge about the system.

Exploration for hydrocarbons subsea is uncertain in its nature as there are many sources for uncertainties. Physical processes in the reservoir that can not be fully anticipated or even fully understood with today's human and technological capabilities. Interviewees explain that with the available technology and knowledge of today, modelling of reservoir produce significant amounts of uncertainty. When it is the rule rather than the exception that the conditions in the reservoir behave in a different way than expected, and even change behaviour during the measurement and analysis, this looks like a quite complex system.

Handling of risks locally is a main principle of Grote’s (2009) proposed strategy for effective uncertainty management. To give the single work system responsibility to cope with uncertainties locally is a principle adapted from sociotechnical theory. Group autonomy has the advantage of giving the people most familiar with the system the responsibility to select what methods and tools to use and how to work. The great deal of human interpretation in the case company's drilling support functions can be seen as an example of local autonomy, and therefore the organization's design may be a good solution in order to manage risks locally. Well and drilling operations seem to be characterized by far less central planning and automated process control than other industries like manufacturing or nuclear power. Interviews indicated that there is a comprehensive set of rules the employees have to relate to but that the rules and the dynamic nature of well operations give them a certain scope of action, which is an example of Grote's concept of flexible use of rules. Rejecting standardized rules requires a certain competence by the operators though, and only experienced workers feel that they have enough competence to deviate from a rule, according to Grote (2007). Informants also tell about non-written routines that have been developed through work experience, for instance how a driller interprets and act on certain signals. It appears that experienced employees develop work practices, and these routines may sometimes be more effective than the standardized written procedures. But some routines and even rules are not appropriate, three of the interviewed engineers suggested, and should be changed. As an example one interviewee explained that rig crew still measured the length of drill string parts manually on rig neck before it entered the well, even though “everybody knows that it expands since the temperature increases“. Identifying routines that are inappropriate and demonstrate the new and better work practices may be helpful in the search for operational improvements. To sum up, the onshore drilling support team seems to have a certain degree of the two KOMPASS criteria (Grote 2004) autonomy and temporal flexibility for two reasons. Firstly, drilling and well operations are so dynamic in its nature that high degree of standardization and central planning is not appropriate. Secondly, the employees posses specialist competence within their field that may allow them to deviate from routines when flexible coping with a situation is more effective than a standard solution.

Utilizing sensor data and analyses for anticipation and preparedness

Geophysical processes may be hard to understand and modelling the geology before even drilling seems to be subject to a significant level uncertainty. In addition there are sources for variability in the development of the analysis techniques and the operation of the systems. Taking an intractable system as a starting point, combining it with complicated tools and techniques for assessing the system you might get a rather complex system. And when an integrated work system is set to operate the whole system, it may be even more complex. But applying simpler measurements and building a less complex system may not be a good answer to the challenges. Greater amounts of data may give more valuable information, interviews suggest. And more knowledge about the processes was reported to be the key factor to safe and efficient operations. The case company has organized their human and technological resources in such a way that they are able to receive and process greater quantities of data. It was reported in the interviews that more measurements is wanted in order to improve performance, and the ability to interpret the data and share the information appropriately was seen as a prerequisite for realization of these effects.

Extensive use of analysis of drilling related data was reported to be one of the main advantages of the company's IO development during the last years. Informants actually expressed a need for more measurements and more analyses. The persons working with optimizing the drilling process said they wanted more analyses and procedures for best practice. If they can get more sensor data of high quality and more human resources they believe that they can do a better job in supporting the drilling crew on rig and provide better decision support for the decision makers. Analytics should be used both on a daily basis to support ongoing operations and for planning upcoming activities. An important aspect would be to ascertain the value of analytics. There was pointed out in the interviews that the driller and the offshore crew in general did not want more data and analyses. For the positive effects of analysis to take place one may need to prove the value of analysis to the operators and the higher level decision makers. Evaluations like the post-run analysis may serve this purpose if the engineers can show the effectiveness of analysis and recommendations they make. A premise for this is access to sufficient data and the resources needed to perform analyses. Quality of data is still a potential for improvement even though it has improved significantly over the last five to six years. Investing in measures that improve data quality and allocating more resources to analytics seems like an investment that will pay off in terms of both safety and operational efficiency.

Other technological means that may support anticipation are IT tools for representation of the data and models. A visual representation of the reservoir, the well design and the processes in the well may be helpful when communicating something to non-subject experts. A study on integrated drilling simulator indicated a lack of understanding across disciplines and departments (Letnes et al 2008), and was regarded a weakness in the industry at that time. These theses indicate that by simulating solutions and presenting them in an informative way could improve understanding of the users and decision makers. The organization's visualization and communication tools therefore seem to be contributors to resilience which may also be valuable for other organizations in similar environments. Especially the recent development in communication tools like video conference (HD quality) and sensor data quality from downhole measurements are important improvements. This should be taken into account when evaluating the effects of IO, since many of the research studies were conducted in the early stages of the IO development.

Team work – collaboration face to face and across borders

Having more people working together seems to produce several benefits. When more people monitor and analyse the same data, a redundancy effect comes about. Two pair of eyes see more than one pair which would be preferred taking into consideration all the information that flows through the data systems. The driller said he has so many different tasks to focus on and is frequently being interrupted by requests from rig crew, that he needs support for monitoring the realtime sensor data. The case company has set data engineers onshore to fill this function which was by one informant described as "we are a second pair of eyes for the offshore drilling team". Another effect of collaboration that mainly seems to take place within teams are the corrections and improvements taking place when workers are looking over and giving feedback on the colleagues' work. Discussion between experts was seen by the interviewees as a way to improve both the work performance and the acquisition of knowledge. Also when more people do the same type of tasks and work on the same inputs, a polyvalence effects takes place. They adapt each others skills and knowledge, and can substitute each other. Some differences in competence areas will always exist, which enables colleagues working closely together in teams to complement each other and facilitate knowledge sharing and learning of skill. Getting feedback and "new perspectives on things" was mentioned by one informant as one of the big advantages of team work. However, for such effects to take place the workers must take advantage of collaboration and get involved in the colleagues' work, or show "Willingness to share ideas and information" as one interviewee put it.

Polyvalence and redundancy may promote buffering capacity in a way that employees can support each other during daily work, and substitute a colleague for a period in case of for instance sick leave. But buffering capacity also requires slack in other resources like time. Interviewees tell about periods with high stress and time pressure where extra resources and support from other employees may are needed. Periods with little backlogs and deadlines is more the rule and this puts an element of flexibility into the work system. Planning for upcoming projects and evaluations of finished projects may wait for a period when immediate requests arise from the ongoing operation.

A benefit with integrated operations is the access to expert knowledge. Literature point at this as a major effect of integrated operations that may improve HSE through faster and better decisions (see e.g. Ringstad et al 2006 or Letnes et al 2008). This benefit was also emphasized by interviewees as an important factor. The organization has access to experts in-house during operations, especially those who work in a collaborative open work space environment. With the communication tools it has available, specialists located other places can be called up for expert judgements. This can provide valuable help and support in a specific situation, but also contribute to the organizational learning process through knowledge sharing.

Much of the discussions between employees take place during daily work, especially in the collaborative open space offices, or in the regular meetings like the section plan meeting were people from different groups meet. Getting to know the people you are going to work with and discuss things together was by interviewees regarded as something that promote collaboration. Meeting the people one is going to work with and establish trust might improve the collaboration across teams and organizational units. Formal meetings or seminars with specific purposes do not seem to be held frequently, but such initiatives where specific topics are discussed may be an arena for sharing knowledge and building social relations. One onshore engineer suggested also that they should meet the offshore people face to face and get to know them. Discussing their work situation could improve the understanding of how they work and what kind of support they need from onshore.

While meeting people from other departments and working closely together with people from other disciplines may have many advantages, it is important to maintain the specific expert knowledge when doing interdisciplinary team work. According to Moltu (2003) working interdisciplinary in teams and working within one's own field of expertise should be balanced. With too much teamwork the team members may be too similar and the advantage of diversity with team work is lost. Individual employee may loose some of their specialist competence when they work too much in multidisciplinary teams and is little concerned with their own field of expertise. One the other hand, expert knowledge may be little valuable when not utilized through team work. Composing teams with people being competent within the same field may be an option to maintain and develop knowledge, like the case company does in its support center. Moltu and Nærheim (2010) found that IO design may give high efficiency, but it was not the workplace design but rather the network and processes that make a workplace good or bad. Criteria for an IO design were to support flexibility and psychological job demands through transparency, simplicity and symmetry. The interview study in this thesis found both workplace design and the work processes as factors that affected efficiency.

The role of individual competence and relations between people

Two interesting findings from the interviews were the factors related to personal motivation and the ability to build competence. Openness, curiosity and interest in the field were seen as contributors to knowledge acquisition and skill development. Curious employees may strive for finding out more about the things they work with and questioning the established. People that are open to changes, that are willing to try new technology and easily adapt to new ways of working may develop their own skills and knowledge. They also improve the work processes and thereby promote the organisational development. The organization's openness to change was said to encourage workers to adapt to changes and think creatively. Creative thinking could be an advantage when operating in a dynamic and fast changing environment. If the environment is changing, the system must adapt in some way and that may require new ways of thinking about the system's operations. With creative thinking and openness to testing completely new things, the organization may undergo more fundamental changes. Relating this to theory, double loop learning instead of single loop learning may take place (Levin and Klev 2009). Regarding handling of risks, safety is often thought of as the control of risks, which implies that other strategies than correction of single factors are effective. In-depth knowledge of the system and understanding of its behaviour can help understanding how the system operates safely and why things do not go wrong. From what the interviewees told, the individual factors of curiosity and interest in the field are important in expanding ones knowledge about the system. And the factors openness to change and curiosity may be a driver for change. Learning from successes and normal performance is a main principle of Resilience Engineering (Dekker et al 2008). It may be so that people particularly interested in their work, that are curios about the systems they work with and are open to adapt to new things drive the organisation towards resilience.

Another interesting finding was the fact that relations between employees were frequently mentioned in the interviews as a factor influencing collaboration. Social relations affect trust between people and may improve or hinder collaboration. Breaking down social barriers, removing practical barriers, organizing for team work and sharing of information may facilitate collaboration. "If you know the people you are working with, collaboration becomes easier" one informant said, while others mentioned practical barriers like having the right communication tools available and knowing who to contact in different situations. The case company has different tools like telephone, e-mail and video conference and has as a practise to use the communication channel that is most appropriate for the given purpose. Other things that may increase collaboration are regular scheduled meetings. When meetings take place on for instance a weekly basis one ensure that collaboration take place regularly. One interviewee pointed out that regular meetings helps maintaining the relation to the people you work remotely with and it is easier to make sure the formal sharing of information takes place. It may sound simple but it may be a good solution if lack of regular meetings lead to less collaboration – at least one may prevent decisions to be made without involving all actors that should be involved. Other routines that break down organizational barriers for collaboration are for instance procedures for informing different people, routines for having people look over each other's work, interdisciplinary planning meetings, regular evaluation meetings an so on and so forth. Relations between colleagues that work together in teams are also important and there are indications that those relations are good since many mention that they find their job interesting and are happy with their work situation. It is difficult to point out from the interview data exactly why they like their job, but the current organization of the drilling and well operations may be beneficiary in that way – or the organization may have attracted the right people to work for them. Relations between superiors and employees are another factor influencing the work situation and the organization's adaptive capacity. “My boss is fantastic” one informant said and emphasized that “he really supports us in our work, and is very open to test out new things”. Superiors that are open to change and are willing to invest in new technology and let the workers try out new solutions may drive the development forward. Both hardware and software applications need to be tested before introduced on a larger scale. By testing out new technological solutions and work forms, the new technology can be fitted to the organization’s needs and the users can adapt to the technology. Adapting to changes is at the core of the Resilience Engineering thinking, and the empirical data suggest that the case company is good at this.

Learning on different levels

A great number of formal processes during a drilling project ensure that lessons learned are documented and stored in written forms. Together with all the stored realtime data (and the analyses) this lays a foundation for a valuable knowledge base. However, it seems that a lot of knowledge remains in the individuals’ own knowledge databases – informants indicate that relevant experience is the single most important factor for a person working with drilling and much of this is not stored in written form. Even though much knowledge is actually already be documented today, interviews indicate that more knowledge could be shared and documented than today. More use of analyses may capture some of this knowledge since doing post run analysis is a way of documenting experience from operations. Besides that the interviews revealed another major source of knowledge; the practical knowledge. This tacit knowledge described by Levin and Klev (2009) as knowing how to do things is more difficult to express explicitly and share through some kind of media. Keeping the experienced employees and enhancing sharing of tacit knowledge between co-workers through team work seems to be a good strategy in order to maintain the practicable knowledge in the organization. Significant amounts of the tacit knowledge may be difficult to share with others, but there are strategies that may help in achieving this. Reflection on current work practice with the individual worker during execution of the task is one way of spreading practicable knowledge according to Levin and Klev (2009). This kind of reflection and knowledge sharing seems to take place within drilling team offshore and within the team of engineers onshore, but there were few indications of this taking place between onshore and offshore workers. With such reflection taking place, it could perhaps make the case company less dependent on the experience of the drilling contractor’s personnel since more of this knowledge would be “in-house”. In general there are some indications that reflection on work practice across teams and disciplines is little present in practice, and that sharing of knowledge between could be improved. This may expand the organizational redundancy and polyvalence beyond that one between colleagues working together daily to spread it to more people elsewhere in the organization.

The fact that interviewees mentioned drilling and reservoir specific knowledge was interesting from a complex system perspective. The uniqueness of a complex system may require specific knowledge about the system's behaviour and they way informants describe drilling and well operations indicate that experience from relevant operations to a certain degree is a key factor for efficient and safe operations. Hollnagel (2010) point out that specific knowledge about the system and its environment is central in anticipating and detecting risks. To achieve/ensure good learning, specific and relevant information is needed – and given the aspects of tacit knowledge discussed in the previous section – having the people with the right knowledge is important in order to achieve resilience in drilling and well operations.

Principles from sociotechnical theory illustrated

What was visible in the interviews was the aspect of small autonomous groups and joint optimization. The case company has organized their human resources into smaller groups that work together on tasks within a specific field. The work groups interact with each other and contribute to the whole systems performance. Interactions in the system are visible through decisions, plans, analyses and other types of output from one team that other work groups use as input in their work. By looking at the work situation one can find several of the core principles from the sociotechnical school. A number of data sources and different types of tools are used when performing the jobs, which is regarded good for individual development and maintenance of skills. Applying different IT tools illustrates the interaction between human and technology that make up the whole organization. The jobs they do consist of whole tasks within their specialist field and are not decomposed into smaller tasks and then delegated. Instead they interact with other people and work groups to complete their work. In order to make sure their work is useful for the receiver, and the organization as a whole, they need to involve the people that receive so that they understand the product that is delivered. For example the planning tasks done by well planners seem to be whole tasks but at the same time performed in cooperation with subsurface people and drilling engineers. The same seems to apply for the realtime data engineers that work autonomously but in collaboration with drilling optimization engineers and the offshore drilling crew. They use a set of inputs, apply different software and communication channels and collaborate with several other colleagues. Also the people using the output in their transformation processes, using Grote's (2004) words, may have preferences in respect to what output they receive. Since their work has impact on others work a joint optimization takes place, and collaboration with other work groups seems to make the employees see the big picture and understand the whole system better.

Risk awareness and Proactiveness

Risks are assessed at different stages in a drilling project and by different actors in the organization. Already when evaluating a project in the concept phase, possible risks are addressed. From early geological surveys and selection of target locations through well profile and well collision to wellbore architecture and final well design, some kind of risk assessments are performed. The authorities' regulations definitely play a role in ensuring that risk assessments are performed and that safety is a focus area. But also the employees told they are very aware of safety risks the organization is exposed to in its daily operations. And it was not only HSE staff or drilling superintendents that expressed strong focus on safety. All people from geologists and well planners to drillers, drilling engineers and drilling optimization engineers mentioned safety as one of their main tasks. From what they tell, they are not only being aware of risks through the company's safety activities like risk assessments, but they actually see possible safety risks in daily operations with their own eyes. Also incidents and accidents in drilling, above all the Deepwater Horizon disaster, have been given attention from the media and may work as a reminder of the potential risks in drilling and well operations. Risk assessment is in general regarded a proactive safety measure, in the sense that it both identifies possible safety risks and safety measures, but also facilitate understanding of the system and increase risk awareness. By including different types of risk assessments at different stages the organization seems to be proactive, since the outcome of a risk assessment should be an organization better prepared to manage the risks it may be exposed to.

Measures of resilience

The stream of realtime data provides a valuable source for monitoring current operations, and from what interviewees indicate one can use it to indicate future scenarios by utilizing historical data and knowledge about the system. Since specific knowledge about the specific well and reservoir was regarded as so important and much of the knowledge appears to be tacit, the organization seems to rely quite heavily on individuals' knowledge. More indicators of safety available for use during operation might be valuable for assessing risks and make operational decisions. Perhaps increased efforts to analyse historical data could establish stronger causal relationships of lagging as well as leading indicators. The great number of runs on the same oil field can provide a great statistical material for creating quantitative indicators and the sensor data transmitted realtime could then be more automatically monitored than today. For instance certain changes in drilling parameters like temperature and pit volume may give clearer indications on changes in risk level than is the case today. Through stronger empirical evidence of an indicator's validity, it might be more valuable as decision support. And along with that the organization could develop procedures for a greater number of situations, which might be useful for the onshore drilling support engineers and the driller. Taking on a Resilience Engineering perspective, successful handling of events provide important learning – not only absence of risks but also successful coping with risks when they occur indicate resilience – and development of best practice should focus on learning from successes as well as failures like the post run analyses seem to do. Furthermore, documentation of the effectiveness of analyses and recommendations from drilling optimization engineers may increase trust in their support work. If one is able to show the effectiveness of analytics and establish relationships between recommendations and successful operations, one may increase the credibility of analytics. The organization may then be willing to utilize collaboration technology more and benefit more from IO.

Besides indicators of the physical processes downhole, measuring the organization's status with respect to human and organizational factors might be valuable. This study found several human and organizational factors that were seen as important for safety performance in drilling and well operations. Measuring these aspects may seem difficult at first sight, but a number of indicators have been suggested by researchers. In the Norwegian petroleum industry a methodology for operational risk analysis (BORA 2007) has been developed in order to model both technical, human and organizational causes for process leaks. Here risk influencing human and organizational factors are included in a total risk analysis. Another source for measures of organizational and human factors is the safety culture indicator project by Swedish Radiation Safety Authorities, where a greater number of leading indicators of safety are listed for each category feedback, monitor and drive indicators. However, inclusion of human and organizational in risk assessments seems little established (Weltzien 2010) and new approaches may be necessary. This thesis sought to address the impact of organizational factors on safety in IO, and the qualitative analysis of the case may be seen as a way of addressing that.

Automation

Introduction of new technology is one of the main characteristics of Integrated Operations, and with new technology one may introduce more automation. Taking on Grote's perspective on limits to control in automated system one comment should be made on this subject. Practising of skills familiarization with the system is important in order to operate and control the systems in the right way. This is in line with the already mentioned aspect that several informants' comment about lack of offshore experience, which may limit the onshore support engineers' understanding of what is going on on the rig. With new technology and more automated systems one may not only loose personnel with experience from operating the traditional systems, but the present organization may also have less opportunities for attaining knowledge about the new systems. However, the systems in drilling today does not seem to be very automated as there are people interpreting the signals and doing analyses on the data, and they therefore seem to know the data and software they use quite well. What may be an area of improvement is the offshore people's knowledge about drilling optimization technology. If the driller had more knowledge about the drilling parameters, he may have been more able to use the data or at least more willing to utilize more analytics when performing the job. For the driller it seems difficult to have deep knowledge about everything from formations and physical processes in the reservoir to measurement tools, drilling equipment and design of the well. But a better understanding of the systems and methods used for analysing realtime data may make it easier for the driller to utilize analytics. Support from other experts seems to be important, but a certain amount of knowledge about the system one collaborates with seems to be advantageous. For example in one interview mentioned the rig crew's unwillingness to use more measurements in the drilling operations.

The data indicate that access to realtime data and employment of analytics has been one of the positive effects of IO with respect to safety. Utilizing more new technology in the future may give potential for automatic detection of risks and initiation of response. As long as the indicators the automated systems use are valid and reliable – and human operators assist with quality controls of the system and perform assessments the AI system is unable to do – artificial intelligence type tools may be valuable. However with introduction of more AI (artificial intelligence) systems, one should also be aware of the limits to automation control and the possible negative effects of operators being less familiar with the system. As companies integrate their operations and utilize more automated systems that may be a rising problem if employees do not get enough possibilities to practice skills and be familiar with the systems they will operate.

Engineering a resilient and high reliable organization

A summary of characteristics of the case organization that may explain how and why resilience is achieved concludes this discussion. Many of the empirical findings in this study are also present in theory, and the thesis therefore derives from this suggested ways of engineering a resilient organization. The empirical data showed that the central principles from sociotechnical systems theories were embedded in the case company's drilling and well operations. Analysis of the data also clearly indicated the relevance of Resilience Engineering and HRO. Especially when asked about the special characteristics of drilling and well operations and challenges related to drilling the interviewees made visible the uncertain and complex attributes of this environment. Performance variability and the dynamic nature of events was frequently underscored in the interviews, and is precisely what the theories of Resilience Engineering and HRO focus on through people's adaptive capacity respectively functional decentralization and organizational redundancy. These findings from the empirical data and theory may justify use of the principles of Resilience Engineering when operating in similar environments. Based on the findings recommendations on how to engineer resilience and maintain a resilient organization are presented.

5.2 Recommendations

Extracted from the collected data, and supported by theory, a set of recommendations for how to engineer a resilient organization in the environment of drilling and well operations are presented here. The recommendations are mostly relevant for oil companies operating in similar contexts, but may also be useful for oil companies in other environments and organizations from other industries operating in similar contexts. Eight points summarize the recommendations for engineering resilience:

- **Expert teams.** Working in team of specialists creates an environment for collaboration, sharing of ideas and knowledge, and redundancy. The employees can share their own views, ideas and tacit knowledge with colleagues as a natural part of their daily work, and colleagues can look over each other's work and give feedback. The case company is one example where engineers with background from relevant disciplines like petroleum engineering, geology or mechanical engineering work together in open space offices in the onshore drilling support center.

- **Extensive relevant experience.** Work practice from similar contexts makes employees familiar with the systems they work with and gives the right knowledge. Team work as described in the previous point is one way of attaining relevant knowledge, but also experience from the specific systems and environments one will cooperate with like offshore work experience for onshore support engineers is advantageous. For instance it is preferable that geologists have worked with the same oil fields for some years, that drilling engineers have experience from both offshore and onshore, and that optimization engineers have worked in onshore support centres (e.g. as a realtime data engineer).

- **Processes that facilitate collaboration and learning.** Frequent evaluations and documentation, both the regular planned and the informal irregular activities, influence collaboration and the learning process positively. Simultaneous meetings and morning meetings are examples of planned meetings while the Obs reporting is an example of a more irregular type of documentation. Having meetings with people from other organizational units can make employees understand each others needs better and ensure that relevant actors are present when decisions are made. However collaboration across organizational borders and disciplines should be balanced with working in expert teams so that also the specialist competence is developed and maintained.

- **Extensive use of analytics.** Application of statistical and mathematical analysis on realtime as well as historical data may serve as valuable decision support during planning and operation. Combined with experience, more can be anticipated and operations can be safer and more stable.

- **Best practice database.** Reports from operations and drilling projects, risk assessments and procedures for handling different types of situations should be documented and shared within the whole organization. In addition attempts to document tacit knowledge through discussions and reflection on work practice should be made.

- **Invest in new technology and facilities.** In order to get accurate and reliable measurements investment in ICT infrastructure, software and quality assurance systems that are reliable should be prioritized. With trust in the data and technology people may be more willing to use it. Having the right facilities, like open space offices and video conference rooms, may facilitate collaboration and integrating of operations. Data quality and reliable technology is vital for safety.

- **Openness to change and innovation.** Managers that support and encourage innovation and change can help stimulate employees to test out new technology and new ways of working, which again can drive the organizational development process forward. For example testing of new software applications may lead interfaces that fit the organizations needs better and thereby improve the systems for monitoring of risks. Because the environment changes continually, the organization need to adapt in order to maintain resilient.

- **Curiosity and risk awareness.** The organization should courage its people to question the established and not take past successes as a guarantee for future success but instead constantly look for risks. For example questioning a well established safety procedure may reveal new ways of handling risks. Being curious about how the system and its environment functions may help people understand the system better and know what is the most important details to focus on in order to monitor and respond to risks.

6 Conclusion and implications for further research

This thesis suggests that the way the case company has organized its drilling and well operations is one way of creating a resilient organization. The organization undergoes changes of different types and has to make different adaptations. The step change in technological development and integrating of operations has gradually taken place over the last decade through a multitude of smaller changes. Transmission of sensor data from rig to shore in realtime, communication with people and access to huge databases with historical data is the result of the development over the recent years. Sufficient data quality, reliable technology and use of analytical methods has supported technology as a driver in this development. Another driver for change that has enabled the organization to make use of the new technology are the organizational changes like new work processes, new organizational structure and new work forms. In addition changes may occur in workforce due to retirements and recruitment of employees, in the employees' behaviour due to general changes in the modern society, and in the organization's work procedures due to new regulations. Such changes will probably also affect the organization in some ways and illustrates the need for the organization to constantly analyse the present situation and respond to changes.

In daily operations the people have to constantly monitor the processes and adjust to changes in the environment. The theories of Resilience Engineering – which has roots from theories within the sociotechnical school, HRO and other disciplines like ecological resilience, complexity theory and systems thinking – view these features as typical for a modern system and propose strategies for creating resilience under such conditions. People that are open to change and curious about how the system is functioning make a contribution to the safety in the organization. Along with their interest in their work they develop specialist competence through work experience. Investment in new technology and the organization's willingness to apply the new technical equipment and solutions lays a foundation for improvements. The organizational division into into expert teams and the integration of people across work groups and geographical locations seems to be a good arrangement in order to utilize its human and technological resources.

The specific recommendations for how to engineer resilience into an organization are summarized in the eight points listed in chapter five. Based on the empirical data from the case, which mainly was centred around the onshore drilling support center, and compared with theory the following main points for how to engineer resilience are suggested:

- Teams of experts working closely together in open space offices, developing the workers' competence by having discussions around their work and giving each other feedback.
- Experience from relevant work practice
- Organizational processes facilitating collaboration, like planning meetings and evaluations.
- Extensive use of analytics. Utilizing the access to historical and realtime data by applying analyses on the data and derive recommendations from the analyses.
- A database of lessons learned and best practices.
- Investment in new technology and workplace facilities.
- Encourage openness to change among managers as well as engineers and offshore drilling crew. Stimulate employees to test out new things and create positive attitudes toward technological as well as organizational change.
- Attract people that are curious in general and interested in their field to the organization and encourage people in the organization to question the established and constantly look for possible risks and improvements.

As with all changes there are both positive and negative effects. Because the new things IO brought about have improved a lot during the last years, many of the negative effects and possible safety risks have been reduced. But as changes are likely to occur in the future, the change management process should be continuous. It is also of high importance to be aware the possible negative outcomes a change may produce and the second hand effects that the system may produce. Decreasing offshore experience among the employees and increased ICT dependency are challenges that should be addressed. Although the organization seems to be aware of many factors that may affect the risk level negatively, the recognition of those factors does not imply safe operations in the future. In the same way that absence of incidents does not guarantee future safety, knowledge about possible problems alone does seldom solve the problems unless solutions are produced and implemented. A constant discussion about risk and the ability to invest in safety even when things look good are other essential resilient abilities. And especially for systems that are exposed to frequent changes the implications of the changes should be evaluated on a regular basis.

The recommendations in the previous chapter list possible key factors in achieving resilience, like human redundancy, curiosity and openness to change, team work and use of analytics, that may be helpful in engineering a resilient organization – not only for the case company in maintaining safe operations but also be other companies. Other developments like introduction of AI systems and safety indicators from drilling parameters should be investigated more in detail before a recommendation is made. Even though they may improve operational efficiency, possible risks with automated systems and the limitations of quantitative safety indicators should be taken into account before implementing them.

While this thesis focuses on many important factors related to safety, not all relevant aspects are examined. Other important factors like power and the trade off between safety and economic aspects are not the main focus of this thesis and might be interesting for other researchers or students to focus on. Neither the role of the authorities or laws and regulations were investigated in detail, but what type of regulatory regime and internal rules that apply to drilling and well operations and their impact on resilience might be interesting to study. To perform case studies on other oil companies or organizations in other industries in order to establish a better understanding of how resilience is achieved in similar context and thereby correct or supplement the recommendations in this thesis might also be a possible avenue for future research. Another specific interesting topic to study is the impact of ICT dependency; how to reduce risk associated with ICT dependency and how to operate when IT infrastructure breaks down and offshore crew is limited or absent. The effects of changes in the society that new consumer electronics and the social media revolution produce and their effect on job performance and HSE could also have been compassed in a study like this thesis. Finally, development of quantitative indicators based on realtime data and automated systems for detection of risks and initiation of responses would be interesting to study more in detail for future research.

7 Limitations

This master thesis studied one case, and only a portion of the employees participated in the data collection through interviews and observations. Interviewing more people might give a more accurate picture of the organization's and its functioning. However both the alternative of more case objects and more interviewees would be far too much work for one semester's work. As mentioned in the conclusion other researchers may find it interesting to do similar studies on other organizations or expand this type of study with an even greater data collection. On the other hand, having done depth interviews with four people from the study object's core unit – the onshore drilling support center – should give a rather good picture of that unit. In addition to that interviewing personnel from other major units in the organization's that are involved in drilling and well operations was intended to give a better picture of the organization's drilling and well operations as a whole. Interviewing more offshore employees may also have given other results, even though many of the interviewees had some experience from offshore. The transferability to other industries may be hard to determine, and more research is needed to evaluate the transferability of this study. Even though theory supports the findings, empirical data from other studies would be to prefer before general guidelines can be developed.

Social interactions in the interview setting may influence the informants according to Bryman (2008). Using questionnaires instead could have prevented this, but surveys have other disadvantages like response rate and misinterpretations of questions. By keeping a consistent conversation and avoiding interruptions the effects of social interactions and interviewer variability may be reduced (Mieg and Näf 2005). Other possible sources of uncertainty are the misinterpretation of answers and misunderstandings by the researcher and the representativeness of the subjects answers. Most of the informants were contacted only once during the period of data collection and only one interview may not be 100% representative for their views and opinions. On the other hand the results of this study were sent over to the interviewees for verification and the informants had the possibility to correct and add things to their answers. Review of the report by the thesis supervisor and the case company's contact person was another measure to reduce these sources of limitation.

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Appendix

Appendix A: Interview guide

<u>Part one</u>

Introduction

My name and background
Purpose of interview
Confidentiality and handling of data

Interviewee's background

osition/role

epartment (company)

ducation/field of expertise

Guiding principles

Open questions, semi-structured.
Facts first, then attitudes and opinions
Ask for clarifications when necessary
Be aware of objectivity and neutral behaviour yet taking on expert role

General description of work

Who does what?
How many people are there per work team/group?
What coordination with other departments takes part?

Tasks

hich main services/goods are produced?

hich secondary tasks (e.g. maintenance) are there?

o your tasks cover a whole production process/product, or just part of it?

Organization

hich roles and functions do you have?

hat decision latitude

ho is coordinating your work?

ow much is your supervisor involved in your work?

Communication

Which formal and informal meetings take place?
Who and how often?
How much communication is there with internal vs external?

Order processing

hat type of orders do you receive from other systems?

hich systems are "downstream" and "upstream"?

hich inputs are received and which outputs are produced?

Variances and disturbances

re there often changes in the orders?

hich variances occur?

hat are the sources and causes of variances?

<u>Part 2</u>

Interview course/process: Start with general questions on daily work, IO and safety. Then dig into specific topics. Try to examine all relevant topics, but focus on the most interesting in each interview situation. Use the list to check that all items are covered.

<u>Core questions</u>

- **General about work, collaboration technologies, safety**

1. Which collaboration technologies (tools and applications) do you use in your work? (11, 12)
2. Does collaboration technology enable you to do a better job?
3. Can you mention some main safety issues in well and drilling; what contribute to safety and what could suppress safety? (2-10)
4. Are there situations when unexpected conditions/disturbances occur? What types? How is it solved/managed?
5. What in your job (environment) demands extra awareness, experience and collaboration? (2-7, 9, 10)
6. How is safety monitored? (2, 3)
7. When do you intervene, take special action, and make changes? (2)
8. Do you feel/are you of the opinion that use of collaboration technologies makes operations safer? (2-12)
9. Why is drilling and well operation safe/not so safe? (2-12)
10. Are there situations were procedures must be strictly followed? Situations were local adjustments (improvisation and flexible use) are more adequate than rule compliance? (7)
11. How do your work influence (and are being influenced) elsewhere in the organization? (6, 7)
12. How are you bounded and depended on other workers/units? (6, 7, 10)
13. How do you feel that you contribute to resilience (safety and efficiency//regularity/flow?

<u>Specific topics</u>

- **Monitoring and responding – what you look for and how you respond**

1. Indicators of safety, regularity, cost, progress
    1. List?
    2. Leading, current and lagging?
    3. Quantitative and/or qualitative?
    4. Temporary or permanent changes?
    5. Measurement frequency?
2. Too which degree are there interpretation vs automatic detection
3. Describe the transparency of work flow (seeing what other actors do)?
4. Which criteria are there for when to intervene/make changes?
5. Are there predefined events and situations (list) for which responses are ready made?
6. Which resources are needed and are they available when needed?
7. How are the event list and response selected, verified and reviewed?

- **Anticipation**

1. What is anticipated/forecasted?
2. Who anticipates and how is it communicated?

3. Fundamental assumptions and model of risk?
4. Transparency of work flow (seeing what other actors do)
5. What is the risk acceptance criteria applied?

- **Learning**

1. Is learning a discrete or continuous process?
2. Is it event driven, regular/planned activities? Does daily unplanned learning takes place naturally?
3. Which principles for searching/investigation (WYLFIWYS)
4. Does learning from failures and exceptional events dominate, or is successes and normal operation used for learning?
5. Are the necessary resources available?
6. How are the “lessons learned” shared and communicated?

- **Variety**

1. Does the tasks provide use of different
    1. Techniques and methods
    2. Tools (materials)
    3. Duration per job
    4. Sequence of operations
    5. Cooperate with different people?

- **Autonomy and dependency**

1. Autonomy (decision latitude) on individual and group level:
    1. goal setting,
    2. organization of work,
    3. ways/means of processing orders
2. Involvement by work system's members in planning and decisions
3. Clear distribution of responsibilities
4. Bounded by decisions made by others (geologist, drilling superintend,) ?
5. To which degree can you continue your work independent on other?
6. Other teams dependent on your work (deliveries, approvals, deadlines)

- **Procedures (flexibility and routines)**

1. Flexibility in work flow
2. Opportunities for local corrections and adjustments
3. How is the balance between flexibility and standardization?
4. Which types of rules are used (normative, goal, procedural guide, exceptions)
5. Are procedures adequate for the majority of your work? Situations where rules and procedures are inadequate?
6. What possibilities (and requirements/restrictions) are there for local improvisation?
7. Could you give examples of flexible rules (adjusting the rule) and flexible use (applying a rule in other situations) of a rule?

- **Risk assessments in daily operations**

1. Which risks assessments are done during daily operation?
2. When are risk assessments revised?

- **Communication and coordination**

1. Communication form, channels and tools
2. Coordination and mutual problem solving
    1. Within rig team

2. With contractors
3. With ODC
3. Requests, provision of support and need for support

- **Competence building, knowledge sharing and skill development**

1. Which competence is required and how
2. Problem solving required?
3. How much of your knowledge is employed weekly, and is acquisition of new skills and
4. Polyvalence of employees
5. Sharing of experience within the a) company and b) with contractors

Appendix B: Observation guide

Observation of work practice

- What communication tools are used?
- Which is used for which purpose?
- How is data from drilling process monitored and analyzed?
- What collaboration takes place within teams and with other teams?

Observation of meetings

What communication tools are used?
Which topics are discussed?

Check list:

- Write down notes as quickly as possible after seeing/hearing something interesting, at the very latest at the end of the day
- Vivid and clear notes
- Clear focus; knowing who and what to observe; and what the research problem is
- Mutually exclusive (not overlapping) and inclusive (cover all aspects)

- Guidelines for interpretation (when f.ex difficult to understand the difference/distinguish between two types of behaviours)
- Record incidents, record for short periods of time, long periods of time.
- Ad libitum sampling: recording everything. Focal sampling: all behaviour of interest from a specific individual. Scan sampling: scan entire group at regular intervals (only one or two types of behaviour). Behaviour sampling: watch entire group and record who is involved in particular kinds of behaviour.
- Be aware of reactive effect (changing behaviour when being observed)