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Well Integrity Assessment: Challenges related to Human and Organizational Factors - The case study of Veslefrikk

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Preface

This thesis is submitted in fulfilment of the requirements of the Subsea technology MSc program at the Norwegian University of Science and Technology (NTNU). The research presented has been carried out at NTNU in Trondheim in the spring semester of 2015. The reader is assumed to be familiar with the specialized field of human and organizational factors regarding drilling and well operations. A decent understanding of the work done by James Reason (Reason, 1990) and Barry Kirwan (Kirwan, 1994) is recommended to fully understand the findings in this thesis. The reader is further assumed to have a basic knowledge of different standards and guidelines like NORSOK D-010, NORSOK D-002 and OFL-117. The reader should also be familiar with subject in the NTNU courses TPK4120 Safety and Reliability Analysis, TPG4200 Subsea production systems, TPK5165 RAMS Engineering and Management and TPG4105 Petroleum technology

The job market for the oil and gas industry is not at its peak at the moment. Discussion with my supervisor Marvin Rausand reviled that a project related to human and organizational factors could help opening doors for a possible career in other industries than the oil and gas industry. The project started when Marvin sent me a survey performed by Birgit Vignes which gave me many ideas on how to perform the project. The project has been carried out in cooperation with a drilling supervisor from the global oilfield service company Archer, employed at Veslefrikk.

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Alexander Fon Hals

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I would like to thank Marvin Rausand and Anne Barros, professors at the Department of Production and Quality Engineering at NTNU, for excellent supervision and helping me determining the theme of this thesis. I wish to acknowledge the drilling supervisor at Veslefrikk Harald Engesland for providing the necessary data needed to be able to complete and produce a decent result relevant to the industry. I would also like to thank Ann Kristin Fon, Knut Edvard Hals and Tonje Ødegaard for help and support during my MSc degree work.

A.F.H.

Summary and Conclusions

Well integrity affects safety, humans, the environment, production, reputations and assets value. The concept of well integrity in relation to human and organizational factors have gained considerable attention in the petroleum sector in Norway over the last few years. This is not without reason. Resent studies shows that a simple mistake like dropping a hammer, may not only be caused by the obvious direct cause like inattention but may be caused by several underlying causes such as deficiencies in the design of the drill floor, operating instructions, follow-up of safety notices, competence, planning and implementation, deficient management, and breach of procedure. Historical events like the Piper Alpha incident shows that these underlying causes or human and organizational factors are vital to develop and improve the systems. This means that improving human and organizational factors may contribute to the improvement of well integrity.

This thesis will explain the concept of human and organizational factors through a detailed literature Survey. Different models and methods have been presented (the human performance model, Decision making, the "Step ladder" decision model, performance influencing factors, human error causation paradigm, human-, technology- and organizational perspective) to give the reader a decent understanding of the concept. It is important for this thesis that the reader is given a detailed insight in this aspect since most of the project tasks in this thesis is answered using these models and methods.

Human error has been identified as a primary causal factor in 70-80% of accidents in the oil and gas industry. Identifying and classifying the human and organizational factors of an accident is an effective tool to assist in the investigation process, the target training and make it easier to implement prevention efforts. Through discussions and careful analysis of five methods deemed fit for classification of human and organizational factors in the oil and gas industry, was the STEPP method identified as the best classification scheme for human and organizational factors relevant to well integrity in various phases of a well's life.

Well integrity is vulnerable to unforeseen factors that have a critical influence on the work performance. Understanding these unforeseen factors and the relationship between them through a human, technological and organizational perspective can give better working environment

and an opportunity to improve the health, safety integrity, and work performance. Challenges revealed through the human, technological and organizational perspective were identified and categorised as: well control training and knowledge, well integrity training and courses, human computer interface, qualification and testing of well barrier elements, verification of well barrier elements, automation, national and international standard, well integrity management system, handover documentation and well barrier schematics.

Challenges related to human and organizational factor at Veslefrikk have been identified using the human error causation paradigms. The different paradigms (the engineering error paradigm, the individual error paradigm, the cognitive error paradigm and the organizational error paradigm) look at the situation from different points of view. The results from this thesis identifies challenges at Veslefrikk related to: the driller's chair, placement of communication equipment, disturbing elements, alarms with no essential function, drillers workload, service companies and their lack of risk understanding, difficulty in locating relevant procedures, the sheer amount of procedures, time pressure, installation specific training, experience, meetings is being prioritized ahead of actual drilling operation and the departure meetings are too general. Comparison with the overall industry shows that the human and organizational factor situation related to well integrity on Veslefrikk is overall better.

When all of this is taken into consideration means that this thesis objective:
Have the implemented measures proposed by PSA and DNV had any effect on the HO factors related to well integrity in the various phases of a well's life, at Veslefrikk?
Can simply be answered with the word, **YES.**

Measures can be initiated to eliminate the identified challenges at Veslefrikk and in the overall industry.

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Chapter 1

Introduction

1.1 Background

Well integrity is defined in NORSOK D-010 as "application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well". Maintaining well integrity during all well operations has become a major concern for operators worldwide. An increasing well stock with old wells and the higher cost associated with new wells, makes well integrity a critical element of asset lifecycle management. Unfortunately pinpoints many accidents like the Snorre incident(Petroleum Safety Authority, 2005; Pettersen et al., 2006), the Montare incident (Stuart and Foo, 2010), the Macondo incident (BP., 2010) and the Piper Alpha incident (Oil and Gass UK., 2008) that the focus on well integrity in all phases of the well, still need further improvements.

Investigations of major accidents show that a problem area related to well integrity in all phases, is the clear lack of focus on the interaction factors between human, technology and organizational elements. These critical interactions of human and organizational (HO) factors may be hard to detect if not all of the possible interactions between the different elements are considered. Unforeseen critical interactions/factors may have a critical influence on the work performance of the operators and crews, and may have a bad influence on well integrity. Therefore the awareness of HO factors related to well integrity increased significantly over the last few years. This thesis mainly addresses the studies preformed by the Petroleum Safety Authority (PSA) and Det Norske Veritas (DNV) on the Norwegian continental shelf (NCS) (Asland et al., 2005, 2007; PSA, 2011a; Vignes et al., 2006; Vignes and Aadnoy, 2008; Vignes, 2011; Vignes and Jayantha, 2011). The goal of the studies was to obtain a better understanding and overall perspective of the challenges in the industry. The main studies were preformed in 2005-2006 and have led to industrial well integrity involvement as a development of the Norwegian Oil Industry Association (OLF), Well integrity forum (WIF), OLF well integrity Guideline Number 117, well integrity engineers, increased focus on well integrity competence and training exchange of well integrity experience, handover documentation, well barrier schematics, well integrity categorization, well integrity management systems (WIMS) and an increased focus on well integrity in a life cycle aspect.

Relevant literature from academic articles and books related to the specialized field of human and organizational factors has been gathered which enables the opportunities to identify, evaluate and study the challenges related to the complex interactions between human, technology and organizational elements. The main literature sources for this thesis are the books *"Human Error"* and *"A Guide to Practical Human Reliability Assessment"* written by James Reason and Barry Kirwan and relevant articles and documents written by Birgit Vignes in collaboration with PSA. Other relevant articles , websites and books are listed in the bibliography. The necessary data from Veslefrikk were manufactured using the questionnaire made by PSA and DNV. The questionnaire is given in Appendix B.

Measures proposed by the PSA and DNV studies have been implemented for a few years now. So a comparison with todays situation will revile if the implemented measures have had any effect. Discussions with the drilling supervisor at Veslefrikk reviled that measures had been implemented as a result of the studies, but he was uncertain if the implemented measures have had any effective on the overall work performance. He emphasized that this is of interest for his company (Archer) because it may lead to money savings, fewer accidents, etc. This led me to the following question and this thesis objective:

Have the implemented measures proposed by PSA and DNV had any effect on the HO factors related to well integrity in the various phases of a well's life, at Veslefrikk?

The problem area will be delimit to the HO factors in the drilling and well operations at Veslefrikk. The results gained from the studies conducted by PSA and DNV are used as a benchmark to be able to compare today's situation on Veslefrikk to the overall situation in the industry.

1.2 Project tasks

The following project tasks will be conducted to be able to answer this thesis objective:

1. Carry out and document a detailed literature survey related to human and organizational (HO) factors.

2. Suggest a classification scheme for HO factors relevant to well integrity in the various phases of a well's life.

3. HO factors in the concept of well integrity: What does it mean and what is the importance?

4. Identify HO factors challenges in the drill and well working operations related to well integrity and thereby indirectly improving well integrity.

5. Compare today's situation on Veslefrikk with the overall industry, relevant to HO factors.

1.3 Limitations

The identified challenges in the drill and well working operations are limited to the literature review within this thesis. When writing a Master's thesis, time is a limiting factor when collecting information and analyzing the results. Also, I would like to mention that I am a student and not a professional within the areas studied in this thesis.

There are some limitations regarding the questionnaire survey given to Harald Engesland. The questions have not been customized for the human error causation paradigm. The full potential of the method might have been hindered due to the fact that the data received was imprecise in regard to the methods point of view. Also there is only one viewpoint for one individual analyses which means that the results might give a false indicator on the "true" situation on Veslefrikk.

I would also like to mention that I've been unable to identify which implemented measures was initiated on Veslefrikk, as a result of the original survey. I am therefore unable to identify witch measures that have had any effect on reducing the challenges.

1.4 Approach

The approach to solve this thesis objective:
Have the implemented measures proposed by PSA and DNV had any effect on the HO factors related to well integrity in the various phases of a well's life, at Veslefrikk?
is influenced by the fact that the author has limited experience and knowledge in the areas studied in this thesis. Therefore the theories and models presented might seemed a little bit simplified.

This thesis objective introduces a range of questions: What is HO factor, how can we classify HO factors, how can we identify HO factors, what is HO factors in the context of well integrity and so on. The project tasks are selected to try to answer this thesis objective in the best possible way. The scientific approach to solve this thesis objective is:

1. First, a detailed literature survey will be presented to give the reader an insight into different methods and model related to the HO factors. A presentation of the human-, technology- and organizational (HTO) perspective together with an introduction to HO factor "way of thinking" will be given. This will give the reader a detailed insight to HO factors and make it possible to solve this thesis project task number one.

2. The objective of this thesis is strongly related to previous accidents, and how future accident can be avoided. The ability to prevent future accidents is the backbone of classification schemes. The author's approach to identify a classification scheme deemed fit to the oil and gas industry, will be to present different methods of classification, then recommend the best suited method to solve this thesis project task number two.

3. This thesis objective seeks to understand the challenges the industry is facing, regarding HO factors in the context of well integrity. The author's approach to understand and identify the challenges will be to give an introduction to the well integrity concept and identify

challenges from a HTO perspective. This will solve this thesis project tasks number three and four.

4. Finally, today's situation on Veslefrikk must be properly understood to be able to compare the results with the overall industry. Is the situation worse, better or the same, and why? These questions are of interest for the oil and gas companies and it might be possible to answer or, at least give a hint toward the solution. The author's approach to get an overview of the complex work settings on Veslefrikk is to analyze the feedback data collected with the human error causation paradigms. The result will then be compared with the results from project task number four. Improvement measures proposed by Asland et al. (2005, 2007) will be listed. This will solve this thesis project task number five.

1.5 Structure of the Report

The rest of this thesis is organized as follows:

- Chapter 2 gives the reader an insight into the human performance model, decision making, work performance, performance influencing factors (PIFs) and the human error causation paradigm. A presentation of the HTO perspective together with an introduction to HO factor "way of thinking" is also given.
- Chapter 3 presents the concept of Human Reliability Assessment (HRA), followed by the general objectives and advantages of human error classification. The classification methods: "What, How and Why questions", "Skill-, Rule-, and Knowledge-Based Behavior", "Slips, Lapses, Mistakes, and Violations", "Technique for Human Error Rate Prediction" and "Sequential Time Event Plotting Procedure" are then presented. The method best suited to classify HO factors related to well integrity is the recommended by the author.
- Chapter 4 will give the reader an introduction to the concept of well integrity and elaborate on how HO factors can contribute to well integrity. The HTO perspective will be used to identify the human element in improving well integrity, the technical element to improve well integrity and the organizational element in improving well integrity.

- Chapter 5 presents today's situation on Veslefrikk regarding HO factors. The human error causation paradigms are classified into four different paradigms: the engineering error paradigm, the organizational error paradigm, the cognitive error paradigm and the individual error paradigm. These different paradigms are used to identify and classify the challenges in the drilling and well operations from different points of view. The identified HO factor challenges will make it possible to compare today's situation on Veslefrikk with the overall situation in the industry. Recommendations for possible improvement measures for each paradigm proposed by Asland et al. (2005, 2007) will be listed.

- Chapter 6 presents the summary and conclusion of the objective of this thesis, then the summary and conclusion of this thesis project tasks, followed by the recommendations for further work.

Chapter 2

Literature Survey related to Human and Organizational factors

This chapter will give the reader an insight into the human performance model, decision making, work performance, PIFs and the error causation paradigms related to HO factors. Also a presentation of the HTO- and HO factors perspectives will be presented.

2.1 The Human Performance Model

The human performance model examines the factors involved in human performance and gives an overview of the complex work setting. It helps to spot factors that may have a large potential to contribute to work performance (Bailey, 1996). The model can thereby help to identify human and organizational issues.
Performance can be divided into two levels (Bailey, 1996):

- The perfect performance
- The acceptable performance

The human performance is the activities carried out by the system's human elements (Reason, 1997). Optimal performance is something designers strive to achieve, but the reality is that designers rarely have the requirements and resources to design for optimal performance. The only requirement is that the designers need to be able to ensure an acceptable level of human performance. Work performance is described further in section 2.3. According to Bailey (1996) the following components are needed to be able to predict human performance and to be able to accomplish an acceptable or close to optimal performance: *the human*, *the activity* the human performs and *the context* in where the human activity is performed. The areas where the human, the activity and the context collide and interact are also important to study. The interactions between the human and activity element are a critical interface in regard to the human-machine activities, while organizational barriers can unintentionally create interface problems by providing resistance to change, or that the management does not pay attention to reward good user interface. It is also important to understand that it is equally important to assess the human, activity and context together, and the interactions between them, as to study them separately (Bailey, 1996).

The human

The human is the most complex of the three elements in the human performance model (Bailey, 1996). The senses (vision, hearing, etc.), the brain at cognitive level (the ability to think, find reasons and make decisions) and the responders (arms, fingers, mouth, etc.) are considered in the human elements. The designers do not know the humans who will work in their systems, but it is important to understand and implement in the design how people sense, respond and process information (Bailey, 1996).

Human performance can be affected both in a negative and a positive way. Reduced performance could, for example, be expected because of poor sleep, unsatisfactory hearing, unacceptable behavior (due to for example conflicts, attitude and lack of motivation), lack of abilities or poor eyesight. Lack of knowledge, abilities and wrong attitude may be a source for bad and incorrect decision making and lead to poorly acceptable performance. This illustrates that attitude, knowledge and ability limitations affects the human capabilities and response to an unexpected situation. It may therefore be a hindrance to be able to achieve the main purpose of the task. Human qualities, characteristics and deficiencies should therefore probably be better understood by the designers and engineers, and in the best possible way take them into account when producing the system and making decisions. They have to handle the strengths and weaknesses expected in an expected population of users (Bailey, 1996).

The activity

The activity performed is the next component in the human performance model, and includes any required tools or equipment (Bailey, 1996). The conditions of performance and the executed activities are controlled by the designer, both positively and negatively. It is important to know which type of work can best be performed by certain people and what can be best performed by computer- or automation systems. To be able to achieve sufficient skills for an acceptable or near perfect level of human performance, it is important to know what kind of training is required for the human to perform the activity.

The context

The context in which humans perform the activity may affect the performance and make a significant difference for human performance. Decent working conditions must be provided to the operators. Without this, distractions occur more frequently, which means safe operation of the system may be compromised and the efficiency will drop. It is also important to match the system to the mental ability and skill of the staff (Wong, 2002). Bailey (1996) defines the context as *"the circumstances in which an event occurs"* and tree context considerations are described:

- The physical context
- The social context
- The psychological context

Physical context

The physical context includes the location and the environmental conditions. Examples are noise level, temperature, lighting, vibration and pollution. Noise is probably the single most studied factor in the physical context (Bailey, 1996).

Social context

The social context includes conditions that may affect human performance, such as the effects of other people, crowding, isolation and clustering (Bailey, 1996).

Psychological context

The psychological context may affect human behavior (Wong, 2002). Humans are unpredictable and can have emotions that influence the way they behave and how they respond to the culture at work. A strong and enthusiastic priority to develop a safety culture, education and training related to the work performed is therefore important.

2.2 Decision Making

2.2.1 Potential Decision Making Challenges and Risks

Decision making may be very complex due to dependences between systems components that contribute to a more challenging decision making process. Many parallel events and activities take place in a complex system and these parallel activities may interact in non-obvious manners if the system is characterized by high interactive complexity (Rosness et al., 2004). This may lead to risk due to an increased probability of taking the wrong decisions with serious consequences. Serious accidents may occur because decision making has been deficient due to the fact that a incorrect decision was taken or because no decision was taken when required. According to Hollnagel (1984), the decisions the person makes can shape the performance.

Today, operation centres may receive to much real-time data, and offshore personnel have to cope with more information from the operation than they can handle (Grøtan and Albrechtsen, 2008). In addition, decisions taken at a distance from the actual operation, may increases the likelihood of poor understanding and knowledge of the work settings. The conditions under which decisions are made, strongly influence the outcomes and decision processes (Rosness, 2001). Figure 2.1 shows that communication and cooperation problems, conflicting objectives and a demand of unnecessary information or too little information can cause risks. Also, more group-based decision making may obscure who is responsible for performing the action.

Figure 2.1: Main negative contributions - changes for interaction, communication, decisions and safe operations. The figure is inspired by Tveiten et al. (2007)

2.2.2 Two Dimensions and five Categories for Decision Making

As mention earlier decisions are made in different places in the actual operation. Rosness et al. (2004) note that some decisions are made at the "sharp end" close to the hazard sources, others are made at the blunt end, removed from the hazard sources. The level of authority indicated by the decision makers and decision settings also differ. A manager can issue orders and directives to his or her subordinates, and an inspector can issue directives and impose sanctions on companies (Rosness et al., 2004). Thus we can according to Rosness et al. (2004) characterize decision settings, procedures and outcome according to two dimensions. This is illustrated in Figure 2.2

- *Proximity to the hazard source* (operators facing a gas leakage are in a different situation than the designer of the system)
- *Level of authority* (who can give orders and directives to whom)

Figure 2.2 also shows us that pilots, offshore platform superintendents or aircraft line maintenance personnel usually find themselves at the sharp end, i.e., close to the hazard source. Designers, planners, analysts and regulatory institutions typically operate at the blunt end. Many managers will move to the right in the Figure 2.2 in crisis situations and take a more operational role and even "sharp-end" - decisions, which under normal conditions are left to the operator (Rosness, 2001). These relationships are complex, since decision-makers also adapt to circumstances not covered by these two dimensions. However, Rosness et al. (2004) believe that even a grossly simplified model of these relationships may be helpful in sensitising us to the way decision-makers adapt to their setting. Therefore, five distinct decision settings can be identified and different proposals for associated typology of decision models can be made (Rosness et al., 2004), see Table 2.1. It is also important to acknowledge that Hollnagel (1984) presented different categories to define human decision making and actions.

- Decisions in situations that are familiar and frequent
- Decisions in situations that are familiar but infrequent
- Decisions in situations that are unfamiliar and infrequent

Table 2.1: Dominant constraints, decision criteria and typical problems in different decision mods (Rosness et al., 2004)

Decision mode	**Dominant constraints**	**Dominant decision criteria**	**Typical problems**
Political	Conflicts of interest	Robust consensus	Inconsistency Non-optimal decisions Erosion of safety margins
Managerial	Information processing capacity	Find an option that is good enough (satisficing)	Inafequate problem definitions Stick to SOP Erosion of safety margins
Analytical & Bureaucratic	Hands-on Knowledge	Comply with ruls & standards Optimise selected attributes	Unrealistic assumptions Deficient models Erosions of safety margins
Routine operations	Workload situation awareness	Smooth, efficient operation Optimise workload	Slips Miss warnings Local warnings Erosion of safety margins
Crisis handling	Stress Time to obtain information and act	Avert catastrophic outcomes Avoid extreme stress levels	Defective coping if danger materialise

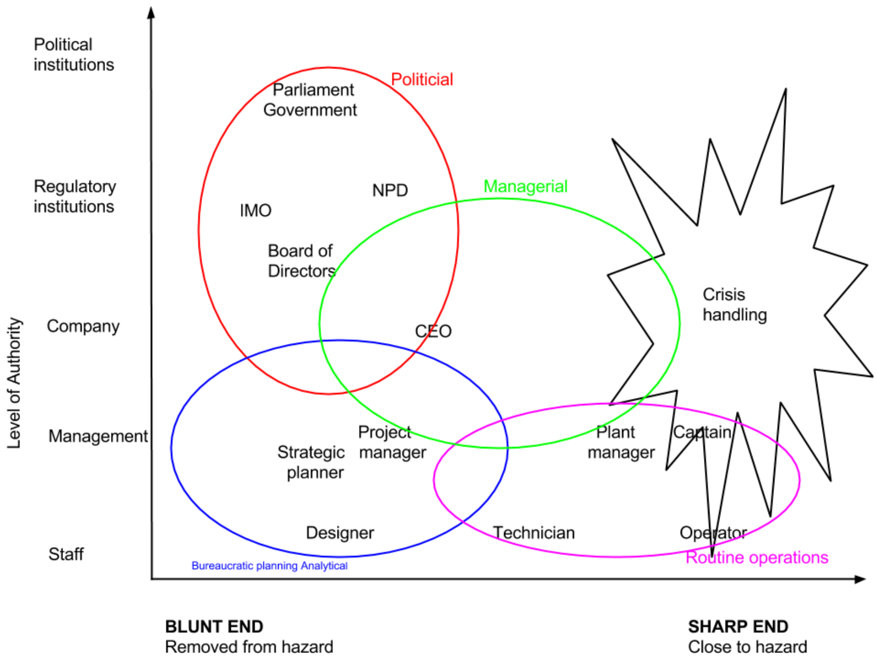

Figure 2.2: Two dimensions for characterising setting for safety related decision making and classes of decision processes. Adapted from (Rosness, 2001). (IMO - The International Maritime Organisation; NPD - The Norwegian petroleum Directorate; CEO - Chief Executive Officer.)

The five different categories listed in Table 2.1 are (Rosness et al., 2004):

1. Political and bureaucratic decision making which is applicable in situations characterized by conflict of interest. This conflict is between the parties who have roughly equal power in relations to the decision. Typical decision problems may be inconsistency, non-optimal decisions and erosion of safety margins (Rosness et al., 2004).

2. Managerial also known as "satisfying decision making" characterizes many management decision makers that do not have the capacity to search for the optimal action alternative. The manager therefore chooses the first acceptable alternative. The working day for managers at high levels are characterized by many decisions, lack of time and large amounts of information to be handled. Typical decision problems are inadequate problem definitions and erosion of safety margins (Rosness et al., 2004).

3. Bureaucratic planning or optimization means that one under the given constraints seek an optimal decision alternative based at models that does not capture the reality together with incomplete knowledge. Designers, planners and risk analysts often have sufficient

time to focus on optimization, but they often lack experience with the systems they are working with. Other problems may be unrealistic assumptions, limited feedback, deficient models and erosions of safety margins (Rosness et al., 2004).

4. Routine operations decision may lead to conflicting objectives between process operators and others who work close to sources of danger. The most of the time they have a focus on operating efficiency, avoidance of interruption and keeping their workload at an acceptable level. The routine decisions can be fully automated or programmed through procedures and instructions. Typical problems may be slips, missed warnings and erosion of safety margins (Rosness et al., 2004).

5. Crisis handling decision happens when the decision maker face imminent threats. A typical problem may be unpleasant stress, psychological limitations and defective coping if danger materializes (Rosness et al., 2004).

2.2.3 The "Step ladder" Decision Model

Decision models are proposals that predicts how the internal processes of the decision making system are organized and structured, and account for how decisions are made. The human performance model known as the Step Ladder Model is the best known model and developed by Rasmussen (1983). The model is illustrated in Figure 2.3. This model, depicts the various stages that a worker could go through when handling a process disturbance (Rasmussen, 1983).

If the worker has to utilize the knowledge based mode he or she will traverse every information processing stage represented by the boxes connected by the arrows in Figure 2.3 (Embrey). As in the GEMS[1] model, if the situation is immediately recognized, then a pre-programmed physical response will be executed in the skill based mode (e.g. by moving the process on to the next stage by pressing a button)(Embrey). The "Step-ladder" model identifies eight steps of decision making from activation to execution (Redmill and Rajan, 1997) and three types of decisions are identified (Rasmussen, 1986) listed in Table 2.2.

According to Embrey, it might be necessary to go to the rule based level if the nature of the problem is not readily apparent. A diagnostic rule will be applied to identify the state of the

[1] A generic error-modelling system

Table 2.2: Identified steps of decision making and different types of decisions (Redmill and Rajan, 1997; Rasmussen, 1986).

Decision making	***Decisions types/categories***
1. *Activation* - Detection of need for data processing.	1. *Skill-based* - decisions proceed directly from detection to the execution with few intermediate mental steps.
2. *Observation* - Gathering of information and data.	2. *Rule-based* - decisions require a mental representation of the system state (e.g. the air traffic situation), and the selection of an appropriate procedure based on the recognition.
3. *Identification* - Naming the present state of the system.	3. *Knowledge-based* - Decisions proceed through casual reasoning.
4. *Interpretation* - Considering the consequences for current task, safety, efficiency, etc.	
5. *Evaluation* - Evaluating the alternatives in relation to the chosen performance criteria.	
6. *Goal Selection* - Selecting the appropriate change of system conditions. 7. *Procedure selection* - Planning the sequence of actions.	
8. *Execution* - Carrying out the planned actions and coordinating them.	

plant and an action rule will be used to select an appropriate response. Embrey further says that control will revert to the skill based level to actually execute the required actions. More abstract functions such as situation evaluation and planning will only be required at the knowledge based level if the problem cannot be resolved at the rule based level.

The thicker blue arrows in Figure 2.3 represent typical short cuts that skip steps in the information processing chain. This short cuts may be an efficient and safe way to make decisions and lead to errors only in certain cases. For example, the worker may erroneously believe that he or she recognise a pattern of indicators and may immediately execute a skill based response, instead of moving to the rule based level to apply an explicit diagnostic rule (Embrey). The dotted lines in Figure 2.3 represent the various feedback paths that make it possible for the individuals to identify if a particular stage of the processing chain was executed correctly. In other words if the operating team executed a planned strategy to handle a complex plant problem, eventually feedback would be obtained regarding whether or not the plan was successful. A different set of feedback loops exists at the rule and skill based levels, and indicate opportunities for errors

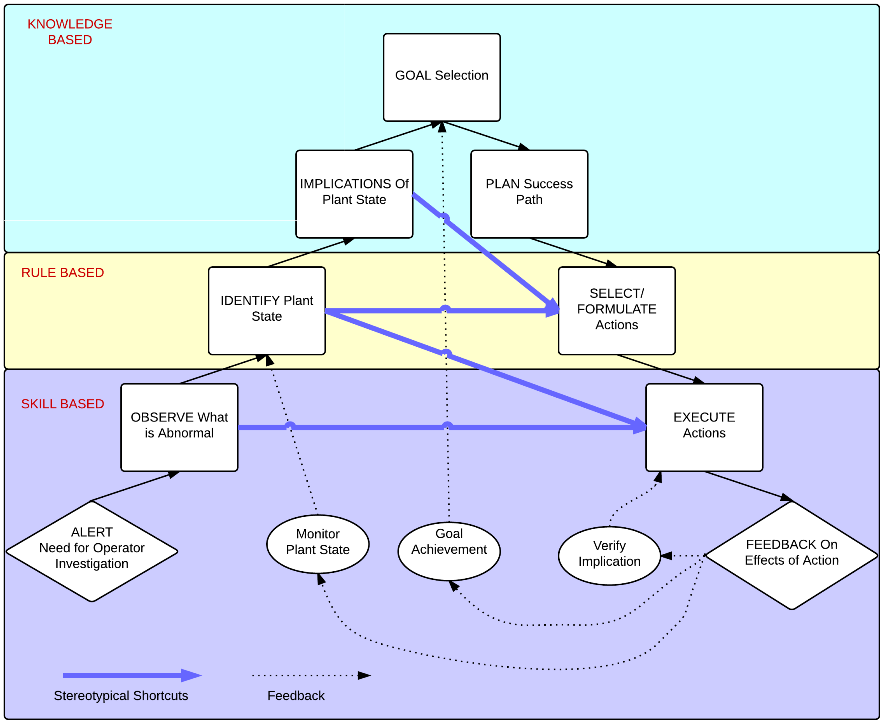

Figure 2.3: Decision-Making Model including Feedback (adapted from Rasmussen (1983))

corrections (Embrey).

This model has been applied with some success by a number of researchers (Redmill and Rajan, 1997). One of the advantages of the "Step-ladder" model is that it specifies the correct and complete way to execute the procedure and it also accounts for the various ways in which shortcuts be made (Hollnagel, 1984).

2.3 Work Performance

Work performance is in direct relation to the quality of employees as well as their desire for success for the company and themselves. The work related activities expected of an employee and how well those activities were executed determine the performance. Through self motivation and motivation from management, work performance can be improved to create a positive environment. This means that to be able to assess and improve the human performance, HTO elements and the HTO interactions in complex work settings, the knowledge of work performance can be used to create a work situation which actively contributes to a safe and efficient operation, taking into account opportunities, limitations and human needs.

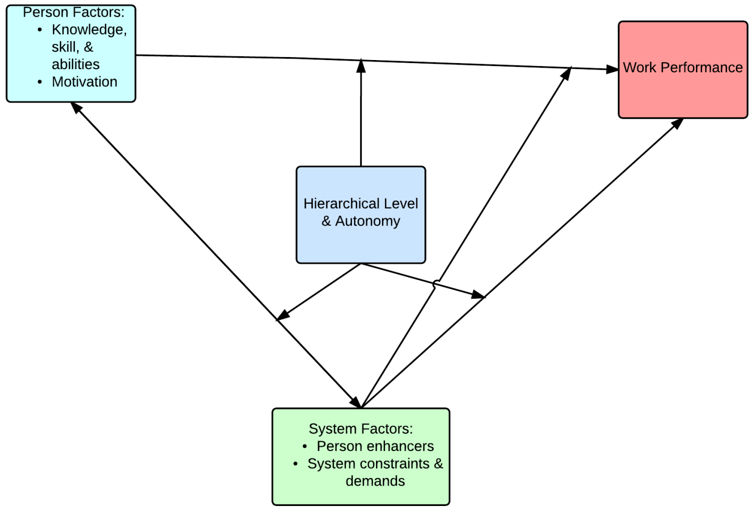

Figure 2.4: A System-Focused Model of Work Performance (Waldman, 1994).

Work performance is defined by Campbell (1990) as behavior associated with the accomplishment of expected, specified, or formal role requirements on the part of individual organizational members. Thus, work performance includes in-role behavior that can be contingently tied to reward. This definition may be difficult to understand. Figure 2.5 shows work performance together with its dimensions and indicators to give a more clear description of what work performance is and what it consists of. Important elements of work performance like job satisfaction, job attitudes, personality , motivation, leadership, and, to a lesser extent, group processes and organization design are important to understand to be able to achieve an acceptable or close to optimal human performance. These elements are not further described in this thesis, but is covered in more detail by Blumberg and Pringle (1982).

It is now clear that for companies to achieve efficient and safe workplace, an optimized work performance should be reached, but this is challenging due to many unexpected factors influencing the work performance under different working conditions and operational settings. To understand what is meant by work performance the first step is to make informed decisions (Redmill and Rajan, 1997). Different PIFs affect the work performance and the human ability to improve performance. To elaborate and to improve work performance in complex work settings the human error causation paradigms can help.

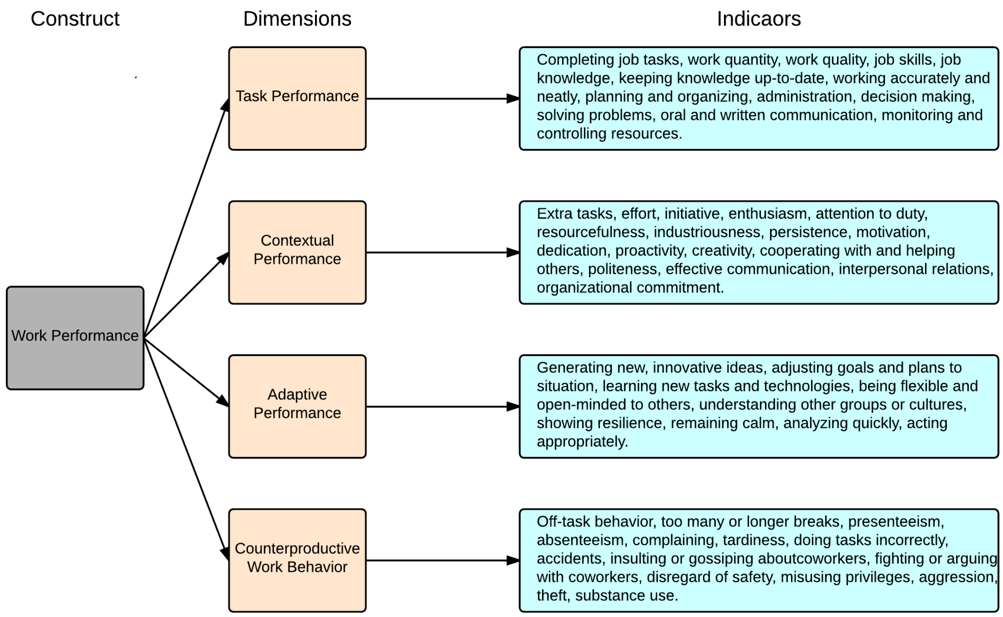

Figure 2.5: Heuristic framework of work performance (Koopmans et al., 2011)

2.3.1 Performance Influencing Factors (PIFs)

Performance Influencing Factors (PIFs) or Performance shaping Factors (PSFs) (Jae and Won-dea, 2003), are factors that combine with basic human error[2] tendencies to create error-likely situations. This means that these factors may and can often be the reason for human errors. The ability to improve and improvise work performance may also be affected by these factors. Embray (2000) defines PIFs as *"those factors which determine the likelihood of error or effective human performance"*. When PIFs relevant to a particular situation are optimal then performance will also be optimal and error likelihood will be minimised (Embray, 2000).

Identified PIFs can be used as an audit tool, to identify problem areas that give rise to increased error potential (Embray, 2000). To be able to achieve a safe and effective performance a detailed understanding and knowledge about PIFs is critical. Valuable information is gained that make it possible to make specific measures to reduce the negative effects on the performance. The human sense organs; eyes, ears, nose, taste and sensory receptors in the skin receive stimuli which are processed in the human brain, and may affect the performance.

ExproBase. (2008) suggests that PIFs can be divided into workplace related factors and hu-

[2] The failure of planned actions to achieve their desired ends-without the intervention of some unforeseeable event (Reason, 1997)

man related factors:

- *Workplace related factors* (economy, environment, equipment, routines, layout, personnel policy)
- *Human related factors* (psychological factors, personal factors and physiological factors)

Another way of classifying PIFs is suggested by Redmill and Rajan (1997) and is shown in Figure 2.6.

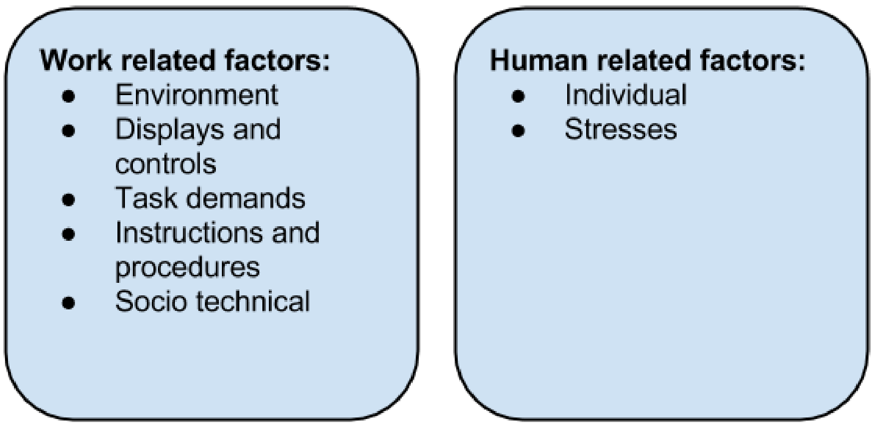

Figure 2.6: PIFs, work related and human related factors (Redmill and Rajan, 1997).

PIFs combined with basic human errors are factors that can create critical operational situations with serious consequences. Luckily, the likelihood of errors happening can be minimized if PIFs are identified, classified and optimized. A result of the identified PIFs is that the work performance may also be improved. This means that failing in this identification of PIFs may have a significant impact to human errors, poor decision making and reduced performance.

2.4 The Human Error Causation Paradigms

"A common failing of mankind is to never anticipate a storm when the sea is calm" is a quote written by Niccolo Machiavelli. It means by not anticipating that thing, once they had become calm, could ever stir back up, would result in higher likelihood of getting caught unprepared when trouble arose (Philosiblog., 2012).

The sources, issues and conditions for human error are almost endless in a given work setting. To get a clear understanding of the complex interactions together with an informative overview of the complex work settings, the human error causation paradigms that were proposed by Redmill and Rajan (1997) are presented in this section. These can be a tool for helping companies to be *"prepared for a storm"*. Or to put in different words, implement measures to hinder such situations (*storms*) by spotting the critical influence factors that have a great potential to influence and contribute to safety and work performance risks.

The human error causation paradigms include the engineering error paradigm, the individual error paradigm, the cognitive error paradigm and the organizational paradigm (Redmill and Rajan, 1997). To be able to evaluate the challenges from different points of views, are the paradigms different from each other. The different paradigms help to identify and to seek to answer what are the challenges and influencing factors in the given working situations and what can be done to improve the work setting. The four paradigms are shown in Figure 2.7.

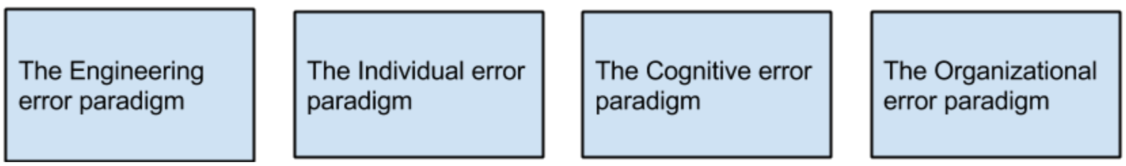

Figure 2.7: The four error causation paradigms (Reason, 1997).

The Engineering Error Causation Paradigm

The engineering error causation paradigm relates to the design and the technical aspect of a system. The main characteristic of the engineering error paradigm is the recognition that the human is an unreliable part/hardware component in the system (Vignes and Jayantha, 2011). Human-mahine design, human-computer design and automation are important aspects in this paradigm and these are performed by the companies to improve the performance and to reduce the risk and the cost (Brown and Hellerstein, 2009). Automation is used to replace the operators with a machine and thereby design the human "out of the loop". This has great influence on the error potential since the human constitute a major part of the possible error potential. Automation is performed to "engineer out" human failures and thereby removes the "human factor" entirely (Redmill and Rajan, 1997). New sources of human unreliability can be introduced when using automation. According to Bainbridge (1983) and Redmill and Rajan (1997) *"the ironies of automation"* occur where errors can be introduced into a system by a system designer during a design process. The operator may also become de-skilled over time, and errors can occur when the automated system fails and the operator has to perform the task (Vignes and Jayantha, 2011). Therefore, automation is not always proven to be cost-reducing and effective, but rather the opposite (Redmill and Rajan, 1997; Brown and Hellerstein, 2009). The automated systems constantly needs maintenance, updated structured inputs and design, implementation and testing which contributes to a massive expense. According to Vignes and Jayantha (2011), the most important issues related to the risk and the recovery from failures or errors are considerably more complicated in an automated process than in a manual process. From a human-machine interaction view (illustrated in Figure 2.8), errors can often occur as a

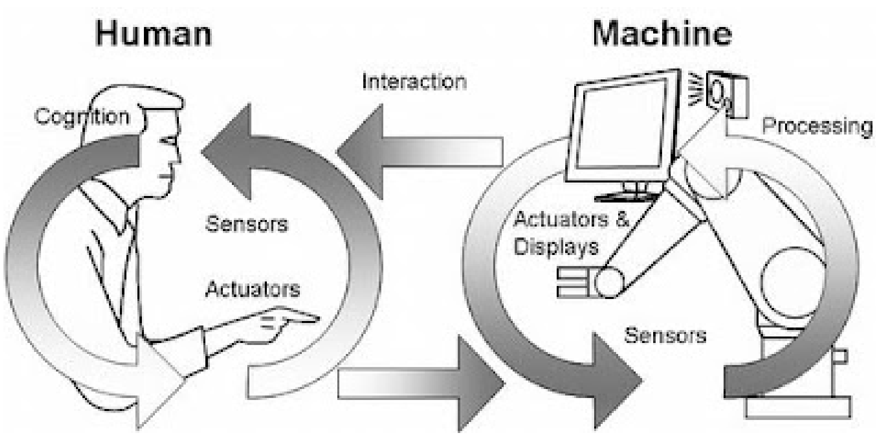

Figure 2.8: Human Machine interaction (University in Zurich, 2014)

result of a human-machine mismatch between the demands of the task, the physical capabilities of the person, and the characteristics of the interface(Redmill and Rajan, 1997). This can be illustrated by referring to the PSA and their safety assessment related to alarm systems on seven offshore production installations in Norway (Bjerkeback and Eskedal, 2004). The assessment states *"poor alarm systems performance and management represents the greatest human factor challenge within control room environments offshore"*. The alarm rates during a normal operation varied from 1 to 20 alarms per ten minutes and the alarm rates during a tripp[3] or a shut down ranged from 33 to 399 alarms during the first minute. The high alarm rates was the main consequence of poor alarm system management. The rates were unacceptable in terms of introducing a risk of overlooking, misunderstanding, or giving inadequate operator response

[3] The act of running or pulling drill pipe into or out of a wellbore on a drilling rig

when important alarms are introduced (Bjerkeback and Eskedal, 2004).

The individual and the immediate work situation is a big part of the engineering error paradigm, mainly because there is a clear connection to the socio-technical working context and the human-machine interactions which is in direct contact with the operator (Redmill and Rajan, 1997). All attributes of an interactive system (alarm management, panels, displays, screens, task aids, controls and software devices) that provides the information and controls necessary for the operator to perform tasks is included in the term Human Machine Interface (HMI), illustrated in Figure 2.9.

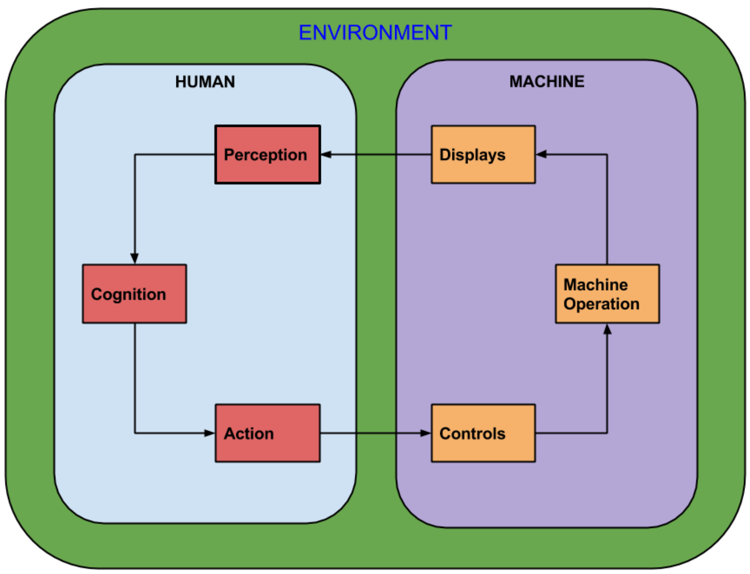

Figure 2.9: A simple Human Machine Interphase (HMI) model.

The Individual Error Causation Paradigm

The individual error causation paradigm relates to personal characteristics, such as the person's personality, attitude, and safety attributions (Vignes and Jayantha, 2011). Even a very professional design may have the tendency to lead to errors in the presence of such personnel characteristics. The human is very difficult to control and predict its moments/action because of its unpredictability and diversity. This view presents that human errors occur because the human is "not trying hard enough" or "not playing sufficient attention to the task", and the solution to human error are often related to disciplinary measures such as dismissal and suspension

(Redmill and Rajan, 1997). According to Redmill and Rajan (1997) is the Airbus A320 (1992) accident, which crashed into a hill near Strasbourg is a good example illustrating the individual error paradigm related to motivation and safety attribution. The accident rapport stated that the pilot ordered the aircraft to descend at 3300 feet per minute rather then an angel of 3.3 degrees. The error occurred because the aircraft had different modes in the display that looked almost the same. One described the climbs and descend in degrees, the other in units of 100 feet per minute. The error that was made is well known and well understood but still it happened, and tragically resulted in severe consequences. In this particular case, the pilot made an individual error that can be related to the pilot's personality, motivation, and safety attributions (Vignes and Jayantha, 2011). Human (in this case the pilot) performing "corner cutting" in work situations can be attributed to safety attitudes, beliefs, risk-taking behavior, conflict and motivation (Redmill and Rajan, 1997) and in this case this was exactly what happened. The Airbus A320 accident can also be read as an engineering error paradigm focusing on the technical aspects of a system, the design of man-machine, and human-computer interfaces. A better engineering error causation paradigm focus would have avoided the possible misunderstanding of the different modes in the autopilot display by good design of the human-machine interface. However, even a very professional design may have a tendency to lead to errors, in the presence of problems of personality, motivation, and safety attributions of the human operators (Vignes and Jayantha, 2011).

For some time now, has there been an increasing focus by the petroleum industry on the violations of rules or procedures and particularly non-malevolent violations such as not wearing personal protection equipment or corner cutting. This is a form of human failure that can be attributed to safety attitude and motivation; it can also affect the safety culture within a company, the risk taking behavior, and factors such as the conflict of productivity and safety goals (Redmill and Rajan, 1997). The Texas City disaster in 2005 at BP's refinery in Texas is a good example illustrating the individual error paradigm related to safety culture (BP., 2005; Petroleum Safety Authority Norway, 2009). Fifteen people were killed and over 170 people were harmed because of fire and explosion caused by leaking hydrocarbons. The accident report concluded that the safety culture at the refinery was unsatisfying. Personnel did not follow the established policies and procedures, also the focus to the company was more about the incident statistics rather then actual process safety and the risk of major accidents. Current research is looking at perceptions of risk and safety climate or safety culture issues (Redmill and Rajan, 1997). According to Sharp (2004) can the climate account for 20 to 30% of the business performance. The climate is defined as how the people feel about working for a company (Ivancevich and Matterson). This means that getting the best out of people will eventually pay off for the company. Further research also shows that the level of control over its basic risk factors in an organization is related to the climate and whether the people are healthy, happy, and productive employees (Vignes and Jayantha, 2011).

The Cognitive Error Causation Paradigm

The cognitive error causation paradigm focuses on the psychological attributes and the information processing-related causes of human errors, and it covers both skills and decision making errors and considers the capabilities and limitations of the individual human information processing system (Redmill and Rajan, 1997; Wong, 2002). With the cognitive view human errors are analysed in relation to the abilities of information processing, the interaction with individual tasks and situations, and human error tendencies.

An example that emphasizes the importance to maintain an overview on the complex set of factors in the system to reduce decision making errors is the Chernobyl disaster (Wong, 2002). The water cooled nuclear reactor at Chernobyl was known to be unstable, and meltdown was possible if output was below 20 %. The reactor included a safety system to prevent operation below 20 %. The investigation report states that the safety system was removed because of testing and the possibility for a meltdown with the safety system disabled was never seen as a real danger. The reactor becomes unstable during testing and because of design weaknesses, the manual intervention done by the operators was too slow to prevent the disaster (Vignes and Jayantha, 2011). This accident pointed out that a number of issues exist that directly challenges the cognitive capacities and capabilities of operators of complex systems.

The cognitive error causation paradigm assumes that mismatches between mental and physical capabilities of people and the demand of the job performed is why the human errors occurs. According to the paradigm, the error reduction is dependent on the cognitive causes such as information overload, memory failure, attention failure, and decision making failures (Redmill and Rajan, 1997; Wong, 2002). The mental state of humans, and errors related to the emotional state of mind, can even be caused by very personal reasons such as divorce or separation, death in the family, or other work-related complaint or protest. Therefore these human errors can never be totally eliminated, but the person can be removed from work tasks until the situation has improved and he or she has gained a better attitude (Wong, 2002). Redmill and Rajan (1997) states that errors related to the "I don't care" attitude can also result in lack of motivation, concentration and behavior and performance in respect of rules and regulations.

The Organizational Error Causation Paradigm

The Organizational error causation paradigm has a broader perspective than the paradigms presented earlier. The paradigm focuses on the management practices, such as safety management and decision making, and issues such as safety culture, participation, competence, control, and communication (Redmill and Rajan, 1997). The paradigm also assumes that human errors are caused by certain preconditions in the work context. These can include aspects such as poorly designed procedures, unclear allocation of responsibilities, lack of knowledge or training, low morale, poor equipment design, and time pressure. To illustrate the important of the organizational error paradigm the Ekofisk Brovo blowout (1977) can be used as an example (Oil Rig Disasters database., 2009). The accident happened during a workover at a production well. Ten thousand feet of production tubing was pulled out of the well, the christmas tree had been removed, and the BOP had not been installed. The well then kicked[4] and an incorrectly installed downhole safety valve failed. All of these factors resulted in a blowout and uncontrolled release of oil and gas, luckily the platform personnel were evacuated, and none were injured. The official investigation reports stated that the mechanical failures of the downhole safety valve occurred because of human error. The human errors included faults in the installation documentation, equipment identification, well planning, and well control. The conditions required for situations like Ekofisk Bravo blowout to happen, can be tracked back to management and organizational policies and decisions. Other general failure types and aspects which may cause unsafe acts and affect decision making are poor management decision making and planning, communication failures, poor safety management, inappropriate workload levels and lack of

[4]A kick can quickly escalate into a blowout when the formation fluids reach the surface

competence (Redmill and Rajan, 1997).

2.5 Human, Technology and Organization perspective

The HTO perspective was developed during the 1980s within the nuclear power industry. The aim of the HTO perspective was to improve the overall safety. When developing safety elements, the focus was usually only put on the technical improvements. This focus was successful and near-accident incidents caused by technical failures were noticeably reduced. This effect of the reduction of the technical failures resulted in that the incidents caused by humans become more "visible" as they represented a larger proportion of the reported incidents. This resulted in an increasing focus on the field of potential "human error" and safety was further improved. After this revelation and understanding that safety needed a technical aspect and a human aspect, it also become apparent that it was necessary to consider organizational issues as well. This led to the realization that all three HTO components in the system need to be addressed to improve safety (Eklund, 2003).

The system view from the HTO perspective was considered successful for improving safety and developing a more thorough safety culture and has thereafter spread to other domains (Rollenhagen, 1997, 2003). The HTO perspective has now been developed to analyse and further develop the understanding of highly complex work activities. It has been understood that successful development is only achieved if all three components are considered together. Figure 2.10 illustrates the relations and the components in the HTO perspective. The HTO perspective is also valuable in research as it ensures that a broad range of factors are considered. Where a specific focus is chosen for research, for instance focusing on technology while human and organizational aspects may be analysed and treated as influencing factors (Westlander, 1999a). There is a relations to the earlier socio-technical system theory, which aims at improving working conditions as well as organizational performance (Pasmore, 1988). The HTO perspective, however, distinguishes between the individuals and the organization.

In the HTO perspective, the "H" stands for the Human component and introduce the important aspects that are strictly individual and at the same time considered important to perform task or a change. Such aspects may, for example, include individual skill, knowledge, experi-

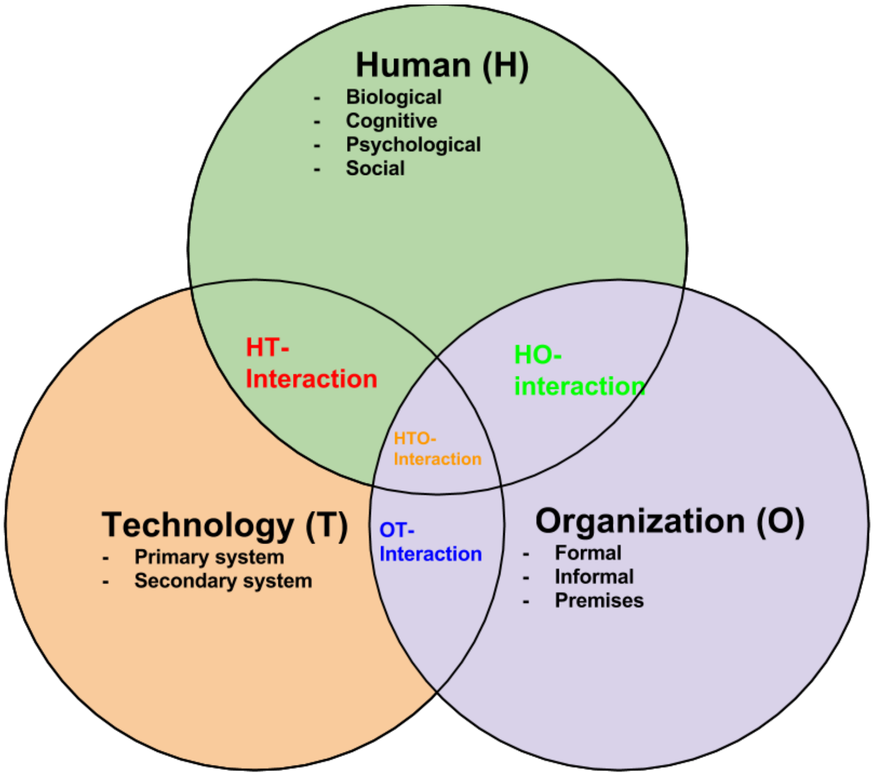

Figure 2.10: The H-, T-, and O-component in the HTO perspective.

ences, and established relations with other people. They are not easily replaceable in a short term perspective. The H-component focuses on the individual's contribution to the business process. According to Daniellou (2001) the H-component can be described at any of the following four levels.

1. The biological level, regarding the human as a physiological system.

2. The cognitive level, where the human is considered as an information-processing system, including thought processes, representation, and decision-making.

3. The psychological level, where the human has a unique history, leading to a specific subjective processing of the situations he/she experiences.

4. The social level, emphasizing that every single individual is a member of several social groups with different cultures, which will partly determine his/her values and habits.

The second component is the "T" and stands for the technical system. This can be divided into two different parts. The first part is the *primary technical production system* that includes the production equipment. It is primarily devoted to maintaining the abilities of the company to stay competitive in the business and to produce customer value. There are different ways of describing these complex technical systems concerning the technical limitations, problems (both recurrent and stochastic), availability, reliability etc. Because the technical system is so complex leads to the need to consider these systems as networks of linked autonomous parts, which are to a large extent separately controlled and managed. The second part of the technical system is the *secondary technical system*. The secondary technical system is the system that assists the administration and procedures of the company, but is not directly associated with the value-adding activities of the business (Wäfler, 2001). This information system includes both hardware and software that the scheduler uses as decision support tools.

Some criteria that have proven to be valid for the design of the scheduling software system set by the HT-interaction are (Wiers, 2001):

- Whether it is integrated with the taks
- Whether it is tolerant of errors
- Whether it provides relevant feedback
- Whether it is transparent for the scheduler i.e. that the scheduler can understand or has confidence in the relation between the decision support and his/her own understanding of the situation

The third and last component is the "O" that stands for the Organization component and it represents the H-component in an aggregated sense (Berglund and Karltun, 2007). It is therefore not considering single individuals but humans in a statistical interchangeable way (Westlander, 1999a). The O-component comprises how the work is organized and structured, both formally and informally, furthermore it includes rules, procedures and cultural factors as well as relations between system components and subsystems, which all have both a formal and informal side (Westlander, 1999b). It can also be important to notice that the O-component have a physical aspect regarding where people are located and how premises are design (Weisbord, 2004). Examples of this are job definitions, responsibilities and powers, hierarchical positions, policies, business goals and strategies (Berglund and Karltun, 2007). Problems related to the organizations is often goal conflicts between departments (subsystems) and are something the schedulers also must deal with.

The interaction between the scheduler and the organization is naturally very extensive and can be described with different levels and from different perspectives. There are role expectations and roles sent form different parts of the organization, naturally from managers following the hierarchical position but also from colleagues and workers (Berglund and Karltun, 2007). According to Katz and Kahn (1978) the roles become more complex when they require the individual to be simultaneously involved in two or more subsystems, since each one is likely to have its own priorities and to some degree its own subculture. The performance of the schedulers is believed to be influenced by the demands and expectations that are placed upon them. The complexity of the schedulers roles is described by Jackson et al. (2004) and suggested to divide these into three main roles: *the informational role, the interpersonal role and the decisional role.*

It is now clear that knowledge and understanding of the H-,T- and O-components and the HTO interactions are vital to achieve a safe and effective operation, decision making and work performance. The human performance model, PIFs and human error causation paradigms presented earlier, are all apart of the HTO perspective and can help identifying and solve challenges related to the perspectives "way of thinking". This may result and contributes to a better decision making process and a higher performance, reliability, effectiveness and safety.

2.5.1 Application of HTO knowledge

The application of the HTO knowledge can provide clarity, increased understanding and awareness of the interplay between human, technological and organizational matters. Better understanding may have a positive effect to the improvement of safety, performance, reduced system vulnerability and the decision making quality. According to Vinnem and Liyanage (2008) the enabling of technologies and infrastructure to support complex operations is a way to draw attention to critical interactions and interfaces between human and organizational components of the systems.

Better knowledge and understanding of the interactions between the HTO elements is crucial in understanding the underlying causes of incidents and accidents in work processes and to achieve success in the preventive work (Petroleum Safety Authority Norway., 2011). A situation when human, technology, organization and work processes are combined and make complex interactions can lead to big loses. The interactions are illustrated in Figure 2.11.

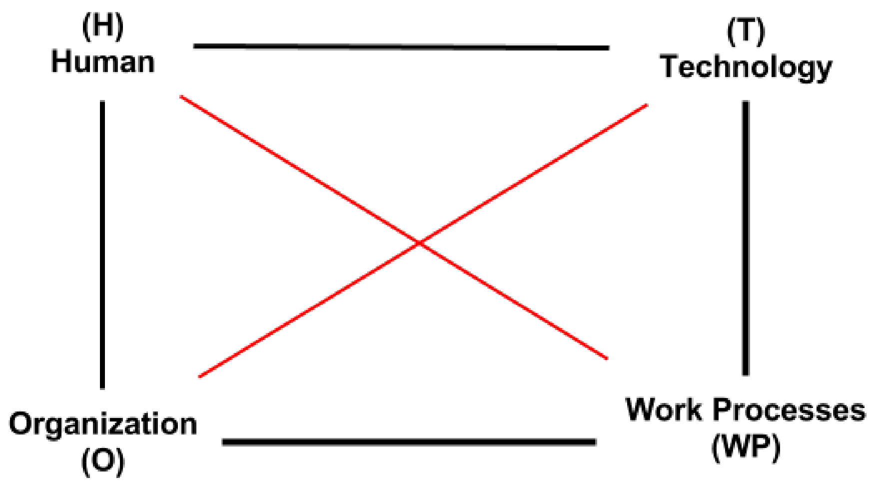

Figure 2.11: HTO - and Work Process interactions .

According to Bridger (1995) the improvement of the interactions between human components, technical components and organizational components is crucial to the system to function better. This is a basic element in the HSE (Health, Safety and Environment) regulations in the petroleum activities (Petroleum Safety Authority Norway., 2011).

The socio-technical system in which modern society is based, tends to increase the system complexity. This has a unavoidable consequence, namely that the interactions and dependency between the individual systems increase, and thereby the systems become more closely coupled (Hollnagel, 2004). Tighter couplings results in systems become more difficult to use, in therms of maintenance, operation, monitoring, management and control (Hollnagel, 2004). Harmony between the human, technological and organizational elements of operational setting in a complex setting/system is extremely critical for exposure of operational risk. Table 2.3 describes examples of some components and situations concerning the human, technology and organizational elements which must be handled during complex operations. HTO knowledge application can help to create a better understanding of the interactions between the elements, and it can provide a greater overview of the modern complex work system. A lack of identification an classification of HTO limitations, together with PIFs studies, may lead to human errors and reduced work performance. It illustrates the importance and advantages of a proper knowledge

Table 2.3: Describes components and situations concerning the human, technology and organizational elements

The Human element	**The Technology element**	**The Organization element**
✓Competency and education ✓Abilities, experience and learning ✓Planning ✓Manning and training ✓Communication and co-operation ✓Physiology, Psychology and sociology ✓Time and human limitations ✓Human needs and responsibility ✓Operational work tasks ✓Decision making ✓Work Performance ✓Complex work tasks ✓Stress and workload ✓Data interpretation ✓Too much or too little information ✓Attention ✓Personality and motivation ✓Behavior during operations ✓Alertness ✓Ability to perceive abnormal conditions ✓Cognitive workload and demands ✓Fatigue ✓Memory and attention ✓Attitude to safety ✓Etc.	✓Design of the system ✓Limitations due to the design ✓How the technical element supports the operators to perform their work safe and effectively ✓Degree of automation ✓Functionality ✓Usability ✓Integration ✓Operational tasks ✓Noise, vibration and temperature level ✓Compatibility of usertechnology interface ✓Functional characteristics of control panels ✓False alarms ✓Design faults ✓Technical error ✓Clarity of signals and user-friendliness ✓Work space ✓Compatibility and reliability of displays and controls ✓New technology and equipment ✓Location ✓Etc.	✓Responsibility, roles and management ✓Procedures ✓Communication ✓Competency ✓Organizational manning ✓Resource availability ✓Training programs ✓Planning and routines ✓Culture and structure ✓Framework ✓Power relations ✓Cooperation ✓Decision making ✓Work Performance ✓Handover documentation ✓Standardization ✓Contractual issues ✓Psychosocial working conditions ✓Working environment ✓Sharing of experience ✓Control of environment ✓Team structure ✓Decision support systems ✓Physical working conditions ✓Conflicts ✓Work instructions ✓Time constraints ✓Interaction with other tasks ✓Etc.

of complex work settings from an HTO perspective and an overall understanding of the capabilities, interactions and PIFs is critical to achieve the organizational goals, and safe and effective operations.

2.6 What are Human and Organizational factors?

The concept of HO factors is important for this thesis, therefore the concept is explained in detailed in this section. Some repetition will therefore occur.

Accidents have always been present in all sorts of industry. Incident investigation is therefore a core skill for health and safety in a company. Incidents happen for a number of reasons and without finding out the cause, an event cannot be prevented from recurring. Analysing the system reveals inherent weaknesses and help identifying root causes of serious incidents. When the causes of incidents is revealed, safety barriers to prevent them from happening can be put into place. The notion of safety barriers in industry is based on the accident theory known as the energy model, pioneered by Gibson (1961) and Haddon (1980). Since the idea was developed, the safety barrier concept has evolved from simple physical barriers protecting against harmful energies to include successive risk reducing measures either of a human, technical or organizational nature. In the later years this interaction between human, technology and organization has been identified as a critical factor regarding safety. This interaction between human, technology and organization is called HO factors and can be defined in several ways. Koester (2001) defines HO factors as a:

Discipline regarding human abilities and limitations in relation to the design of systems, organizations, tools etc.

Another definition by Chapanis (1996) is as follows:

Human factors are a body of information about human abilities, human limitations, and human characteristics that are relevant to design

The International Ergonomics Association. (2000) has a more complex definition of HO factors:

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human well being and overall system performance. Practitioners of ergonomics, ergonomics, contribute to the planning, design and evaluation of tasks, jobs, products, organizations, environments and systems in order to make them compatible with the needs, abilities and limitations of people.

By putting all of these definitions together we can understand that HO factors is a term used to describe the interactions of individuals with each other, with facilities and equipment, and with management systems. The interaction between these elements is influenced by both the working environment and the culture of the people involved. This mean that one good working system in one part of an organisation, may be identified as a problem area in a region where for example culturally driven attributes to risk taking may be significantly different. Figure 2.12 shows the different elements in HO factors and what the different elements consists of according to OGP (The International Association of Oil & Gas Producers).

Figure 2.12: Culture and working environment, nation, local and workplace culture, social and community values (OGP.).

The different definitions mentioned may be difficult do understand without a proper psychology training. Therefore is the definition proposed by the Health and Safety Executive HSE (1999) widely acceded inn industries:

"Human factor refers to environmental, organizational and job factors, and human and individual characteristics which influence behavior at work in a way which can affect safety".

A better understanding of the elements in this definition gives us a simple way to view HO factors. The tree aspects are: the job, the individual and the organization and how the impact on people's health and safety-related behavior.

The job (HSE, 1999) - Tasks should be designed in accordance with ergonomic[5] principles to take into account limitations and strengths in human performance. Matching the job to the person will ensure that they are not overloaded and that the most effective contribution to the business results. *Physical match* involves the individual's information and decision-making requirements, as well as their perception of the tasks and risks. Mismatches between job requirements and people's capabilities provide the potential for human error.

The individual (HSE, 1999) - Tasks should be designed in accordance with ergonomic principles to take into account limitations and strengths in human performance. Matching the job to the persons will ensure that they are not overloaded and that the most effective contribution to the business will be obtained. Physical match includes the design of the whole workplace and working environment. Mental match involves the individuals information and decision-making requirements, as well as their perception of the tasks and risks. Mismatches between job requirements and peoples capabilities provide the potential for human error.

The organization (HSE, 1999) - Organizational factors have the greatest influence on individual and group behaviour, yet they are often overlooked during the design of work and during investigation of accidents and incidents. Organisations need to establish their own positive health

[5] The applied science of equipment design, as for the workplace, intended to maximize productivity by reducing operator fatigue and discomfort.

and safety culture. The culture needs to promote employee involvement and commitment at all levels, emphasising that deviation from established health and safety standards is not acceptable.

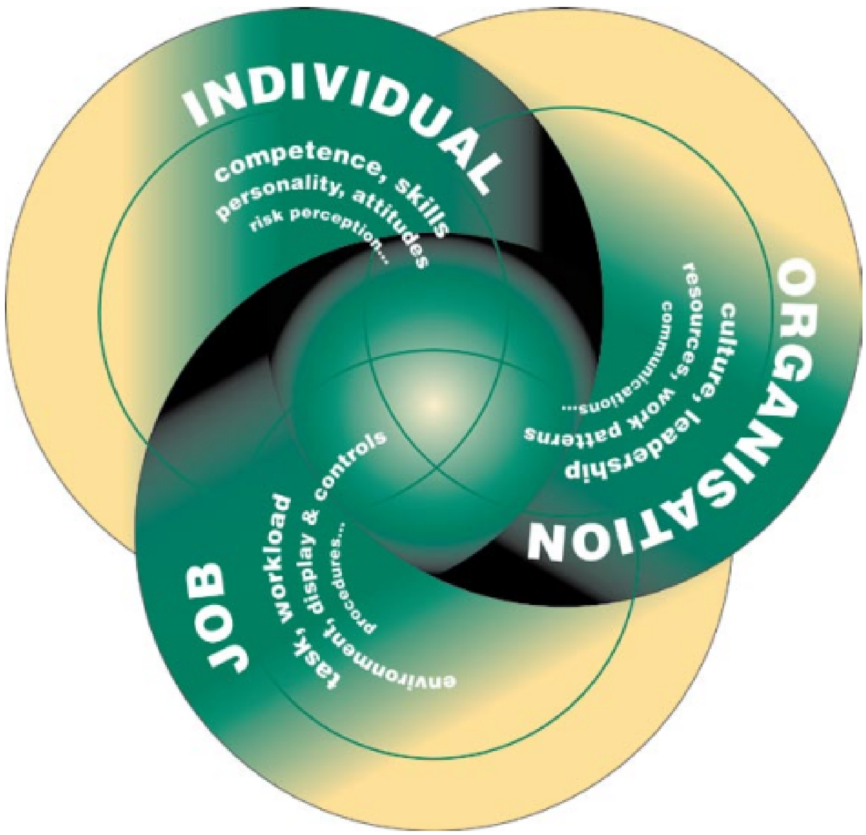

Figure 2.13: Human factors in occupational health and safety (HSE, 1999)

Figure 2.13 highlights some of the key issues for each area. By thinking about these aspects you are asking questions about:

1. What are people being asked to do and where (the task and its characteristics)?
2. Who is doing it (the individual and their competence)?
3. Where are they working (the organisation and its attributes)?

HO factors in the HTO context

HO factors are a part of the human element in the HTO context presented above, and have over the past two decades, gained grate attention in the oil and gas industry in Norway. OGP. conducted a case study which resulted in the observation that by improving engineering, improving health, safety and environmental management systems (HSEMS) and incorporation of HO factors, the rate of incidents decreased, see Figure 2.14. A better understanding of HO factors gives

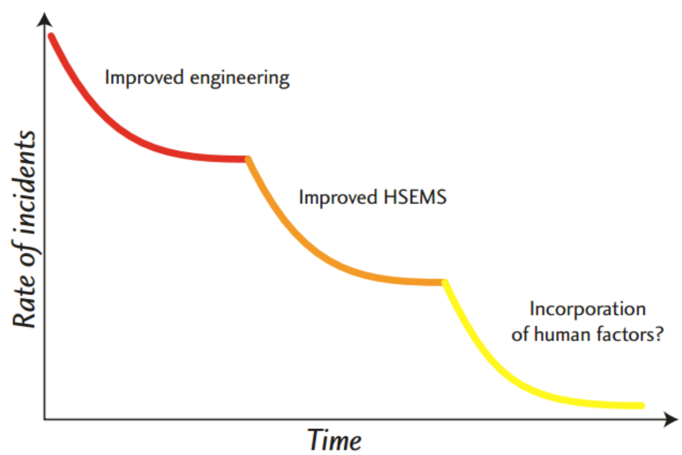

Figure 2.14: Incident frequency in the Oil and Gas industry (OGP.).

a strong backbone in companies policies and procedures to be able to correctly identify what causes human error and how to prevent future human errors. The HO factors play a major role in causing and preventing accidents, since people design, manage, operate, maintain and defend hazardous technologies (Reason, 1997). The objective of HO factors is to minimize human errors, and the effects of human errors, and maximize the safety, and effectiveness of human performance by making it hard to do things wrong and easy to do things right. HO factors also play a major part in work performance and must be accounted for during design of system and workplaces.

A definition of HO factors defined by HSE (1999) and others, is already presented earlier but to get a better understanding of HO factors in relation to the HTO-concept can the HO factors discipline defined by PSA be mentioned. Petroleum Safety Authority Norway. (2011) describes the HO factors discipline as a systematic analytic tool which includes methods and knowledge that can be used to improve, evaluate and assess the HTO interactions. The focus is on the human being and their interactions with tools, machines, procedures, environments and work-place. Humans are both assets and liabilities in these different settings. According to Wong (2002) maintenance, engineering and operations are human interfaces to be considered.

A number of serious accidents have highlighted failures in HTO- and HO factors aspects, and maid it clear how important this aspects are to achieve a safe operation and high performance. Barriers are a central concept to describe the preventive elements to prevent an accident from occurring and reduce the impact (Petroleum Safety Authority Norway., 2011). A barrier consists of one or more technical, operational, organizational or human components (based on specific procedures or administrative controls) that is implemented to prevent, control, or imped energy releases from reaching the assets and causing harm (Rausand, 2011). Example of some categories of barriers are listed in Table 2.4. All the defensive layers would in an ideal world be intact, allowing no penetration by possible accidents trajectories (Reason, 1997). But sadly this is not true in the real world. Every step in a process has the potential for failure, to varying degree. Dormant errors in the work tasks and environments can be "moldering" under the surface without causing damage (Wenner and Drury, 1997), these dormant errors can find opportunities for a process to fail or in other words, "holes" in the security barriers which can then lead to error that can pass through all the safety barriers and cause accidents. To illustrate this, Reason (1997) proposed what is referred to as the "Swiss Cheese Model" of system failure.

Table 2.4: Categories of barriers (Rausand, 2011).

Physical barriers:	***Administrative barriers***:	***Management barriers***:
- Equipment and engineering design	- Hazard identification and analyses	- Training
- Personal protective equipment (e.g., clothes, hard hats, glasses)	- Line management oversight	- Knowledge and skills
- Fire walls, shield	- Supervision	- Rules and Regulations
- Safety devices (e.g., relief valves, emergency shutdown systems, fire extinguishers)	- Inspection and testing	
- Warning devices (e.g., fire and gas alarms)	- Work planning	
	- Work procedures	

The "Swiss cheese model"

The "Swiss cheese model" is a good illustration of how different layers, i.e. human, organizational and technical barriers, under a given set of conditions, can lead to hazards and potential human, economical or material losses. An error may allow a problem to pass through a hole in one layer, but in the next layer the holes are in different places, and the problem should be caught, see Figure 2.15. Each layer is a defence against potential error impacting the outcome.

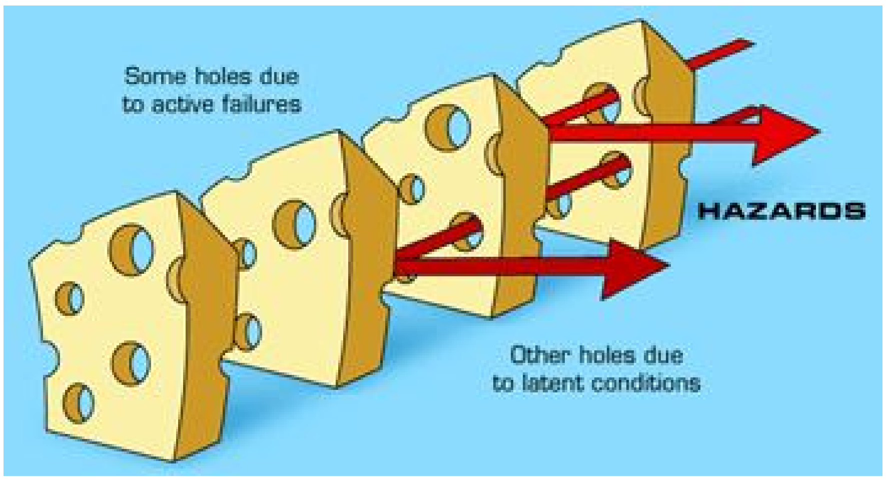

Figure 2.15: Reason's "Swiss cheese model" whit a successful layer of defences, where "cheese slices" illustrates defensive barriers (Reason, 1997).

For an accident to occur, the holes need to be aligned for each step in the process allowing all the defensive barriers to be defeated, resulting in an accident. If all the layers are set up with all the holes lined up, then this is a flawed system that will allow a problem at the beginning to progress all the way through to adversely affects the outcome. Figure 2.16 illustrates a flawed defence system. Barriers listed in 2.4 can be considered as "holes" leading to breach of the organizational defences, barriers and safeguards leading to incidents, accidents or catastrophic events.

The HO factor knowledge can help to better match people limitations, capabilities and needs by improving elements such as tools and equipment and improve the environment in which people uses these elements. It can also improve the efficiency (increased reliability/reduced downtime), effectiveness, and productivity of systems and work environments. This will eventuality lead to fewer accidents, lower lifetime costs associated with the maintenance and re-engineering of systems and a more productive workforce.

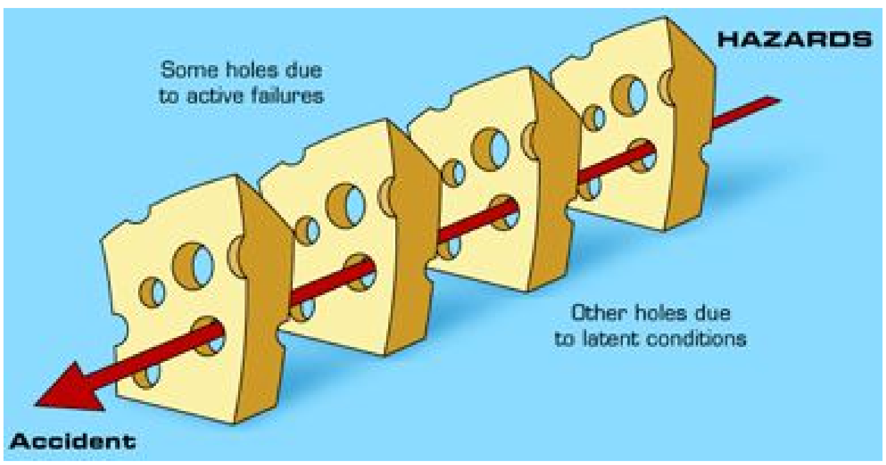

Figure 2.16: Reason's "Swiss cheese model" with a unsuccessful layer of defences, where "cheese slices" illustrates defensive barriers (Reason, 1997).

Chapter 3

Classification for Human and Organizational Factors

3.1 Introduction

Awareness of HO factors and human reliability has increased significantly over the last 15 to 20 years. Primarily as a result of major catastrophes that have had significant human error contributions, e.g.Three Mile Island, Challenger space shuttle, Chernobyl. Each of these and other incidents have identified different types of human errors and failings; some of which were not generally recognized prior to the incident.

Due to the results of these events has it been widely recognized that more information about human actions and errors is needed to improve safety and operation in all sorts of industry. For a long time the Fault Assessment/Reliability world realized it needed data on component and system failures and created schemes for collecting suitable data. Probabilistic Safety Assessment[1] (PRSA) studies have started to incorporate human actions and errors; PRSA specialists are now demanding human reliability data to incorporate within PRSA models.

Analysis of human error data requires human error classification. As the human factors/ reliability subject has developed, so has the topic of human factor/error classification too. The classifications vary considerably depending on whether it has been developed from a theoreti-

[1] The subject of PRSA will not be covered in this thesis. For more detail an the PRSA itself see Cox and Tait (1991) and Green (1983)

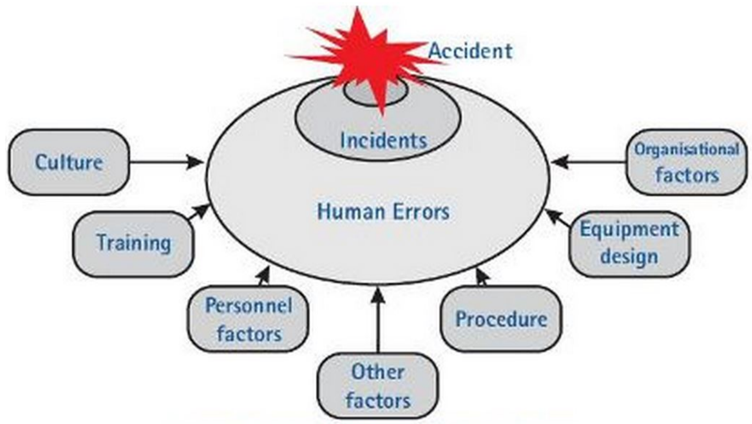

Figure 3.1: Contributing factors to human error (Garg et al., 2010)

cal psychological approach to understanding human behavior or error, or whether it has been based on an empirical practical approach. This latter approach is often adopted by different industries such as the oil and gas industry which is constantly in need of rapid alterations and practical improvements.

This chapter will try to reach this thesis objective and identify classification schemes for HO factors related to well integrity in the various phases of a well's life. Through a detailed literary survey (see Reason (1990); Kirwan (1994); Wilson and Stanton (2001); International Atomic Engergy agency. (1989)) no clear way of classifying HO factors have been identified, but a pattern emerges. The author notice the pattern and believes therefore that the best way of classifying HO factors is to classify human error. Little knowledge in this area of expertise presents a challenge: How can classifying human error be a way of classifying HO factors? Hopefully will Figure 3.1 blur the confusion and give the reader an idea of why this may be a way of classifying HO factors. Figure 3.1 shows that classifying human errors will evidentially pinpoint contributing factors such as HO factors (culture, organizational factors, training, etc.) that safety engineers may be able to "fix". If the contributing factors is not fixed an incident then an accident may occur. This way of classification is therefore more suited for the industry since it highlights factors that personnel may be able to improve and eliminate the possibility of an accident. Therefore is the concept of human reliability assessment (HRA) presented because it involves the use of qualitative and quantitative methods to asses the human contribution to risk. The general objectives and advantages of human error classification is then presented followed by different methods of classification. The recommended method best suited for answering the project task number two of this thesis is then presented. I also like to mention that I am not a professional and that I am "new to the game" as a student.

3.2 Human Reliability Assessment

Accidents are not usually caused by a single failure or mistake but by the confluence of a whole series, or chain, of errors. In offshore operations, accidents are often initiated by errors induced by technical failures, human and organizational factors or a combination of both.

HRA primary goals is to properly assessing the risks attributable to human error and for ways of reducing system vulnerability. Therefore is HRA introduced as a subject in this section to help define a set of useful tools for the analysis and help classifying HO factors/errors. This will results in a reduction of those errors which could lead to system accidents.

To reduce the risk, a deep understanding of what can go wrong in the system needs to be established, or in other words, the human errors in the system needs to be systematically identified and classified. Human and organizational errors refer to unacceptable or undesirable performance on the part of an individual (human error) or a group (organizational error) that can result in unanticipated or undesirable effects (US, Coast Guard, 2004).

To bee able to achieve the primary goals to the HRA, three principal functions must be achived:

1. *Human Error Identification (HEI)*: identifying *what* errors can occur.
2. *Human Error Quantification (HEQ)*: deciding *how likely* the errors are to occur.
3. *Human Error Reduction (HER)*: enhancing human reliability by *reducing* its error likelihood.

HRA is inherently inter-disciplinary for two reasons. Firstly, it requires an appreciation of the nature of human error, both in terms of its underlying psychological basis and mechanisms, and in terms of the various HO factors, such as training and the design of the interface, affecting performance. Secondly, it requires both some understanding of the *engineering* of the system, so that the intended and unintended human-system interactions can be explored for error potential and error impact, and an appreciation of reliability- and risk-estimation methods, so that HRA can be integrated into the 'risk picture' associated with a system. This picture can then act as a summary of the impacts of human error and hardware failure on system risk, and can be used to decide which aspects of risk are most important.

Human error

The term *human error* has been pragmatically defined by Swain (1989) as follows: "any member of a set of human actions or activities that exceeds some limit of acceptability, i.e. an out of tolerance action [or failure to act] where the limits of performance are defined by the system". The effects human error on system performance have been demonstrated most vividly be large-scale accidents.

Human errors may cause accident but accident may not be caused purely by human errors. In order to reduce casualties, safety analysts must first identify the type of human and organizational errors that cause casualties and then study and determine how accidents happen. To identify and classify HO factors are extremely difficult, because the type of human and organizational errors varies. Even though this classification process is extremely difficult, the reward of doing so is absolutely worth it. Human error is covered in more detailed in the book "huamn error" written by Reason (1990).

3.3 Human Error Classification

There are many different human error classifications schemes, which helps to assist, analyse human error and behavior. Hence which classification scheme to be use is dependent on the objectives of the analyst.

A psychologist may be interested in understanding the psychological causes of a human error to compare with a theoretical model. A petroleum engineer will want to classify human errors in a way that enables practical error reduction steps to be taken quickly. In both cases the human error classification allows human error data to be handled and "root causes[2]" to be clas-

[2] The root cause of a specific failure is the most basic cause that, if corrected, would prevent recurrence of this

sified. However, there is likely to be considerable variance on what each user as a "root cause". The petroleum engineer may define root causes along a practical basis, e.g. deficient procedures, lack of training. A psychologist may prefer to use "root causes" related to a theoretical psychological model of human behaviour.

In all cases the human error classification is used to assist the analyst to achieve his or her own objectives. As there can be many different objectives for analysing human behavior there are many different means of human error classification. Regardless of all the different means of human error classification has International Atomic Engergy agency. (1989) identified three overall objectives:

1. to provide qualitative improvements to plant safety, i.e. identification of human error problems and introduction of measures to reduce or prevent those human errors that are related to safety;

2. to provide qualitative improvements to plant performance/availability, i.e. identification of human error problems and introduction of measures to reduce or prevent those errors that affect plant performance/availability;

3. to provide numerical data for use in PRSAs or other safety studies.

These overall objectives emphasize that this approach is well suited to classify HO factors as well as quantify the influence these HO factors adds to the system.

3.4 Advantages of Classification

A better understanding of HO factors gives a strong backbone in companies policies and procedures to be able to correctly identify what causes human error and how to prevent future human errors. The HO factors plays a major role in causing and preventing accidents, since people design, manage, operate, maintain and defend hazardous technologies (Reason, 1997). The objective of HO factors is to minimize human errors and the effects of human errors and maximize the safety and effectiveness of human performance, by making it hard to do things

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and similar failures

wrong and easy to do things right. HO factors also play a major part in work performance and must be accounted for during design of system and workplaces.

The classification of human errors is the backbone of HEI, its infrastructure and framework. A classification itself is simply the partitioning of a group of phenomena (e.g. human behavior) into categories or types (e.g error types) that are based upon a set of descriptions (e.g. omission, commissions, etc.) which can be applied relatively reliably (e.g. by different assessors) to the group of phenomena in question. The advantage of a classification is that without it the intellectual process grinds to a halt, since what one person is talking or writing about is opaque to any other person. It is difficult to describe, for example, the colour of a rose without using a classification system (involving colour, hue, saturation, warmth, etc.); indeed, the word 'rose' it itself part of a rather large classification system or taxonomy

If a study wishes to use a human error datum to quantify a human error probability (HEP), to show similarity in HEP, it will be proper to use either a particular datum or just any. Such a discretion can only be made on the basis of a classification system. This point may seem laborious, but it is a recurring theme throughout this and other sections. It is also fundamental to any robust and scientific human reliability assessment. The advantages of a classification scheme, or taxonomy, of human error are as follows:

Similarity, in HEP, if one wishes to use a human error datum to quantify a HEP, it is appropriate to use this particular datum or select another one instead. Such a judgement can only strictly be made on the basis of a classification system. This point may seem laboured but it is fundamental to any robust and scientific HRA. The advantages of a classification system, or taxonomy, of human error are as follows:

- It offers a *structure* to the user, such that categories can be used ether predictively, to identify errors, or retrospectively, to classify events.
- If robust, it offers a mean of rendering *HEI* both reliable and repeatable, to the extent that two independent assessors are able to identify the same errors.
- It can add meaning to the assessment by defining the causes and reasons underlying the errors, and thus making the assessment more obvious.

- It offers a means by which human error data can be collected and/or generated, matched with identified human errors and the quantified predictively.
- In theory, a good classification system will at least enhance (and sometimes even guarantee) the comprehensiveness of the error identification process, such that no critical errors are omitted from the assessment.

As seen her is classification a worthwhile objective since it offers so many advantages, and can make the process of error-identification less of a 'black box' affair (Kirwan, 1994). However, according to Kirwan (1994) are there two major pitfalls that has been identified and may cause some concern:

- If the classification scheme is not complete, important error may be omitted from the analysis.
- If the classification of errors is incorrect or superficial, critical difference in error typology may be overlooked, leading later to an inappropriate and incorrect quantification of human reliability

In practice we can now see that classification systems of human error are being used in three main ways:

- For the analysis of incidents: to identify what happened and then prevent it's recurrence; as well as to derive *data* from such incidents.
- For *HEI* purposes: to identify errors which may have an impact upon a system's goals, as well as the level of inherent risk.
- *HEQ*: to match existing data to identified human errors in order to quantify the likelihood of the latters' occurrence.

Having briefly outlined the importance and rationale of a classification, plus its objectives, advantages and limitations, it is now appropriate to consider some of the basic classification methods related to well integrity.

Table 3.1: Methods/Tools well suited for well integrity assessment

	Method/Tool	In full
General methods	WHW questions	What, How and Why questions
	SRK	Skill-, Rule-, and Knowledge-Based Behavior
	SLMV	Slips, Lapses, Mistakes, and Violations
Advanced methods	THERP	Technique for Human Error Rate Prediction
	STEPP	Sequential Time Event Plotting Procedure

3.5 Classification Methods

There is no universal agreed classification scheme for human error, nor is there on in prospect. A scheme is usually made for a specific purpose, and no single scheme is likely to satisfy all needs. Nearly everyone who has published in this field has devised some form of error classification scheme. Consequently, the literature abundance with such schemes, reflecting a variety of practical concerns and theoretical orientations and ranging from the highly task specific to broad statement of underlying error tendencies.

A total of 72 potential human reliability related tools and acronyms were identified by (Health and Safety Executive, 2009). After reeding the details of these 72 methods, 35 was identified as potentially relevant for classification purposes. Table 3.2 shows the acronym and full title of all the 35 tools identified for review. Through a high level assessment of the available information, HSE considerer 17 of these methods to be of potential use to major hazards directorates. These 17 methods is listed in Table 3.3.

As shown in the Table 3.3 are there many different classification schemes that can be used to classify human and organizational factors. It is impotent do notice that most of this methods are developed for the nuclear and aviation industry and is therefore not well suited for the oil and gas industry. Most of the methods is therefore not covered in more detail in this thesis. The authors goal by listing all of this methods is to give the reader an insight in the huge specialized field of human and organizational factors. A summery of all the methods identified as being of potential use to HSE major hazardous identification can be found at HSE's websites listed in the Bibliography (Health and Safety Executive, 2009). Table 3.1 shows methods identified by the author that is well suited for the oil and gas industry. The methods listed in Table 3.1 will be covered in more detail.

Table 3.2: Acronym and full title of the 35 tools identified for review (Health and Safety Executive, 2009)

Method/Tool	In full
ASEP	Accident Sequence Evaluation Programme
AIPA	Accident Initiation and Progression Analysis
APJ	Absolute Probability Judgement
ATHEANA	A Technique for Human Error Analysis
CAHR	Connectionism Assessment of Human Reliability
CARA	Controller Action Reliability Assessment
CES	Cognitive Environmental Simulation
CESA	Commission Errors Search and Assessment
CM	Confusion Matrix
CODA	Conclusions from occurrences by descriptions of actions
COGENT	COGnitive EveNt Tree
COSIMO	Cognitive Simulation Model
CREAM	Cognitive Reliability and Error Analysis Method
DNE	Direct Numerical Estimation
DREAMS	Dynamic Reliability Technique for Error Assessment in Man-machine Systems
FACE	Framework for Analysing Commission Errors
HCR	Human Cognitive Reliability
HEART	Human Error Assessment and Reduction Technique
HORAAM	Human and Organizational Reliability Analysis in Accident Management
HRMS	Human Reliability Management System
INTENT	Not an acronym
JHEDI	Justified Human Error Data Information
MAPPS	Maintenance Personnel Performance Simulation
MERMOS	Method d'Evaluation de la Realisation des Missions Operateur pour la Surete (Assessment method for the performance of safety operation.)
NARA	Nuclear Action Reliability Assessment
OATS	Operator Action Tree System
OHPRA	Operational Human Performance Reliability Analysis
PC	Paired comparisons
PHRA	Probabilistic Human Reliability Assessment
SHARP	Systematic Human Action Reliability Procedure
SLIM-MAUD	Success likelihood index methodology, multi-attribute utility decomposition
SPAR-H	Simplified Plant Analysis Risk Human Reliability Assessment
STAHR	Socio-Technical Assessment of Human Reliability
TESEO	Tecnica empirica stima errori operatori (Empirical technique to estimate operator errors)
THERP	Technique for Human Error Rate Prediction

Table 3.3: A list of the 17 tools considered to be of potential use to HSE major hazard directorates (Health and Safety Executive, 2009)

		Method/Tool	Comment	Domain
Publicly available	1st generation	THERP	A comprehensive HRA approach developed for the USNRC	Nuclear with wider application
		ASEP	A shortened verson of THERP developed for the USNRC	Nuclear
		HEART	Relatively quick apply and understood by engineers and human factors specialists. The method is avaiable vie published research papers. (A manual is avaiable vie British Energy)	Generic
		SPAR-H	Useful approach for situations where a detailed assessment is not necessary. Developed for the USNRC[1] Based on Heart	Nuclear with wider application
	2nd generation	ATHEANA	Resource intensive and would benefit from further development. Developed by the USNRC[1]	Nuclear with wider application
		CREAM	Requires further development. Available in a number of published references.	Nuclear with wider applications
	Expert Judgement	APJ	Requires tight controls to minimise bias, otherwise validity may be questionable. Viewed by some as more valid that PC and SLIM.	Generic
		PC	Requires tight controls to minimise bias, otherwise validity may be questionable	Generic
		SLIM-MAUD	Requires tight controls to minimise bias of SLIM element, otherwise validity can be questionable. The SLIM element is publicly available.	Nuclear with wider application

		Method/Tool	Comment	Domain
Not publicly available	1st generation	HRMS	Comprehensive computerised tool. A roprietary method	Nuclear
		JHEDI	Faster screening technique than HRMS, its parent toll. A proprietary method	Nuclear
		INTENT	Narrow focus on erors of intention. Little evidence of use but potentially useful- Available by contacting HSE.	Nuclear
	2nd generation	CAHR	A database method that is potentially useful. Available by contacting the authors (CAHR website).	Generic
		CESA	Potentially useful. Available by contacting the HSE	Nuclear
		CODA	Requires further development and CAHR or CESA may be more useful. Available by contacting the HSE.	Nuclear
		MERMOS	Developed and used by EdF[3] its development is ongoing. A proprietary tool.	Nuclear
	3rd generation	NARA	A nuclear specific version of HEART (different author to the original). A proprietary tool.	Nuclear

3.5.1 What, How and Why (WHW) questions

There exist several different classifications schemes of human error by using knowledge of human cognitive behavior. Most classifications have multiple levels of analysis, such as what happened, how it happened and why did it happened. Asking these questions is a very general way to classify human error, and can be a tool for practical application of acquired knowledge and to increase competence. There are three categories of taxonomy that can help to study and analyse the nature and extent of human error (Redmill and Rajan, 1997):

1. Phenomenological taxonomy (What happened?): describes the error in superficial terms that refer to observable events, and are widely used in HRA. Substitutions, repetitions and omissions are typical categories.

2. Cognitive mechanism taxonomies (How did it happen?): classify errors in the stages of human information processing, and are increasingly used in post-accident investigations. Memory lapses, misinterpretation, mistake alternatives, attention errors and perceptual errors are such examples.

3. Taxonomies for bias and deep-rooted tendencies (Why did it happen?): that error is believed to reveal, and currently tends to be research tools. The classification at this level

of the performance error-shaping factors can be done by using Skill- Rule and Knowledge based behavior theory.

By asking WHW questions, can one learn from, analyse and study human error and accidents that have occurred in a complex work systems. Thereby, one could improve the performance, procedures, rules, reliability and behavior. One can eliminate, reduce and control the errors in situations that are safety critical. The questions can also provide input to a HRA and can be used for post-accident investigations and research (Redmill and Rajan, 1997). This gives the opportunity to improve the technical system design and operations, and provide input to risk and safety analysis. Organizational design, management and planning can also apply this knowledge (Redmill and Rajan, 1997). This shows a wide range of factors that can utilize the results from the WHW questions for improvement, learning, control and increased security. The importance of these questions addresses how the use of knowledge will contribute to a safe and improved performance and operation of complex work systems where humans are involved.

3.5.2 Skill-, Rule-, and Knowledge-Based Behavior

One of the most influential methods for classifying HO factors/behavior is the skill-, rule-, and knowledge- based behavior (SKR) method of Rasmussen (1983). Basically, the three levels represents the following types of behavior:

Skill-based: Sensory-motor performance which take place without conscious control. Routine and highly practices tasks are carried out in a highly automatic fashion with occasional conscious checks on progress (Rasmussen, 1983). The person may be unable to describe how they control and on what information they pass the performance through the highly integrated smooth automated patterns of behavior (Redmill and Rajan, 1997). At the skill-based level the information from the environment is perceived as signals. Here, *slips* and *lapses* are types of errors that may occur when a skilled person are performing a familiar task

Rule-based: Actions according to an explicit rule or procedure (Rausand, 2011). Rule-based behavior is when the operator does not have the same level of practice as for skill-based behavior when performing a task. The procedure may not have been carried out in the proper sequence, or some hesitation in recalling the procedure, or some steps may not be performed precisely. Rule-based errors are often concerned with the misapplication or inappropriate use of problem solving rules (Rausand, 2011).

Knowledge-based: Coping with unfamiliar situations without a procedure (e.g., diagnosis) requires conscious problem solving and decision-making. Knowledge-based behavior includes situations where the operator needs to contemplate the situation, interpret information, or make a difficult decision (Rausand, 2011).

Application of the SRK-bahavior method

The SRK method contribute to integrate and coordinate organizational design, system safety and HO factors by classifying human errors. The SRK method shows the main distinctions between tree levels of human performance (Reason, 1997). These performance levels are distinguished by psychological and situational variables that together define an "activity space" where the tree performance levels can be classified (Reason, 1997). The performance levels can coexist at the same time. Figure 3.2 show that humans can control their actions through various combinations of two control modes - conscious (paying attention to something) an automatic (largely unconscious) (Reason, 1997). It also illustrates the second dimension defining the "activity space" of the situation, where the two extremes are highly familiar everyday situations and routines, and entirely novel problems.

3.5.3 Slips, Lapses, Mistakes, and Violations.

Reason (1990) classified errors in terms of slips, lapses, mistakes, and violations. The terms has been defined in terms that is easy to understand by Rausand (2011) and is therefore directly quoted:

1. *Slip:* An action that is carried out with a correct intention but a faulty execution (Rausand, 2011). A slip is an action that is unplanned and usually is not a very dangerous event (e.g.,

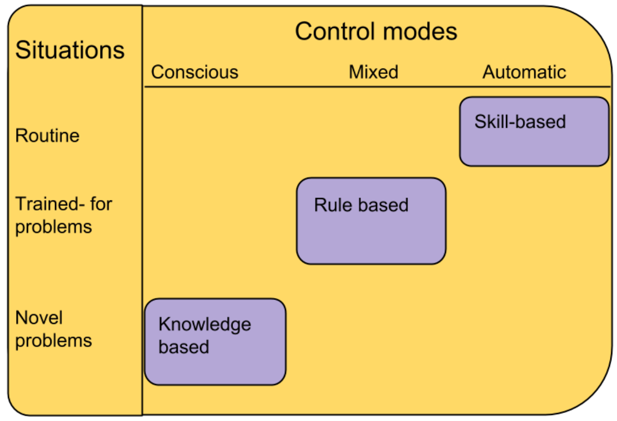


Figure 3.2: Location of the three performance levels within the "activity space" defined by control modes and situations (Reason, 1997).

inadvertently pushing the wrong button, reading error, slip of the tongue[4]).

2. *Lapse:* A failure to execute an action due to a lapse of memory or because of a distraction (Rausand, 2011). A lapse may not necessarily be evident to anyone other than the person who experienced the lapse. Lapses may be dangerous and are difficult to contain (e.g., omitting a step in a sequence of actions, "jumping" from one sequence to another, more familiar, sequence of actions). Slips and lapses will usually not be eliminated by training and need to be designed out (HSE., 2005).

3. *Mistake:* A correct execution of an incorrect intention. An operator may believe an action to be correct when it is, in fact, wrong. He/she may, for example, press the wrong button or switch off the wrong engine. Mistakes often appear in situations where the behavior is based on remembered rules or familiar procedures and are generally more dangerous than slips and lapses. Training is important to avoid mistakes.

4. *Violation:* A person deliberately applies a rule or procedure that is different from what he/she knows is required, even though he/she may often do it with good intent. A familiar rule violation is when someone knowingly drives his/her car above the speed limit. Viola-

[4]Note that such errors may be non-critical slips in some contexts and critical errors in other contexts

tions differs form slips, lapses, and mistakes because the are deliberate, or illegal actions (e.g., deliberately failing to follow procedures).

Slips and lapses is experienced by all, even experienced or highly motivated people, while mistakes often are caused by lack of experience or inadequate training. Violations may range from simple "corner-cutting" to dangerous macho behavior, and may be classified as (HSE., 2005):

1. *Routine violations:* Behavior in opposition to rule, procedure, or instruction that has become the normal way of behaving within the current context.
2. *Exceptional violations:* These are rare and happen only in unusual and particular circumstances, when something goes wrong in unpredicted circumstances: for example, during an emergency situation.
3. *Situational violations:* These violations occur as a result of factors dictated by the worker's immediate workspace or environment (physical or organizational).
4. *Acts of sabotage:* These are self-explanatory, although the causes are complex, ranging from vandalism by a demotivated emloyee to terrorism.

3.6 Technique for Human Error Rate Prediction (THERP)

This technique is one of the most widely used in a HRA for PRSA The object of THERP is: "to predict HEP and to evaluate the degradation of a man-machine system likely to be caused by human errors alone or in connection with equipment functioning, operational procedures and practices, or other system and human characteristics that influence system behavior"(Swain and Guttermann, 1983). The method consist of four procedural stages (Reason, 1990):

1. Identify the system functions that may be influenced by human error.
2. List and analyse the related human operations (i.e., perform a detailed task analysis[5])

[5] Task analysis: Detailed examination of the observable activities associated with the execution of a required task or piece of work (Rausand, 2011). For more detail on task analysis see Drury (1983); Kirwan and Ainsworth (1992)

3. Estimate the relevant error probabilities using a combination of expert judgement and available data.

4. Estimate the effect of human errors on the system failure events, a step that usually involves the integration of HRA with probabilistic risk assessment (PRA). When used by designers, it has an additional iterative step that involves making changes to the system and then recalculating the probabilities in order to gauge the effects of these modification.

The method is best used with a systematic task-behaviour taxonomy, such as the system developed by Berliner et al. (1964) and shown in Kirwan (1994). The THERP is well suited for pre-accident and post-accident tasks. The method is old: its origins go back to the early 1960s. The method is clearly described in the *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications* (Swain and Guttermann, 1983). Section in the THERP handbook (Swain and Guttermann, 1983) elaborates different types of problem which can occur in a range of behaviour situation. These sections essentially imbue the reader with a fair variety of human factors perceptions on good and poor task and interface designs (Kirwan, 1994). In addition, the THERP methodology considers a range of PIFs which can give rise to human error. Lastly, the human error data tables themselves found in Chapter 20 of the THERP handbook. The value given in these 27 tables of HEPs relates to nominal HEPs (the probability that when a given task element is performed, an error will occur).

By performing a task analysis of the human activities, the more likely errors can be detected and their probabilities estimated. The influence of a wide variety of PIFs is taken into account. The level of detail of data needed is extensive. The general areas of information required for this technique are (International Atomic Engergy agency., 1989):

- Type of task
- Recovery factors
- Dependency
- Stress
- Type of equipment

- Staffing and experience
- Management and administrative control
- diagnosis time oral and written procedures
- Other parameters related to man-machine interface: displays etc.

According to Kirwan (1994) are the disadvantages of this methodology its lack of rigorous structure. This means that there can be a considerable variation in how different assessors model scenarios (see Brune et al. (1983)) and its failure to consider underlying psychological mechanisms i.e. the reasons why errors occur. Its principal advantage is that it is straightforward and simple to use, and has the potential to model all the errors that can affect a system.

3.7 Sequential Time Event Plotting Procedure (STEPP)

STEPP learns lessons from the past. It is a multiple event sequence technique used to structure incident investigation and accident analysis procedures by piecing together the scenarios surrounding the accident or incident (Wilson and Stanton, 2001). The method distinguishes between events, actions, plant and people. The main purpose is to identify the causal paths and the multi-causality of the incident or accident under investigation (Wilson and Stanton, 2001). The model strives to identify and classify the underlying root causes rather than the obvious superficial events. This means that this model is an ideal method for classifying HO factors. Data needed for the development of the model is collected through interviews with team members, data form measured variables, live and recoded transcripts, eyewitness testimony, printouts from alarm lists, etc.

The first stage in STEPP involves the definition of the "beginning" and "end" states of the accident. This limits the scope of the investigation form the first event that deviated from the planned technical process to the last harmful event in the incident (Kontogiannis et al., 1999). The main events/actions that contributed to the accident is now to be identified followed by the construction of the "event building blocks" which contain the following information (Kontogiannis et al., 1999):

- the time at which the event/action started
- the duration of the event/action
- the agent which caused the event or action
- the description of the event/action
- the name of the source which offered this information

In the second stage, the events/actions are inter-connected with lines. All events should have incoming and outgoing lines which shows "precede" and "follow" relationships between events (Kontogiannis et al., 1999). According to Hendrick and Brenner (1987) can the finished graph be several feet long. Lines (causal paths) closing in on each other shows dependencies between events while lines moving away form each other show the impact on following events. Some paths may be dead ends, others may lead to a single event and some paths may lead to many events. When all the paths has been identified, the underlying root causes for the incident are sought. At this stage the build up of latent or active causes and their effects can be identified (Hendrick and Brenner, 1987).

At the end of the data collection, a multi-linear sequence diagram shows the personnel and plant down the vertical axis with the time-line on the horizontal axis (Wilson and Stanton, 2001).

The accuracy of the event representation is checked using the backSTEPP technique. This technique is simply reasoning backwards in order to examine how each "event building block" could be made to occur. Reasoning backwards helps analysts to identify other ways in which the accident process could have occurred, and this guides the search for additional data (Kontogiannis et al., 1999).

3.8 Recommendation

This chapter shows that there are many different ways of classifying HO factors. The WHW, SRK and SLMV methods undertaken in this thesis were of an general nature and may have trouble fulfilling the objectives of the analysis in regards of well integrity. THERP is a strong and efficient method for classifying HO factors. The method is well proven in many industries, specially the nuclear and aviation industry, but is somewhat behind in the oil and gas industry.

The STEPP method is well suited to describe tractable systems, where it is possible to completely describe the system, the principles of functioning are known and there is sufficient knowledge of key parameter. This means that the method is well suited for classifying an optimizing HO factors in the oil and gas industry. Earlier studies on major accidents such as the Piper Alpha incident confirms that the STEPP method is well suited to analyse, classify and optimize human and organizational factors in the context of well integrity. The method works well by integrating and combine human factors methodology, giving a very comprehensive analysis of human errors (Wilson and Stanton, 2001). The method looks at different aspects of work related behavior, measuring and assessing the potential risks from human errors in that field. In practical terms, this method should ensure that safety margins are maintained and safety cases can be made before changes in working practices are introduced. STEPP examine different aspect of human interaction within the work environment and work related performance and subsequently measure and assess the likelihood of human errors, or potential human errors in that interaction. This means that STEPP also is well suited for quantifying the influences of HO factors.

With all this taken into consideration together with discussions with the drilling supervisor at Veslefrikk, is the method selected to be best suited to reach this thesis project task number two, the STEPP method.

Chapter 4

Well Integrity: The relationship between Human and Organizational factor and Well Integrity

4.1 Introduction

During investigations of major accidents over the last few years it has become clear that there is a lack of focus on the interaction factors between human, technology and organization elements in the oil and gas industry. These critical influencing factors or HO factors may be hard to detect unless all possible interactions between the different elements is considered. Unforeseen critical factor may have a critical influence on the work performance by the operators and crews, and may have a bad influence on well integrity.

Well integrity is an issue affecting the entire life cycle of a well to prevent uncontrolled release of formation fluids through technical, operational, and organizational barriers (Standar Norway., 2004). This thesis shows that there are different ways of looking at these factors affecting the decision making and work performance (the human performance model, the error causation paradigm, HTO and PIFs). It illuminates that these methods can be useful to identify, evaluate and analyse the HTO perspective. A strong knowledge of the systems from an HTO perspective, together with a classification scheme for HO factors and further analysis with respect to dynamic connections between the personnel, the activity, and the context (the human performance model) can give a better working environment and an opportunity to improve the health, safety integrity, and work performance (Vignes, 2011). Comprehending the interactions between HTO, the human error causation paradigm and the knowledge about PIFs may be critical for achieve the goals of safe and effective well operations (Redmill and Rajan, 1997).

This chapter will provide an introduction to well integrity, then try to reach these thesis project tasks number three and four. The HTO perspective will be used to introduce the HO factors in the context of well integrity and a presentation of why HO factors is of importance in the context of well integrity will be given. The HTO perspective will be used as an analytic tool to analyse, evaluate and improve the interactions between human, technology and organizational elements and thereby improving well integrity.

4.2 Well Integrity

4.2.1 What is well integrity

Today the operational phase of a well's life can last for 30 years or more. Wells are being drilled deeper, longer and under more challenging conditions than ever before. This makes it more difficult to manage the well and ensure optimum safe conditions for the whole well designed life. This leads to the concept of well integrity.

Several well incidents have been reported in the past, with significant impact and potential for serious accidents. This could typically be a result from ageing effects or wrong design, unclear understanding of barriers, weaknesses in well design and planning processes, insufficient validation of premises, well conversion and other reasons. All of this categories of failure ranging from the design stage, all the way to the abandonment phase can be put under one category, well integrity.

Well integrity can in its simplest definition be defined as a condition of a well in operation that has full functionality and two qualified well barrier envelopes (Sangesland et al., 2012). Any deviation from this state is a minor or major well integrity issue.

The definition emphasizes the importance of technical and technological solutions to avoid flow of formation fluids from one formation zone to another, or to the surface throughout the life cycle of a well. According to Sangesland et al. (2012), well integrity is not only influenced by equipment robustness, but by the total process, resources and competence of the organization and individual.

This definition is all well and good but in an international industry such as the Oil and Gas industry, there is need for a global understanding of what well integrity is and how to manage it. Therefore different authorities have made standards and regulations to ensure adequate safety, value adding and cost effectiveness for the petroleum industry developments and operations.

Well integrity is defined in Norsok-D-010 as: "application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well".

Norsok D-010 is a functional standard which means that it is the companies that have the full responsibility to comply with the standard. The standard only gives the minimum requirements for the equipments/solutions to be used in a well, but leaves it up to the operating companies to choose the solutions that meet the requirements.

The standard focuses on establishing Well Barriers by the use of Well barrier element (WBE), their acceptance criteria and their use and monitoring of integrity during their life cycle. Well barriers is defined in Norsok D-010 as envelopes of one or several dependent Well Barrier Elements preventing fluids or gases from flowing unintentionally from the formation, into another formation or to surface and are used to prevent leakages and reduce risk associated whith drilling, production and intervention activities. The main objective of a well barrier is to (Standar Norway., 2004):

- Prevent any major hydrocarbon leakage from the well to the external environment during normal production or well operations.
- Shut in the well on direct command during an emergency shutdown situation and thereby prevent hydrocarbons from flowing from the well.

NORSOK D-010 distinguishes between primary and secondary well barriers. A primary well barrier is the barrier that is closest to the pressurized hydrocarbons. If the primary well barrier is functioning as intended, it will be able to contain the pressurized hydrocarbons. If the primary well barrier fails, e.g. any leakage or a valve has failed to close, the secondary barrier will prevent outflow from the well. If the secondary well barrier fails, there may, or may not, be a tertiary barrier available that can stop the flow of hydrocarbons (Sangesland et al., 2012). The standard also covers well integrity management and personnel competence requirements. The standard does not contain any well rig equipment specifications.

When Analyzing well barriers and their role in preventing or acting upon leakages it is important to understand the barrier function and the possible ways the barrier can fail. Methods used to illustrate this is distinguish between:

- Well barrier schematics
- Barrier diagrams

Well barrier schematics and well barrier diagrams is an essential tool for assessment of the reliability and risk in all the phases in the wells life cycle. This also applies for well integrity assessments.

Well barrier schematics

A well barrier schematic (WBS) is shown for a standard production well in Figure 4.1 This well has six *primary* well barrier elements:

- Formation /cap rock above reservoir
- Casing cement
- Casing
- Production packer
- Completion string (below the DHSV)
- Surface controlled subsurface safety valve (DHSV)

- And six *secondary* well barrier elements:

- Formation above production packer
- Casing cement

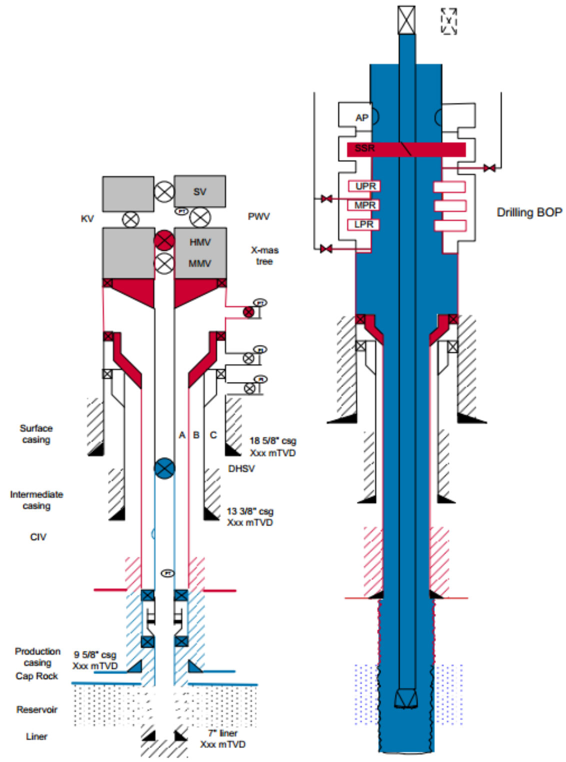


Figure 4.1: Primary and secondary barriers in production and drilling mode (Standar Norway., 2004)

- Casing with seal assembly
- Wellhead
- Tubing hanger with seals
- Annulus access line and valve
- Production tree (X-mas tree) with X-mas tree connection

According to NORSOK D-010, well barrier schematics are developed as a practical method to be used to demonstrate and illustrate the presence, or non-presence of the required primary and secondary well barriers. An example of a well barrier schematic of a production well is shown in Figure 4.1. This is a template typically used for illustrating the well barrier schematic. In the real barrier schematic for a specific well all the data are given (Sangesland et al., 2012)

The different colors represent the different well barriers according to NORSOK D-010. The blue lines represents the primary well barrier and illustrates the "*normal working stage, which* *for some situations is the fluid column or a mechanical well barrier that provides closure of the well barrier envelope*"(NORSOK D-010) and the red line represent the secondary well barrier and illustrates the "*ultimate stage, which in most cases describes a situation where the shear ram/shear valve is closed*" (NORSOK D-010). Well barrier schematics shall be complemented by tables showing the WBEs that are found as primary or secondary barriers.

The schematic presents a well shut in and capable to produce. The blue line indicates the primary barriers: production packer, completion string (tubing section between the downhole safety valve and production packer), and the valve itself. The red line envelope consists of the casing cement, casing, wellhead, tubing hanger, annulus master valve and production tree with the production master valves.

4.2.2 What is the problem with Well Integrity?

Many different types of failures can lead to loss of well integrity. A typical well is built from thousand of components that must withstand the stress from demanding environments. If this is not fulfilled the conditions for well integrity is compromised and the well are at risk of damaging the environment, personnel, etc. In the worst case even a blowout can occur.

This task is not easy and as we can see from the examples listed earlier the problem still exists today. Managing well integrity is a global challenge and statistic collected during the past few years from 3 independent sources (Forum North Sea Well Integrity., 2009) revealed well integrity failures in 45%, 34% and 18% of wells in Gulf of Mexico, UK North Sea and the Norwegian North Sea.

In 2006 the PSA conducted a well integrity survey that indicated about 20 % of wells in the NCS may suffer from integrity issues. Most of the problems were related to deficiency in annulus safety valve, tubing, cement and casing. Pressure build-up in annulus, i.e. sustained casing pressure, is one of the main indicators of a significant well integrity problem (see Figure 4.2) (Vignes et al., 2006)

Well Integrity is maintained by applying technical, operational, and organizational solutions to reduce the risk of uncontrolled release of formation fluids throughout the life cycle of the well.

In the life cycle of an oil/gas well there is four phases the well goes through. Two of them are important for the integrity of the sealant of the well, namely: The well construction phase and

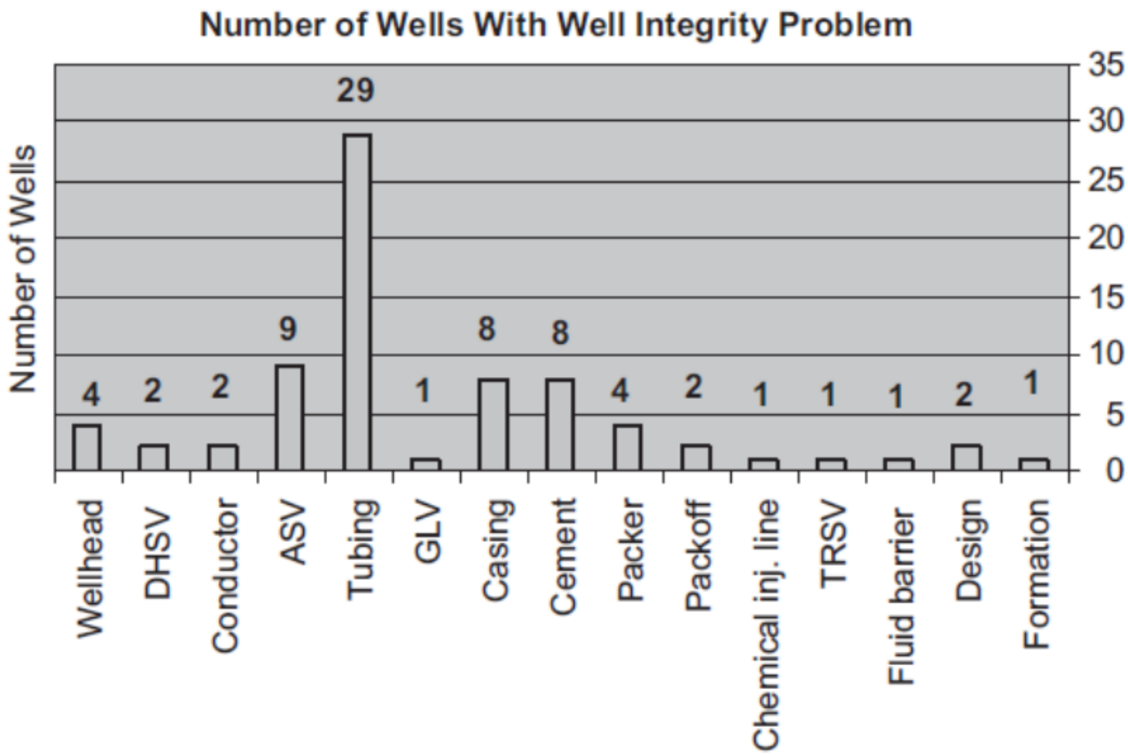


Figure 4.2: Number of wells suffering from different barrier element failure. (Vignes and Aadnoy, 2008)

the production phase.

- *Design Stage:* This involves exploration activities before actual wellbore operations begin.
- *Well construction phase:*
  - Drilling
  - Cementing
  - Completing During this phase, the stresses and resultant wellbore stability will constantly change because the fluctuating gravity of the fluids inside the wellbore. These changes will influence the resultant stresses in the cement sheath
- *Later operational phase* During this phase, the intended operational regime of the well and planned/unplanned human interventions will seriously affect the integrity of the sealant. Typical Actions that happens during this phase:
  - Naturally developing stresses, subsidence, depletion

  - Operational Regime Moderate versus HPHT operation Water/steam injector/gas storage/production
  - Human interventions Changing fluids Pressure testing Perforation Injection Production Propped hydraulic or acid fracturing Hot oiling Sidetracking operations

- *Abandonment phase:* this stage involves plugging and abandoning wells which have reached its economic life.

  Ideally, during the draft of the Well Functional Specifications, the extremes in well operation should be defined. Next, the impact, not only on casing or tubing design, but also on the integrity of the well sealant should be evaluated.

4.2.3 What are the requirements to Well Integrity?

As we now have seen, well integrity is a big subject and involves a lot of different departments and components. According to (Noland, 2012), to serve up a well with integrity, follow this recipe:

- Planning - No such thing as too much planning
- Ingredients - One bad ingredient can spoil the well
- Team - A coordinated broad based team effort is essential
- Technique and Execution - Plans and guidelines must be fit for purpose and followed - no shortcuts
- Sample - Ensure key well parameters are met along the way

This recipe refers to the underlying cause of the failure both in terms of management but also in terms of component failure and is very important to manage in a correct way. But the well integrity requirements refers mostly to the well Barriers and well elements. This is because the technical means of avoiding well integrity loss are the use of well barriers. NORSOK D-0101 specifies that: "There shall be two well barriers available during all well activities and operations, including suspended or abandoned wells and keep the borehole/well to the external environment". This sets the foundation for how to operate wells and keep the wells safe in all phases of the development. This requirement is also referred to in PSA's Activities and Facilities regulation and it implies that operators have to adhere to the two barrier philosophies and maintain sufficient adherence in all phases of their operations.

Well barriers are mandatory to provide well integrity. Well barriers are used to prevent leakages and reduce the risk associated with drilling, production and intervention activities. Standar Norway. (2004) defines Well barrier as a envelope of one or several dependent barrier elements preventing fluids or gases from flowing unintentionally from the formation into another formation or to the surface. The objectives or the requirements the well barriers must maintain are:

- Prevent any major hydrocarbon leakage from the well to the external environment during normal production or well operations.

- Shut in the well on direct command during an emergency shutdown situation and thereby prevent hydrocarbons from flowing from the well.

Well barrier consist of on or more well barrier elements. Well barrier elements are defined in the Standar Norway. (2004) as Object that alone cannot prevent flow from one side to the other side of itself.

Requirements that apply to barriers needs to be distinguish in general (e.g., as stated in PSA's Management Regulations, §4 and §5), and requirements that apply to well barriers in particular (e.g., as stated in PSA's Facilities Regulations, §48). The associated guidelines provide further details and give reference to specific parts of national or international standards. The guideline to §48 of the Facilities Regulations, for example, refers to specific chapters of the NORSOK D-010 standard and also to specific sections of the Management Regulations.

From the guidelines to §48 of the Facilities Regulations, and the referenced standards, the following requirements can be deduced:

- At least two independent and tested barriers shall, as a rule, be available in order to prevent an intentional flow from the well during drilling and well activities.

- The barriers shall be designed so as to enable rapid re-establishment of a lost barrier.

- In the event of a barrier failure, immediate measures shall be taken in order to maintain an adequate safety level until at least two independent barriers have been restored. No activities for any other purposes than re-establishing two barriers shall be carried out in the well.

- The barriers shall be defined and criteria for (what is defined as a) failure shall be determined.
- The position/status of the barriers shall be known at all times.
- It shall be possible to test well barriers. Testing methods and intervals shall be determined. To the extent possible, the barriers shall be tested in the direction of flow.
- Separate regulations are issued by the PSA for handling of shallow gas in drilling operation. When drilling the tophole section, the gas diversion possibility is regarded as the second barrier. This is, however, not a barrier according to the barrier definition above.

4.2.4 Improvement Potential

There is a common denominator between many of the failures experienced on wells and their well integrity :

- Operational decisions during abnormal situations often leads to well failures.
- Design issues such as long-term effects are not sufficiently considered.
- The challenge is to account for rare events that may lead to major incidents. The normal approach is to focus on frequent and low-consequence incidents.

PSA (Vignes et al., 2006) proposed several improvements to try to make well integrity as safe as possible:

- ***Well Documentation.*** Different approaches for transfer of well-barrier responsibilities and insufficient transfer of critical information during operations and license acquisitions may result in reduced barrier control. Improved and user-friendly access and visualization of key well information are needed.

- ***Handover Documentation.*** Several companies include pressure-test-verification charts in their handover documentation without interpretation. These data could be several years old and do not necessarily represent the present status. Well-integrity or well-barrier schematic illustrations, verifications, and how-to-monitor status were not easily accessible. While completion schematics are included in the handover documentation and kept updated at all times, the barrier schematic illustrations with descriptions were often inadequate.

- ***Condition Monitoring.*** Consideration to and evaluations of initial casing design for the lifetime of the well and possible changes o the well usage (example, from production to injection) and also difficult to obtain.

- ***Comments Related to NORSOK D-010 Compliance.*** The NORSOK D-010 defines requirements and guidelines, including the established well-barrier philosophy. It appears to be less known and adhered to than PSA expected at the time when the audits were conducted. The lack of information on well names, dates, and revision numbers complicates easy overview of the status on well barriers. Color coding and descriptions of the barrier envelopes vary from company to company, but also within the same company. In several cases, the barrier illustrations do not contain details of perforations, the X-mas tree, and cement presence, and in some cases they lack barrier elements. Such well details with possible inclusion of dimensions and depth data should be included for updated versions. Verification details of the casing cement barriers are often lacking. Hence, proper planned top of cement (TOC), packer-setting depth, and later proper zonal isolation for later P and A Could imply uncertainties.

- ***Competence and Training.*** The questionnaire revealed a need for strengthening knowledge, communication, and requirements to well barriers and status. The companies generally expressed high interest in sharing and exchanging training material for practical use.

4.2.5 What remains to be done within Well Integrity?

Well integrity has come a long way to become an efficient and reliable tool to prevent accidents. But sadly accidents do happen and will continue happening in the future if the industry continues with it's philosophy and trends. To turn this development in the future the industry needs to change attitude to increase the focus on barrier issues. By changing the focus on to barrier status and the control of barrier status the company has a good chance of limiting any unintentional leaks, well-control situations, and accidents. This important HSE factor give the companies a "well-known" barrier status that enables them to take the right actions in a proactive manner and thereby prevent potential losses and expenses.

According to the Well-integrity survey by PSA (Vignes et al., 2006) 7% of the wells were shut-in because of integrity failures/issues or uncertainty, 9% of he wells were working under conditions/exemptions and 2% of the wells had insignificant deviations for current operation. This means that there is a lot of improvement potential in well integrity.

Well integrity is a complex system that consists of WBE such as tubing, ASV and casing but can also be referred to as the management around all of these components. Therefore, it is important to understand the improvement can not only be focused on the components itself but also the management around the components. Therefore the PSA encourage the industry to the following:

- Improve systems of reliability and condition-based surveillance for well barriers and well-integrity aspects to improve well safety.
- Provide better visualization of barriers for both onshore and offshore users to improve the safety level and user friendliness.
- Agree on standard ways of visualization, technical qualification, documentation, and abbreviations.
- Consider developing a standard handover package containing basic well-engineering data required to give a full overview of the well-barrier situation from spud to abandonment.
- The industry needs to further develop and acquire suitable technology for condition monitoring of wells to improve on systematic and preventive maintenance and to keep better

control on degradation mechanisms.

- Improved attention on verification and condition monitoring of well barriers and well integrity is needed.
- Improve competence and training of involved personnel both from operators and contractors.
- Start the process of updating the NORSOK drilling standards to include recent experiences related to well barriers. This should include the qualification process for barrier elements.
- Operational decisions during abnormal situations often lead to well failure today. This is a problem that concerns many parties, such as training of operators and management. This is something that needs to be worked on in the future.
- Design issues such as long-term effects are not sufficiently considered today, this is a subject that is important to focus on in the future..
- The challenge is to account for rare events that may lead to major incidents. The normal approach is to focus on frequent and low-consequence incidents.

4.3 How can Human and Organizational factors contribute to Well Integrity?

Chapter 2 together with section 4.2.5 tells us that HO factors is a very important concept related to well integrity. It must therefore be included in the engineering and design of a workplace or a working environment because they influence work performance. As mention earlier in this thesis the HO factor aspect consists of environmental conditions with a workplace layout, and the cognitive demands of interface design. HO factors focus on the human element; that includes competence, abilities, human needs and limitations, the technological element; that includes design, functionality, usability, integration and how the technical element supports the operators to preform their work safely and effectively. Finally the organizational element; that can include the manning, support, management and structure. To counteract and prevent a dangerous event from happening doe to human error, human experiences have to be implemented when designing equipment and technologies and make these system to be able to handle errors. In principle, it is important to maintain a comprehensive focus and control interactive factors that have a notable influence on human performance The principal argument is that the actual work performance has to be better understood in the HTO perspective, to reduce system vulnerability and to improve performance from a safety and environmental point of view (Vignes, 2011)

The Human element in improving Well Integrity

The HTO perspective related to well integrity situations can be described related to the human-, technological- and the organizational element. The human element can include challenges related to human limitations, skills, knowledge, competency, education, experience and training. Stress and time pressure are other factors that can affect human performance (Bailey, 1996). The identified challenges related to the human element include well control training and knowledge, well integrity training and courses and human computer interface:

Well control training and knowledge

Under the planning phase, drilling operations and well intervention is the conditions of the formation, and specially the formation pressure, a very important factor. Improper formation pressure detection or handling of kicks may result in loss of well control (Skalle and Podio, 1998). Loss of well control may led to a blowout. A blowout is a result of failure to control a kick caused ether by equipment failure or human error. Well control training is performed to prevent situations where loss of the primary and secondary barriers results in a blowout or other catastrophic events (NSOAF, 2005). Well control training must therefore include all positions from well design, drilling crew, well service crew (contractors) and service personnel (NSOAF, 2005). The North Sea Offshore Authorities Forum (NSOAF) has identified the industrial challenges related to well control management, competency and training including the quality of the simulator training and the focus on passing the exams (NSOAF, 2005). Companies approach to well integrity is usually done whit the NORSOK D-010 standard. The NORSOK D-010 requires regular and realistic well control drills to be performed to train involved personnel to detect and prevent loss of barriers (Standar Norway., 2004). A significant flaw in the training programs today is that well planning , well construction and well integrity is not included in the training program or in the certification process (OLF., 2011). The training program should provide a discussion of past accidents and how they could have been prevented to better be able to identify important features in all the aspects of well control training and knowledge. This is important since the well control decisions require knowledge of these subjects.

Well integrity training and courses

To improve the well integrity on the NCS, has the OLF has published guideline number 117 in an effort to try to improve the well integrity (OLF., 2011). The guideline covers well integrity training. This means that the guidelines helps define what to cover in the well integrity training program and emphasizes who should be participating in the program. To be able to minimize or eliminate the possibility of misunderstandings regarding the well integrity fundamentals, the NORSOK D-010 terminology and company-specific training are often included in the industry well integrity training program. Many operator on the NCS are preforming NORSOK D-010 courses and company internal well integrity seminars every second year to update it's operators on the current status on well integrity. The seminars include operational cases related to well integrity, the regulations, NORSOK D-010 (including well barrier schematics) and well integrity categorization. A positive side effect of these seminars that the companies is starting to understand and exploit is that better well integrity knowledge may lead to increased ability to identification of the challenges related to the human perspective. One example illustrating this is the performance of the negative pressure test in the Macondo accident. One of the barriers in the Macondo accident was the negative pressure test that included failures during evaluation of the test results. The BP report concluded that the requirements and test guideline related to what is an accepted negative pressure test should be evaluated (Graham et al., 2011). This accident is a perfect example that the well integrity knowledge needs to be improved. The focus in the industri needs to be change from just doing the tests, to actually understand why do we perform these tests, what do the tests tell us and what can the consequences be if a non-acceptable test is accepted? Well integrity training and competence need to be improved, and this may also include an evaluation of the test tools (Vignes, 2011).

Human computer interface

Dynamic environments generates a large volume of information from various sources. Control and interpretation of this information is vital to ensure a safe and clear work environment. People in control of human computer interactions may therefore introduce a significant safety perspective in the work place (Randhol and Carlsen, 2007). A good example illustrating this is the driller in the drilling cabin offshore. The driller is responsible for operation of the drilling crew at the drill floor and at the same time manage well control. This means that the driller operates equipment with severe technical complexity in the drilling cabin, combine this with the totality of the drilling module, makes the driller dependent on extensive use of cameras, telephone, and radio communication due to inadequate view. This means that the driller needs to have control over a lot of monitors at the same time. There are limitations related to how much information a human being can receive, analyse and handle. Studies preformed by PSA and DNV shows that a number of drillers sometimes work so hard and starts to move towards an irresponsible practise in the industry. The study also shows that the drillers have to perform too many task during their work performance, resulting in an excessive workload (Asland et al., 2005, 2007). This is an dangerous practice and may lead to catastrophic situations. HO factor analyses should therefore be performed to reduce the amount of information the driller has to evaluate and handle.

The Technical element to improve Well Integrity

The technical aspect of well integrity is perhaps the most dominant element in well integrity. This means that there is many technical challenges that has been identified related to improving the well integrity situations. Several technical challenges have been identified on the NCS with regard to qualification, testing and verification of well barrier elements, and other technically defined challenges are related to the need for automation of certain well operations.

Qualification and testing of well barrier elements

NORSOK D-010 describes the qualification process for well barrier elements. The standard includes 50 well barrier elements acceptance tables in chapter 15 which describe testing and qualification of well barrier elements with reference to relevant standards. The standard is not perfect, well barrier elements such as the gas lift valves (GLV), well isolation materials such as the well formation, Sandaband, Thermaset and drilling operations such as managed pressure drilling (MPD) are not included in this standard.

Equipment that fall outside the specs of the NORSOK D-010 standard can for instance be defined in the ISO standard 14310. The standard defines the leak criteria that are generally used for other equipment than that defined in the standard (Vignes, 2011). There are some identified shortcomings/limitations related to the ISO 14310 concerning qualification of equipment and well barriers (Statoil., 2011). The procedure described in ISO 14310 for testing various equipment, dose not represent conditions the equipment meets out in the field. The test interval is only required to last 15 minutes when the products are expected to last the life of the well. The standard does not include a long term integrity test. The testing is performed in a new casing and in a centralized test fixture, but the installed equipment is placed in non-centralized deviated wells and can experience casing wear over time (Statoil., 2011). The ISO testing is performed for the maximum and minimum values of the equipment performance parameters. Some operators use the equipment somewhere inside the qualified performance test, which is not covered in the testing (Vignes, 2011). To ensure that the equipments can withstand the conditions experienced in the field, should the equipment be tested according to the loads, temperatures, fluids and pressures the equipment will be exposed to during the life cycle of the well. According to Vignes (2011) should the implementation of the equipment qualification and testing probably be defined with a basis in field performance.

Verification of well barrier elements

Verification of a cement plug is performed according to NORSOK D-010: "*The plug installation shall be verified through documentation of job performance; records fm. cement operations (volume pumped, returns during cementing, etc.). Its position should be verified, by means of: tagging, or measure to confirm depth of firm plug*". The cement criteria related to full returns are often used to decide whether to preform a cement evaluation logging operation (Vignes, 2011). Receiving full returns is used as an indicator of cement (or other fluids) not being lost to the formation, but it provides limited information about the cement location, cement channeling or cement contamination (Graham et al., 2011). Proper cement placement, and the mechanical properties of the cement design and logging tools needed further development to be able to verify the cement integrity.

Automation

Technical challenges has been identified related to the tubing computer. Important graphs maid by the tubing computer is being compromised by controlled makeup equipment and poor resolution (Vam Service, 2010). This means that poor resolution can make the graphs look acceptable but with increased resolution, may the graphs not be acceptable (Vam Service, 2010). Other challenges are associated with the HO factors and the operators who monitor and verify the tubing and casing makeup graph. To prevent unwanted events from happening, decision support tools during the evaluation of the torque graph could be a useful aid to lift some of the stress the operators are facing in their working-day. Discussions related to the need for further technology to evaluate the seal integrity as a contributing factor to improving well integrity in tubing, liner and casing connections is presented in more detail in Vignes (2011), section 3.3.1.

The Organizational element in improving Well Integrity

The organizational elements consists of procedures, training programs, handover documentation, well integrity management system, and well barrier schematics. The organizational well integrity elements includes the management system, routines to preform the well integrity jobs, standardization and industry standards.

National and international standards

On the NCS regulations to govern safety and the working environment in the petroleum industry is controlled by the PSA. The regulations is regularly updated and further developed to be able to be as safe and effective as possible (PSA, 2011b). A large number of functional requirements are listed in the regulations where standards and norms specify the *"regulations level of prudence"*. The regulations refer to the industrial standards, such as ISO, API or NORSOK standards, which means that they have to continually be updated by the industry so they can present the best practices available in the industry. Naturally this updating proses of the regulations and standards introduces organizational challenges. Example of standards in need of continuous updating are NORSOK D-001 Drilling Facilities (Tonning, 2006), NORSOK D-002 Syst., Requirements Well Intervention Equipment (PSA, 2011b), NORSOK D-010 Well Integrity standard (SandabandTM, 2006). Perhaps by converting all of these into ISO standards may contribute to minimization of the organizational challenges. The importance of this organizational challenge was further reinforced after PSA identified this as a contribution to the Deepwater Horizon accident. The summery of the PSA report suggested that there is a need for establishing routines for regular updating of the NORSOK standards (PSA, 2011a)

Well integrity management system, handover documentation and well barrier schematics

The fundamental principle of having a safe and productive well during its life cycle depends strongly on having functioning well integrity. Well integrity includes well design, well construction, operations, suspension and abandonment of the wells. All this elements that well integrity consist of is crucial for the well, therefore should well integrity and well integrity philosophy be in the heart of WIMS (Stuart and Foo, 2010). Well integrity includes having all the necessary barriers in place, understanding and respecting the barriers, testing and verifying the barriers and having contingencies in place when the barriers fail (Stuart and Foo, 2010). The purpose of the WIMS is to identify the potential hazards that may occur during the different phases for of the wells life. Properties such as pressure and loads, fluids and formation fluids, temperature, porosity and permeability, wear and fatigue, faults and unconformity[1] are factors according to Vignes (2011) that may influence the well integrity. A detailed description of the minimum criteria for the WIMS is described in the OLF recommended Guideline Number 117 (OLF., 2011). The guideline points out that the WIMS should cover well integrity at all times through the life cycle of the well (OLF., 2011). The main focus for the OLF guidelines is on the operational phase and covers the following elements with a basis in the HSE regulations (Corneliussen et al., 2007): or-

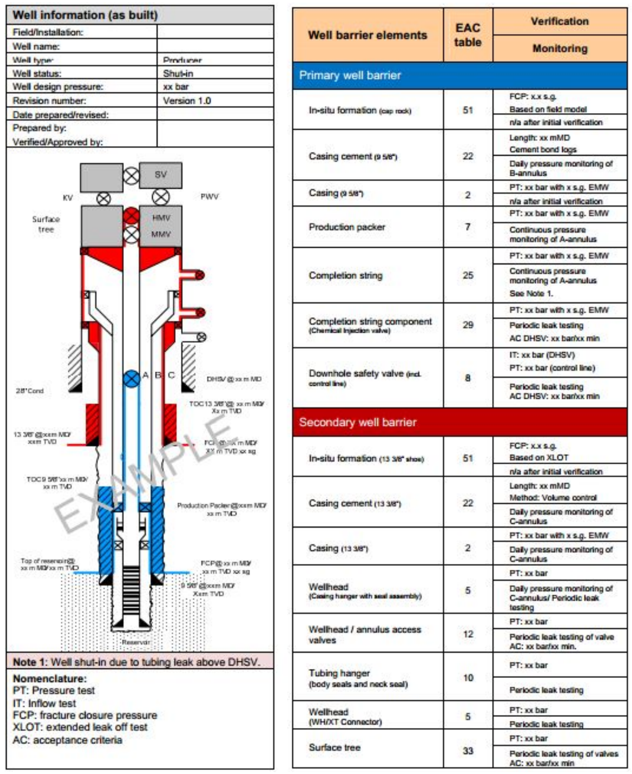
[1]A surface of contact between two groups of unconformable strata.

ganization (licensees, operators, contractors and all involved parties), well design (well design requirements and standards including the ALARP principle) , operational procedures (operational limits, testing/monitoring/verification and maintenance, emergency preparedness and procedures and transfer of information), data system (data system, information system and processes throughout the lifetime of the well), analysis (identify and quantify risk and ensure continuous improvement in all phases) and the programs, procedures and well integrity system to prevent faults and situations of hazard and accident (Vignes, 2011).

The WIMS is a software tool that indicates the well integrity status and how to handle the well integrity problem from construction until the well is permanently plugged and abandoned (Corneliussen et al., 2007; Haga et al., 2009; Tarmoom et al., 2007; Anders et al., 2008; Wakama and Adeniyi, 2004; Smith and Milanovic, 2008). Different key indicators is used by the system to document the process from detection, analysis and implementation of the risk-reducing measures. Talisman Energy Norway includes four categories in their WIMS (Haga et al., 2009): the well integrity status (OLF., 2011; OLF, 2007; OLF., 2008), well barrier status (the well barrier conditions) (Standar Norway., 2004), the annuli status (detects abnormal pressures and pressure against defined criteria) and valve status (based on the valve test results). The WIMS consists of the handover documentation process, real-time pressure and temperature data, well design data (including design limitations, fluids and schematics), operational alarm limits, and the well integrity incidents are summarized with links to the incidents reports.

To be able to make the handover of documentation most efficient should the well integrity management system (OLF., 2011) be able to define what information that needs to be transferred, and how this is done. The handover procedure applies when the well responsibility is transferred from one organization to another e.g from drilling to operation, from the day crew to the night crew and from one company to another. The information needed to be included in the handover from well construction to the well operation team is defined in NORSOK D-010 section 8.7.1 (Standar Norway., 2004). According to the OLF Guideline Number 117 (OLF., 2011) should the handover documentation contain the well construction information, well barrier schematic, completion schematic, handover certificate which presents the status of the valves, pressure and fluids, and the operational limitations.

Well barrier schematics (WBS) is being used in the industry to illustrate and "point out" the well integrity situation in a well in a one-page format (OLF., 2011). An example of a WBS is show in Figure 4.3. The WBS is used to define the well barriers (primary and secondary) in the well. This is a most helpful "tool" for the operators during the life cycle of the well. This is because many factors influence the well integrity station in the well and may change the situation in the well over time. To be able to understand and define the well barriers is therefore very important to control and maintain the well from start to finish.



Well information (as built)	
Field/Installation:	
Well name:	
Well type:	Producer
Well status:	Shut-in
Well design pressure:	xx bar
Revision number:	Version 1.0
Date prepared/revised:	
Prepared by:	
Verified/Approved by:	

Note 1: Well shut-in due to tubing leak above DHSV.

Nomenclature:
PT: Pressure test
IT: Inflow test
FCP: fracture closure pressure
XLOT: extended leak off test
AC: acceptance criteria

Well barrier elements	EAC table	Verification / Monitoring
Primary well barrier		
In-situ formation (cap rock)	51	FCP: x.x s.g. Based on field model
		n/a after initial verification
Casing cement (9 5/8")	22	Length: xx mMD Cement bond logs
		Daily pressure monitoring of B-annulus
Casing (9 5/8")	2	PT: xx bar with x s.g. EMW
		n/a after initial verification
Production packer	7	PT: xx bar with x s.g. EMW
		Continuous pressure monitoring of A-annulus
Completion string	25	PT: xx bar with x s.g. EMW
		Continuous pressure monitoring of A-annulus See Note 1.
Completion string component (Chemical Injection valve)	29	PT: xx bar with x s.g. EMW
		Periodic leak testing AC DHSV: xx bar/xx min
Downhole safety valve (incl. control line)	8	IT: xx bar (DHSV) PT: xx bar (control line)
		Periodic leak testing AC DHSV: xx bar/xx min
Secondary well barrier		
In-situ formation (13 3/8" shoe)	51	FCP: x.x s.g. Based on XLOT
		n/a after initial verification
Casing cement (13 3/8")	22	Length: xx mMD Method: Volume control
		Daily pressure monitoring of C-annulus
Casing (13 3/8")	2	PT: xx bar with x s.g. EMW
		Daily pressure monitoring of C-annulus
Wellhead (Casing hanger with seal assembly)	5	PT: xx bar
		Daily pressure monitoring of C-annulus/ Periodic leak testing
Wellhead / annulus access valves	12	PT: xx bar
		Periodic leak testing of valve AC: xx bar/xx min.
Tubing hanger (body seals and neck seal)	10	PT: xx bar
		Periodic leak testing
Wellhead (WH/XT Connector)	5	PT: xx bar
		Periodic leak testing
Surface tree	33	PT: xx bar
		Periodic leak testing of valves AC: xx bar/xx min

Figure 4.3: WBS example (Standar Norway., 2004)

Chapter 5

Well Integrity in Drilling and Well operations at Veslefrikk: A case on the potential Human Error Causation Paradigms

5.1 Introduction

As highlighted earlier errors are caused by various sources, and the analysis of error causation in complex systems requires a method capable of identifying specific areas that have contributed to the occurrence of a given error. The so-called "human error causation paradigms" proposed by Redmill and Rajan (1997) and listed in chapter 2, seems to provide an interesting basis for further work, especially within the offshore industry (see Figure 2.7).

A letter was sent out to the drilling supervisor at Veslefrikk requesting information on planned activities and improvements in HO factors in drilling operations. The feedback data from the industry is a good base to identify challenges. The human error causation paradigms is used to analyse the feedback data and elaborate on the complex HTO interactions, to get an interesting overview of this complex work setting and to spot the critical influence factors that have a large potential to contribute to safety and work performance risk (Redmill and Rajan, 1997). The different paradigms (engineering, individual, cognitive and organizational) enable the challenges to be looked at from different points of view and necessary discussions can be held regarding improvement measures for the working situations. This has specific benefits from a safety and well integrity point of view, given the complex and dynamic nature of work performance (Vignes, 2011).

Both drilling and well operations have a large tendency for errors during work performance due to the complexity and the dynamic nature of the work setting (Vignes and Jayantha, 2011). Several interactions exist in this process in technical, organizational, and individual terms. The explicit and implicit connections have to be functional and fail-proof to ensure the safety integrity of the work setting (Vignes and Jayantha, 2011). This means that even the smallest error needs to be identified and properly evaluated to have a clear understanding of potential risk. The next section elaborates on those various sources for causation of errors in drilling and well operations at Veslefrikk; these are classified into engineering, organizational, individual, and cognitive.

5.2 Human Error Causation Paradigms in Drilling and Well operations

The human error causation paradigms in the drilling and well operations are classified into four paradigms discussed earlier, namely: the engineering error paradigm, organizational error paradigm, cognitive error paradigm and the individual error paradigm. PSA and DNV has conducted studies related to HO factors and work situation of drillers and wireline operators. Challenges related to the drillers where: design of the driller's chair, switches, display, and an overwhelming amount of information that the drillers had to handle, analyse and respond to. Challenges related to the wireline operator where: design of the wireline cabin, communication within the operator crew, and the number of procedures. Both the drillers and the wireline operators working situation include time pressure, limited supervisor training, and limited time and motivation to conduct the safe job analyse[1] (SJA) (Asland et al., 2005, 2007; Vignes and Jayantha,

[1] A safe job analysis is a systematic and stepwise review of all risk factors prior to a given work activity or operation, so that steps can be taken to eliminate or control the identified risk factors during preparation and execution

2011).

The feedback data obtained by the drilling supervisor at Veslefrikk only includes the working situation for the driller. Therefore the human error causation paradigms will only analyse HO factors and work situation of the driller at Veslefrikk. Today's situation on Veslefrikk will be compared with the findings of the original study conducted by PSA and DNV and will hopefully answer this thesis project task number five. Improvement measures proposed by Asland et al. (2005, 2007) will be listed.

Presentation of the identified challenges based on the human error causation paradigms

First, the challenges identified through the human error causation paradigms will be presented shortly in Table 5.1 to provide an overview. Second, the challenges will be further described from the paradigms different points of view.

Table 5.1: Presenting the identified challenges through the human error causation paradigms at Veslefrikk.

	Human error causation paradigms			
Veslefrikk	**Engineering**	**Individual**	**Cognitive**	**Organizational**
Identified Challenges			✓Simulator training	✓Large amount of procedures
	✓Limited possibility to vary sitting positions	✓Difficulties locating relevant procedures	✓Seminars	✓Prioritize meeting ahead of drilling operations
	✓Limited possibility to shift between sitting and standing work positions	✓Large amount of procedures	✓One-week overlapping	✓Too general meetings
	✓Communication equipment is not easy available	✓Time pressure		
	✓Disturbing elements: telephone and alarms			
	✓Dangerous amount of workload			

of the work activity or operation (Norsk Oil and Gas., 2011).

5.2.1 Error Causation potential from Engineering Paradigm

The engineering error causation paradigm focuses on the technical aspect of the drill operators working situations. The paradigm looks at the driller's as an unreliable "component" of the total working system. The paradigm shows that the driller has challenges related to the large amount of information he has to handle analyse, and respond to.

The Feedback data from Veslefrikk indicates that there is limited possibility to vary the chair's sitting positions, and the shift between sitting and standing is a challenge. The same sitting position throughout the shift has negative consequences for muscle stress and may negatively affect the drill operators concentration, and thereby increase the risk of well accidents. Analysing the work situation is of major importance to ensure that no conflict between the operational equipment placement (e.g., the driller's chair) and the operational tasks during the design phase of the driller's working situations exists. The reduction of conflict helps reducing the risk for well failures because of badly placed controls and switches (Asland et al., 2005).

The drilling supervisor at Veslefrikk (Harald Engesland) has the following comment to questions regarding physical conditions:

"Selve stolen/sete kunne vært mye bedre"

Translated: The chair/seat itself could be much better

The communications equipment (control, switches, radio communication etc.) is from time to time not easy accessible. Badly placed controls and switches on the panels in relation to the drill operators working position (the locations do not interact well with the chair's movement and have bad underarm support) or simultaneous or sequential operations exist on Veslefrikk. During design of new operator stations, it is important to ensure that the equipment placement is not in conflict with operational task (Asland et al., 2005). Sufficient analyses should be conducted early in the planning stages.

In addition to the many responsibilities, the driller experiences essentially two main disturbing elements: the telephone and people in the drilling cabin. The supervisor states that there is many unnecessary telephone calls that is very disturbing for the work progress and can influence the risk in relation to handling well control and well integrity situations.

The drilling supervisor at Veslefrikk (Harald Engesland) has the following comment to questions regarding the demands and control on the job:

"Her gjelder det å holde fokus"

Translated: Here it is important to stay focused

Challenges were identified due to the automation complexity with too many alarms and too many “nice to know” alarms. The feedback indicates that the drillers know what to do with the different alarms but the supervisor claims that the alarms do not function properly. Alarms with no essential function is a irritating element and may distract the drillers from observing real threats to well integrity. The drillers work interactively with the screens that support the execution of the various operations. The level of automation of the driller’s working situation leads to a large amount of information. The amount of information that the driller has to coordinate is significant during his work performance. The feedback for the industry also indicates that the driller’s workload may be on the border of what is considered dangerous, and this is also a risk in relation to handle well control and well integrity situations (Asland et al., 2005, 2007).

Comparison with the original study conducted by PSA and DNV shows that today’s HO factor challenges in drill and well operations related to the engineering error paradigm on Veslefrikk, generally is slightly better than the overall industry practices(Asland et al., 2005, 2007). The feedback states for example that it is pretty easy to notify people when they are in the drilling cabin on Veslefrikk, this has been identified as a challenge in the overall industry

Asland et al. (2005, 2007) concluded that half of the drillers in the industry experienced too much information on the screens and an information overload was present. The situation on Veslefrikk are minimal compared with the industry. The drilling supervisor on Veslefrikk states that the amount of information on the screen is very rare or never a problem.

The drilling supervisor at Veslefrikk (Harald Engesland) has the following comment to questions regarding the technical system:

"Det meste er oppgradert/oppdatert"

Translated: Most of the equipment are upgraded/up to date

Measures proposed/implemented by the companies

Examples, proposed by Asland et al. (2005, 2007) on how companies can regulate the use of telephone in the drilling cabin:

- Change in attitude. Get the message out to all personnel on board to contact the driller through phone calls as little as possible to reduce the disturbance. Call the assistant driller instead.
- Close telephone lines from land.
- Give first priority to radio communication.
- Introduce cordless telephone with number display so the driller does not have to stretch to reach the telephone.

Examples of measures to control access to the driller's cabin Asland et al. (2005, 2007):

- Do not use the driller's cabin as a meeting room.
- Change in attitude. Get the message out regarding access restriction in the driller's cabin. Consider how information regarding disturbances in the driller's cabin can be best communicated to relevant personnel.
- The drillers are encouraged to speak up if there are still too many people in the driller's cabin.

Examples of measures in connection with physical aspects and the drilling systems Asland et al. (2005, 2007):

- Carry out a mapping of physical design of driller's cabins on all rigs together with drilling personnel and personnel with ergonomics/Human Factors expertise. Based on that mapping, make the necessary improvements to satisfy the requirements in NORSOK S-002.
- Carry out a mapping of the user-friendliness of the drilling systems to see which systems do not meet current requirements, including alarm requirements. What should be done to achieve systems that support the driller in his/her work?

- Review the alarm system, focusing on which functions the driller should handle, and what information is necessary in order to safeguard these functions.

5.2.2 Error Causation potential from Individual Paradigm

The individual error causation paradigm within the drill operators considers the time pressure, limited training to act as supervisor, limited time to conduct the SJA, and the operators motivation to perform the SJA.

The drill operation on Veslefrikk appears to have little or no challenges related to the risk perception and the use of risk aversive measures in work performance. The feedback indicates that the driller feels that his own understanding of risk is good. As work supervisor, the driller states that he believes that he is able to ensure that the personnel working for him have a good understanding of risk. The only challenges that the drill supervisor mentions, is the employees in the service companies and their lack of risk understanding. The risk understanding on the part of employees in the service companies is perceived as being good, but the feedback shows a somewhat lower score than the other employees and is therefore identified as a challenge.

The feedback states that the driller on Veslefrikk always has enough time to conduct a SJA, and the driller states that SJA helps bringing attention to aspect in regard to performing a safe job. Procedures and work programs are well understood and is always followed, but some difficulties locating relevant procedures and the sheer amount of procedures is identified as a challenge. This can also be seen as an organizational error paradigm challenge.

The drilling supervisor at Veslefrikk (Harald Engesland) has the following comment to questions regarding the procedures:

"Her er vi blitt mye flinkere enn før"

Translated: Situation today is much better than what it was before

The survey performed shows that the driller on Veslefrikk is from time to time affected by time pressure related to the quality assurance of the work program. The driller also states that there is not enough time to review the work descriptions in the shift meetings. These aspects shows that there is a potential for safety risk related to the opportunities available for the driller and drilling crew to have an overview and proper understanding of risk related to the work situation (Asland et al., 2005, 2007).

Comparison with the original study conducted by PSA and DNV shows that today's HO factor challenges in drill and well operations related to the individual error paradigm on Veslefrikk, is better than the overall industry practices (Asland et al., 2005, 2007). The study shows that many aspect related to SJA is a problem in the industry. 20% of the drillers who attended the original study reported that occasionally they did not have time to conduct a SJA, and some of the drillers have experienced that SJA does not always help to bring attention to aspects in regarding performing a safe job (Asland et al., 2007; Heber et al., 2008). This is not a challenge on Veslefrikk.

Measures proposed/implemented by the companies

Examples proposed by Asland et al. (2005, 2007) of measures regarding procedures:

- The procedures should be made more user-friendly and appropriate.
- Review of existing procedures with the objective of reducing the number of documents.
- The procedures should be more easily accessible. For example, they should be stored where the work is performed.
- Need for improved knowledge regarding the procedures that exist. This may be connected to a general need for training and how new personnel are introduced to rig-specific factors/procedures
- Introduction of periodic procedure courses, to maintain awareness/knowledge about the procedures.
- Review of the mentor arrangement to ensure transfer of the company's desired attitudes and values to new employees, including the principle that procedures must be used and followed.

Examples of measures in relation to the work program Asland et al. (2005, 2007):

- Check whether necessary time is allocated to qualify the work program before the work is started.
- In cooperation with the operator, ensure that adequate time is allowed for reviewing the work program.

5.2.3 Error Causation potential from Cognitive Paradigm

The cognitive error causation paradigm within the drill operators considers the risk understanding, the installation-specific training and experience.

The feedback indicates that facilitation for updating professional expertise is fairly often present and the training the driller receive is often not related the the job they actually do. Three major areas of improvement were highlighted by the driller; Simulator training (beyond training in pressure control simulator), seminars where the team trains together and courses related to professional disciplines. The driller also states that he fairly often receives training in the local conditions when he arrives on a new facility. Training and follow-up of new employees is also pretty good. The feedback shows that the driller often has a good overview of the working situation. Also one-week overlap on new facilities occasionally happens.

The drilling supervisor at Veslefrikk (Harald Engesland) has the following comment to questions regarding what kind of training he misses?:

"Simulator, case studier"

Translated: Simulator, case studies

According to Vignes (2011), the use of ad hoc teams where the personnel are often rotated between installation is a possible source of negative side effects. This situation can influence the quality of the interaction between personnel and also the quality in professional interactions between the members of a given team, and this may lead to some challenges related to integrity issues. This situation can become even more critical when personnel with limited experience are hired in at short notice to perform specific tasks, with limited time to prepare the work.

On the other hand, risk understanding and subsequent behavior during drill and well operations, can be attributed to a large extent to cognition, where competence plays a major role as a prerequisite. Without risk understanding on all levels, it is difficult to conduct specific activities in a safe manner. As the complexity increases with automation and other technological developments, it obviously creates a need for a systematic competence management program, even including some other types of competence and training to cope with the changing work demands (Asland et al., 2005).

Comparison with the original study conducted by PSA and DNV shows that today's HO factor challenges in drill and well operations related to the cognitive paradigm on Veslefrikk, is mostly the same as in the overall industry practices (Asland et al., 2005, 2007).

Measures proposed/implemented by the companies

Examples proposed by Asland et al. (2005, 2007) of training-related measures:

- Personnel are given an opportunity to work as extra personnel in connection with promotions. This will provide better training prior to starting a new job.
- Consider facilitating a one-week overlap in connection with transfers to a new unit.
- Review of existing internal mentor arrangement. Examine training and course matrix, transfer of experience and attitudes.
- Arrange well integrity seminars four times per year, all drillers are to be included in these seminars.
- Offer E-training course in "downhole understanding" to all drillers.

5.2.4 Error Causation potential from Organizational Paradigm

The organizational error causation paradigm within the drill operators focuses on the drillers working situations in relation to the operator competence level, procedures, communication and management.

The feedback indicates that the sheer amount of procedures is a recurring challenge, which causes coordination challenges. The communication between the manager and driller on Veslefrikk is good. The driller states that the supervisor is involved in the work that is performed. The driller also states that he always receives sufficient support and help from the management for their work when needed. However, he also experiences that the supervisor from time to time prioritizes meetings ahead of the actual drilling operations. The driller is pretty satisfied with feedback from the supervisor regarding the work performed and has a regular dialogue with the supervisor. The threshold to contact the drilling supervisor when he is on a meeting is also fairly satisfying on Veslefrikk which means that decision making has a higher chance to be quick and efficient in dangerous situations.

The driller states that he feels that there is a good environment/culture on the shifts, and that he receive help and support form the team. This can also be seen from an individual error paradigm point of view.

Meetings is a form of communication where management and operators exchanges information to better perform decision making. The survey shows that the departure meeting are too general and that the driller feels that he from time to time is not confident in the job he is supposed to do. The driller is fairly satisfied with the necessary information received in the shift meeting and he is confident that this meeting contribute to the safe execution of the job. This shows that an overview status of the situation and the work to be done is good on Veslefrikk. This is important in order to have an understanding of the risk associated with the work. This can also be viewed in context with the cognitive error paradigm.

Comparison with the original study conducted by PSA and DNV shows that today's HO factor challenges in drill and well operations related to the organizational error paradigm on Veslefrikk, is better than the overall industry practices(Asland et al., 2005, 2007).

According to Asland et al. (2005, 2007); Vignes (2011); Vignes and Jayantha (2011) the original survey shows that the development of competence is a challenge in drill operations because of the fluctuation in the activity levels on the NCS (Asland et al., 2005). These challenges have shown a potential for an increase in incident risk on the NCS during high activity periods. It is difficult for the drilling companies to provide sufficient personnel with adequate competence and experience. The companies then provide an increasing number of people with less experience for a specific set of tasks. This is a short-term solution for the companies. When the activity level on the NCS reduces, the risk for retrenchment increases since the companies cannot hold on to extra resources. This situation often affects personnel with the least experience and those who were last to be employed. After some time, when the activity levels on the NCS rises again, most of the companies are not prepared, and inexperienced personnel are employed. This is a cycle process that has brought much concern in the employment market.

PSA and DNV also discovered that incorrect use of radios and cultural differences are important challenges. According to Asland et al. (2005) the procedures regarding the use of radios a is problem. It is important that all involved are familiar with good radio etiquette and understand which channel and which language to use. Communication challenges related to when operators work at different decks is also identified as a problem in the industry (Asland et al., 2005).

This complex challenges seems to be non existing on Veslefrikk. The feedback has no definitive indication of challenges related to cultural differences, communication between different decks and development of competence but I suspect that this might be because the questions in the survey is not precise enough regarding these challenges.

Measures proposed/implemented by the companies

Examples of measures proposed by Asland et al. (2005, 2007) as regards management:

- Training in the responsibility that follows with the leader's role; the importance of feedback both on a daily basis and in more formal aspects.
- Courses addressing "the difficult talk" and employee appraisal conferences

Examples of measures proposed by Asland et al. (2005, 2007) as regards procedures:

- The procedures should be made more user-friendly and appropriate.
- Review of existing procedures with the objective of reducing the number of documents.
- The procedures should be more easily accessible. For example, they should be stored where the work is performed.
- Need for improved knowledge regarding the procedures that exist. This may be connected to a general need for training and how new personnel are introduced to rig-specific factors/procedures

- Introduction of periodic procedure courses, to maintain awareness/knowledge about the procedures.
- Review of the mentor arrangement to ensure transfer of the company's desired attitudes and values to new employees, including the principle that procedures must be used and followed.

Chapter 6

Summary and Recommendations for Further Work

This thesis explains the concept of well integrity related to HO factors. A detailed literary survey has been conducted to give the reader a decent understanding of the concept and different models and methods has been presented in a detailed manner. A classification scheme has been recommended for HO factors.

This thesis seeks to improve the well integrity situation as it is today by analysing earlier studies and new data created for this thesis. Work done by Vignes (2011); Asland et al. (2005, 2007); PSA (2011a); Vignes and Jayantha (2011) has been looked through with the HTO perspective to be able to highlight challenges related to the human-, technological- and the organizational element in the overall industry. A letter was sent out to the drilling supervisor at Veslefrikk requesting information on planned activities and improvements in HO factors in drilling operations. The human error causation paradigm is used to analyse this new data and help spotting the critical influencing factors that have a large potential to contribute to safety and work performance risk (Redmill and Rajan, 1997). The results from the survey conducted by PSA and DNV and shown in chapter 4, is used as a benchmark to be able to compare today's situation on Veslefrikk with the overall industry.

The summary and conclusions chapter is organized as follows:

- First to give a simple and easy summary and conclusion on this thesis objective.

- Then to give a summary and conclusion of the project task, represented by the different chapters.

6.1 Summary and Conclusions

Summary and Conclusion of the Objective

The author's approach to the summary and conclusion of this thesis objective:
Have the implemented measures proposed by PSA and DNV had any effect on the HO factors related to well integrity in the various phases of a well's life, at Veslefrikk? is to give an easy overview of the identified challenges on Veslefrikk and the overall industry, represented in Table 6.1. The table lists the identified challenges and make it easy to compare the situation on Veslefrikk vs. the overall industry. The symbol ✓ indicates identified challenges and the symbol ✓ indicates if the identified challenges is more challenging.

By analysing Table 6.1 can we easy see that the overall industry has more ✓ symbols which means that the overall industry has more challenges related to HO factors. The answer on this thesis objective can then simply be interpret as **YES.**

Summary and Conclusion of the Project tasks

Chapter 2 addresses this thesis project task number one and gives a detailed literature survey related to HO factors. The reader is given an introduction to different aspects related to HO factors. The human performance model, decision making, work performance, PIFs and human error causation paradigm are presented together with a presentation of the HTO perspective. In this thesis, it is important that the reader is given a detailed insight in this aspect since Chapter 3 and 4 use these methods to analyse different situations.

Chapter 3 addresses this thesis project task number two, identify classification schemes for HO factors. This thesis shows that this can be done in many ways. 17 methods were identified in total by the Health and Safety Executive (2009) to be of potential use to classify HO factors. Many of these methods are developed for other industries (namely nuclear and aviation) and is therefore identified as not well suited for classifying HO factors relevant to well integrity. The

Table 6.1: Summary of chapter 5

<table>
<tr><td></td><td></td><td>Veslefrikk</td><td>Overall industry</td></tr>
<tr><td rowspan="2">Identified Challenges</td><td>Engineering paradigm</td><td>✓ Limited possibility to vary sitting positions
✓ Limited possibility to shift between sitting and standing work positions
✓ Communication equipment is not easy available
✓ Disturbing elements: telephone and alarms
✓ Dangerous amount of workload</td><td>✓ (red) Large amounts of information
✓ Limited possibility to vary sitting positions
✓ Limited possibility to shift between sitting and standing work positions
✓ Communication equipment is not easy available
✓ (red) Disturbing elements: telephone, people in drilling cabin and alarms
✓ Dangerous amount of workload</td></tr>
<tr><td>Individual paradigm</td><td>✓ Lack of risk understanding: service companies
✓ Difficulties locating relevant procedures
✓ Large amount of procedures
✓ Time pressure</td><td>✓ (red) Lack of risk understanding: regular employees and service companies
✓ Difficulties locating relevant procedures
✓ Large amount of procedures
✓ Time pressure
✓ (red) Challenges related to SJA</td></tr>
</table>

<table>
<tr><td rowspan="3">Identified Challenges</td><td></td><td>Veslefrikk</td><td>Overall industry</td></tr>
<tr><td>Cognitive paradigm</td><td>✓ Simulator training
✓ Seminars
✓ One-week overlapping</td><td>✓ Simulator training
✓ Seminars
✓ One-week overlapping</td></tr>
<tr><td>Organizational paradigm</td><td>✓ Large amount of procedures
✓ Prioritize meeting ahead of drilling operations
✓ Too general meetings</td><td>✓ Large amount of procedures
✓ Development of competence
✓ Too general meetings
✓ Prioritize meeting ahead of drilling operations
✓ Communication challenges: work in different decks and cultural differences</td></tr>
</table>

method identified by the author as possible candidates for classification, is carefully analysed. The WHW, SRK and SLMV methods undertaken in this thesis were of a general nature and are therefore not recommended. THERP is an old, very strong and efficient method for classifying HO factors. Many industries use this method frequently and have great success with the result. According to Rausand (2011) are the main limitations to THERP method resource intensive and time-consuming. THERP also requires a level of detail that can be excessive for many assessments. By taking the limitations into consideration together with the study preformed by Health and Safety Executive (2009) the THERP method is not recommended to classify HO factors related to well integrity.

The STEPP method is well suited for classifying and optimizing HO factors related to well integrity. Previous studies preformed by Wilson and Stanton (2001); Hendrick and Brenner (1987) related to major accidents such as the Piper Alpha incident confirms that the STEPP method is well suited to analyse, classify and optimize HO factors in the context of well integrity. After careful consideration and elimination together with discussions with the drilling supervisor at Veslefrikk, the STEPP method is selected as the best classification scheme for HO factors relevant to well integrity in various phases of a well's life.

Chapter 4 addresses this thesis project tasks number three and four. There are unforeseen factors that have a critical influence on the work performance of the different operators in a complex work setting. The situation is no different for systems regarding well integrity. Well integrity is defined as "*application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well* (Standar Norway., 2004) and it stands to reason that a proper knowledge of the well integrity system from a HTO perspective, can give a better working environment and an opportunity to improve the health, safety integrity, and work performance.

Challenges related to the *Human element* were identified and categorised as: well control training and knowledge, well integrity training and courses, human computer interface:

- *Well control training and knowledge:* Well control management, competence and training including the quality of the simulator training and focus on passing the exams have been identified as a challenge. A significant flaw in the training programs today is that well planning, well construction and well integrity are not included in the training program or in the certification process (OLF., 2011). The training program should provide a discussion of past accidents and how they could have been prevented to better be able to identify important features on all the aspect of well control training and knowledge.

- *Well integrity training and courses:* Better well integrity knowledge has been identified as a challenge. The culture in the industry today focuses mostly on just doing the tests and not actually understand why we perform these tests, what do the tests tell us and what can the consequences can be if a non-acceptable test is accepted. Many operators on the NCS have started performing NORSOK D-010 courses every second year to try and change this lack of integrity knowledge. Positive effects of the increase focus on integrity knowledge can be illustrated by looking at the negative pressure test in the Macondo accident. If the culture on the Deepwater Horizon platform had be more focused on understanding what the negative pressure test actually meant, the accident could perhaps have been avoided. The BP report concluded that the requirements and test guideline related to what is an accepted negative pressure test should be evaluated (Graham et al., 2011). This accident is a perfect example that the well integrity knowledge needs to be improved.

- *Human computer interface:* The amount of information in different parts of operation has been identified as a challenge. A good example illustrating this is the driller in the drilling cabin offshore. The drillers responsibilities are many, combined with operation of equipment with severe technical complexity makes the driller dependent on extensive use of cameras, telephone, and radio communication due to inadequate view. All the impressions and information from the monitors can be to much too handle for the driller. Studies done by PSA and DNV shows that a number of drillers sometimes work to hard and have to much information to process at once (Asland et al., 2005, 2007). This is a dangerous practise an may lead to catastrophic situations. HO factor analysis should therefore be performed to reduce the amount of information the driller has to evaluate and handle.

Challenges related to the *technical element* was identified and categorised as Qualification and testing of well barrier elements, verification of well barrier elements and automation:

- *Qualification and testing of well barrier elements:* Some well barrier equipment, crucial for well integrity fall outside the specs of the NORSOK D-010 standard. This has been identified as a challenge in the industry. Today the ISO standard 14310 can be used on equipment that fall outside the specs of the NORSOK D-010 standard. The standard defines the leak criteria that are generally used for other equipment that is defined in the standard (Vignes, 2011). There are some identified shortcomings related to the ISO 14310 concerning qualification of equipment and well barriers (Statoil., 2011). The testing of various equipment does not meet the conditions the equipment meets out in the field. The test interval is only required to last 15 minutes when the equipment are expected to last the life of the well. The standard does not include a long term integrity test. The testing is performed in a new and centralized casing, but the installed equipment is placed in non-centralized deviated wells and can experience casing wear over time (Statoil., 2011). The ISO testing is performed for the maximum and minimum values of the equipment performance parameters. Many operators use the equipment somewhere between the maximum and minimum parameters which means that the equipment is not sufficient tested to handle those conditions (Vignes, 2011). To ensure that the equipment can handle the conditions experienced in the field, the equipment should be tested according to the loads, temperature, fluids and pressure the equipment will be exposed to during the life cycle of the well. According to Vignes (2011) the implementation of the equipment qualification and testing should probably be defined with a basis in field performance.

- *Verification of well barrier elements:* Limitations related to the information about cement location, cement channeling or cement contamination has been identified as a challenge. Verification of a cement plug is performed according to NORSOK D-010. Receiving full returns is used as an indicator of cement not being lost to the formation, but it provides limited information about the cement location, cement channeling or cement contamination (Graham et al., 2011). Proper cement placement, and the mechanical properties of the cement design and logging tools needs further development to be able to verify the cement integrity.

- *Automation:* Technical challenges related to the tubing computer has been identified. Important graphs maid by the tubing computer may look acceptable at first, but with increased resolution the true meaning of the graph is reviled and the graph may not be accepted after all (Vam Service, 2010). Other challenges are associated with the HO factors and the operators who monitor and verify the tubing and casing makeup graph. Tools helpful to prevent unwanted events form happening and decision support tools during the evaluation of the torque graph could be useful to help lift some of the stress the operators are facing in their working-day.

Challenges related to the *organizational element* was identified and categorised as national and international standards and well integrity management system, handover documentation and well barrier schematics:

- *National and international standards:* The sheer amount of standards and regulations, and the constant updating and further development of this regulations are identified as a challenge. The regulations is regulary updated and further developed to be able to be as safe and effective as possible (PSA, 2011a). The regulations refer to the industrial standards, such as ISO, API and NORSOK standards, which means that they have to be continuously updated by the industry so that they can present the best practices available. This updating proses natural introduces organizational challenges. Perhaps by converting all of the regulations into ISO standards may contribute to minimization of the organizational challenges. This aspect was also identified in the PSA summary report after the Deepwater Horizon accident including the need for established routines for regular updating of the NORSOK standards (PSA, 2011a).

- *Well integrity management system, handover documentation and well barrier schematics:* The minimum criteria for the WIMS and the required information needed in the handover documentation are identified as a challenge. The OLF recommended guideline number 117 for well integrity describes the minimum criteria for the WIMS (OLF, 2011). The OLF guideline focuses mainly on the operational phase. The WIMS should cover well integrity at all times through the life cycle of the well. The WIMS should also define what information is to be transferred in the handover documentation, and how this should be done.

Chapter 5 addresses this thesis project task number five. This chapter presents an overview of the drilling operations at Veslefrikk from an human error causation paradigm point of view. Today's situation at Veslefrikk is compared with the finding of the original study conducted by Asland et al. (2005, 2007); Vignes (2011); Vignes and Jayantha (2011) to highlight the improvement that has been made. The intention was to underline the specific challenges in a sensitive work environment in the offshore oil and gas drilling operations that have a large potential to pose some serious threats to health, safety integrity, and work performance efficiency. The human error causation paradigm are illustrated in Figure 2.7 and include the engineering error paradigm, individual error paradigm, cognitive error paradigm and organizational paradigm. The paradigms look at the drilling working situation from different points of view

At Veslefrikk, the ***engineering error causation paradigm*** highlighted challenges related to the driller's chair, placement of the communication equipment(control, switches, radio communication etc.), Disturbing elements (many unnecessary telephone calls and people in the drilling cabin), Alarms with no essential function and amount of the drillers workload. Comparison with the original study indicates that the situation on Veslefrikk is generally slightly better then the overall industry. The feedback states for example that it is pretty easy to notify if people is a disturbance, when they are in the drilling cabin on Veslefrikk. This has been identified as a challenge in the overall industry. Information overload is reported as a big problem for the drillers in the industry. The drilling supervisor at Veslefrikk states that this is a very rare or never a problem. Measures proposed to minimize or eliminate the challenges are listed in section 5.2.1.

At Veslefrikk, the ***individual error causation paradigm*** highlighted challenges related to the service companies and their lack of risk understanding, difficulty locating relevant procedures, the sheer amount of procedures that is involved in drilling operations and time pressure (for time to time the driller is effected by time pressure related to the quality assurance of the work program and not enough time to review the work descriptions in the shift meetings). Comparison with the original study indicates that the situation on Veslefrikk is better than the overall industry. According to Asland et al. (2005, 2007) is aspect related to SJA a problem in the industry. Many drillers reported that occasionally they did not have time to conduct a SJA, and that the SJA does not always help to bring attention to aspects regarding performing a safe job. This is not a challenge on Veslefrikk. Measures proposed to minimize or eliminate the challenges are listed in section 5.2.2.

At Veslefrikk, the ***cognitive error causation paradigm*** highlighted challenges related to the installation-specific training (the training the driller receive is often not related to the job they actually do, simulator training is not beyond training in pressure control simulations, seminar where the team train together is not present and courses related to professional discipline is lacking), time pressure and experience. Comparison with the original study indicates that the situation on Veslefrikk is mostly the same as in the overall industry practices (Asland et al., 2005, 2007). Measures proposed to minimize or eliminate the challenges are listed in section 5.2.3.

At Veslefrikk, the ***organizational error causation paradigm*** highlighted challenges related to the sheer amount of procedures, meetings is being prioritized ahead of actual drilling operation and the departure meeting are too general (not confident in the job is a result of to general information). Comparison with the original study indicates that the situation on Veslefrikk is better than the overall industry practice. According to Asland et al. (2005, 2007); Vignes (2011); Vignes and Jayantha (2011) shows the original survey that the development of competence is a challenge in drill operations because fo the fluctuation on the activity levels on the NCS. Challenges related to the incorrect use of radios, cultural differences and communication between different deck are also identified as problems for the industry. The feedback indicates that this complex challenges is non existing on Veslefrikk. Measures proposed to minimize or eliminate the challenges are listed in section 5.2.4.

6.2 Recommendations for Further Work

This thesis is conducted by a non professional in the specialized field of HO factors. Models and methods presented might not be as relevant in practical use due to shortcoming of each method and the degree of overlapping between methods. The questionnaire survey given to Veslefrikk has some shortcomings related to the human error causation paradigms and might be a contributing factor to prevent the full potential of the method. The understanding of why the situation is overall better on Veslefrikk has great value to the industry, the proven measures on Veslefrikk can be implemented in the industry and help rise the overall work performance. The results from the survey conducted in this thesis may unfortunately be a false indicator for the "true" situation on Veslefrikk. Only one viewpoint from one individual is analysed an mathematically speaking this is not enough to show the "true" situation on Veslefrikk. Recommendations is classified as short-term, medium-term and long-term recommendations:

- The *short-term* recommendation for further work is to obtain a more detailed literary study of the methods to be able to identify which method is best suited for the industry for a more practical use. Collaboration and discussion with the industry is recommended to obtain the methods for "best practice" out in the field.
- The *medium-term* recommendation for further work is to analyse the situation in the industry with the STEPP method. Shortcomings in STEPP method will most likely become visible and it is therefore recommended to take the STEPP method a bit further and combine the assessments of four different analytical methods (STEPP, Safety Culture Questionnaire (SCQ), Systematic Human Error Reduction and Prediction Approach (SHERPA) and Focus Groups (FG)) to examine the range of underlying HO factors.
- The *long-term* recommendation for further work is to customize the questionnaire survey (Appendix B) to be more appealing for the human error causation paradigm point of view. Important influencing factors might be hidden due to imprecise questions which hinders the method to minimize critical influencing factors and "push" the industry towards the

"best practice" in the field. A deeper understanding of why the situation on Veslefrikk is better that the overall industry is recommended, to help the industry increase the overall work performance. This can be done by figuring out which implemented measures that was put into place on Veslefrikk, as a result of the PSA and DNV study, then identify which of the measures that had any effect. More individual viewpoints from the industry should also be collected and analysed to better reveal the "true" situation on Veslefrikk.

Appendix A

Acronyms

ALARP As low as reasonably practicable

API American petroleum Institute

DHSV Down hole safety valve

DNV Det Norske Veritas

GEMS A generic error-modeling system

HEI Human error identification

HEP Human error probabilities

HEQ Human error qualification

HER Human error reduction

HMI Human machine interface

HSE Health, safety and environment

HSEMS Health, safety and environmental management systems

HO factors Human and organizational factors

HRA Human reliability assessment

HTO Human-,technology- ans organizational perspective

ISO International organization for standardization

MPD Manage pressure drilling

NCS Norwegian continental shelf

OLF Norwegian oil and gas association

PIFs Performance influencing factors

PRA Probabilistic risk assessment

PRSA Probabilistic safety assessment. Also referred to as PSA

PSA Petroleum safety authority, Norway

SJA Safe job analyses

SLMV Slips, lapses, mistakes, and violations

SRK Skill-, rule-, knowledge

STEPP Sequential time event plotting procedure

THERP Technique for human error rate prediction

USNRC US nuclear regulatory commission

WBE Well barrier elements

WBS Well barrier schematics

WHW questions What, how and why questions

WIF Well Integrity Forum

WIMS Well integrity management system

Appendix B

Questionnaire survey

- *Sett kun ett kryss for hvert spørsmål, dersom du svarer feil, skraver hele ruten*
- *Det finnes ingen rette eller gale svar.*
- *Ikke tenk for lenge på hvert spørsmål, det første svaret som kommer til deg er som regel det mest korrekte.*

KRAV I JOBBEN

	meget sjelden eller aldri	nokså sjelden	av og til	nokså ofte	meget ofte eller alltid
1. Er det forstyrrende for arbeidet ditt at du må ta telefoner?	☐	☐	☐	☐	☐
2. Føler du at du er fastlåst til stolen i borekabinen?	☐	☐	☐	☐	☐
3. Er krav til loggføring en belastning for deg?	☐	☐	☐	☐	☐
4. Er det rom for å stoppe opp litt dersom du har behov for det?	☐	☐	☐	☐	☐
5. Er det belastende for deg når det er nedetid?	☐	☐	☐	☐	☐
6. Sier du ifra hvis du har for mye å gjøre?	☐	☐	☐	☐	☐
7. Opplever du at du har for mange oppgaver?	☐	☐	☐	☐	☐
8. Jobber du så hardt at det er på grensen av det forsvarlige?	☐	☐	☐	☐	☐
9. Er arbeidsoppgavene dine i konflikt med hverandre?	☐	☐	☐	☐	☐
10. Opplever du at dine arbeidsoppgaver er for vanskelige for deg?	☐	☐	☐	☐	☐
11. Er det mange unødvendige telefoner?	☐	☐	☐	☐	☐
12. Blir du sliten i øynene av å arbeide i borekabinen?	☐	☐	☐	☐	☐
13. Synes du at mengden med alarmer er håndterbar?	☐	☐	☐	☐	☐
14. Støtter alarmsystemet deg godt ved driftsforstyrrelser?	☐	☐	☐	☐	☐
15. Vet du alltid hva du skal gjøre med hver alarm?	☐	☐	☐	☐	☐
16. Støtter systemet deg i å ha oversikt over de viktigste sikkerhetsrelaterte alarmene ved driftsforstyrrelser?	☐	☐	☐	☐	☐
17. Gjøres det tilstrekkelig tiltak for å forbedre alarmsystemet?	☐	☐	☐	☐	☐

Når opplever du toppbelastning i din arbeidssituasjon? Skriv i boksen under

KONTROLL I JOBBEN

	meget sjelden eller aldri	nokså sjelden	av og til	nokså ofte	meget ofte eller alltid
18. Får du avløsning når du føler behov for det?	☐	☐	☐	☐	☐
19. Er det forstyrrende at folk kommer inn i borekabinen ved kritiske situasjoner?	☐	☐	☐	☐	☐
20. Er det mye å sette seg inn i når du kommer tilbake på jobb etter friperioden?	☐	☐	☐	☐	☐
21. Hjelper skiftmøtene deg til å få god oversikt over situasjonen?	☐	☐	☐	☐	☐
22. Er arbeidsprogrammene vanskelige å forstå?	☐	☐	☐	☐	☐
23. Er det nok tid til å kvalitetssikre arbeidsprogrammet på forhånd?	☐	☐	☐	☐	☐
24. Hender det at du mister konsentrasjonen når du sitter i stolen?	☐	☐	☐	☐	☐
25. Er det for mange administrative systemer å forholde seg til?	☐	☐	☐	☐	☐
26. Hender det at du sitter med en følelse av manglende oversikt?	☐	☐	☐	☐	☐
27. Er det vanskelig å si ifra til folk at de forstyrrer når de står i borekabinen?	☐	☐	☐	☐	☐

28. Går det utover konsentrasjonen din når ledende personell står inne i borekabinen?	☐	☐	☐	☐	☐
29. Er det tungvint å lese arbeidsprogrammene på engelsk?	☐	☐	☐	☐	☐
30. Føler du at du har kontroll over oppgavene du skal gjøre når du kommer tilbake på jobb etter friperioden?	☐	☐	☐	☐	☐
31. Hender det at du har problemer med å holde deg våken når du sitter i stolen?	☐	☐	☐	☐	☐

Har du andre kommentarer omkring krav og din kontroll i jobben? Skriv i boksen under.

DIN OPPLEVELSE AV NÆRMESTE LEDER

	meget sjelden eller aldri	*nokså sjelden*	*av og til*	*nokså ofte*	*meget ofte eller alltid*
32. Opplever du at informasjon fra planleggingsmøtene med boreleder er et viktig bidrag i arbeidet ditt?	☐	☐	☐	☐	☐
33. Blir operasjonen prioritert foran møtene for boreleder/boresjef?	☐	☐	☐	☐	☐
34. Er det høy terskel for å ringe etter boreleder/boresjef når de er på møte?	☐	☐	☐	☐	☐
35. Er boreleder/boresjef engasjert i arbeidet ditt?	☐	☐	☐	☐	☐
36. Får du tilstrekkelig støtte og hjelp i ditt arbeid fra boresjef/boreleder?	☐	☐	☐	☐	☐
37. Får du tilbakemelding på hvordan du har utført jobben fra din nærmeste leder?	☐	☐	☐	☐	☐

DIN EGEN ROLLE SOM LEDER

	meget sjelden eller aldri	*nokså sjelden*	*av og til*	*nokså ofte*	*meget ofte eller alltid*
38. Gir du dine kollegaer tilbakemelding på jobben de gjør?	☐	☐	☐	☐	☐
39. Har du tid til å lytte til dine kollegaer dersom de trenger det?	☐	☐	☐	☐	☐
40. Føler du at du har tilstrekkelig tid og ressurser til å fungere som arbeidsleder ?	☐	☐	☐	☐	☐
41. Sikrer du som arbeidsleder at de som utfører jobben har god risikoforståelse i arbeidet?	☐	☐	☐	☐	☐

STØTTE FRA KOLLEGER

	meget sjelden eller aldri	nokså sjelden	av og til	nokså ofte	meget ofte eller alltid
42. Har dere en god tone på skiftene?	☐	☐	☐	☐	☐
43. Om du trenger det, kan du få støtte og hjelp i ditt arbeid fra dine kolleger?	☐	☐	☐	☐	☐
44. Om du trenger det, er dine kolleger villige til å lytte til deg når du har problemer i arbeidet?	☐	☐	☐	☐	☐

Har du andre kommentarer omkring støtte fra leder og støtte fra dine kolleger? Skriv i boksen under.

PROSEDYRER/ARBEIDSBESKRIVELSER

	meget sjelden eller aldri	nokså sjelden	av og til	nokså ofte	meget ofte eller alltid
45. Følger du det som står i prosedyrene?	☐	☐	☐	☐	☐
46. Har du tid til å stoppe arbeidet og lese relevante prosedyrer?	☐	☐	☐	☐	☐
47. Hender det du tar snarveier i forhold til å følge prosedyrene?	☐	☐	☐	☐	☐
48. Er det lagt inn nok tid på skiftmøtene til å gjennomgå arbeidsbeskrivelsene?	☐	☐	☐	☐	☐
49. Er prosedyrene lett tilgjengelige?	☐	☐	☐	☐	☐
50. Hender det at du ikke vet om det finnes noen prosedyrer på den jobben du skal gjøre?	☐	☐	☐	☐	☐
51. For arbeid uten arbeidsbeskrivelse, igangsetter du da SJA ved behov?	☐	☐	☐	☐	☐
52. Hender det at det daglige arbeidsprogrammet ikke er underskrevet av boresjef/ boreleder?	☐	☐	☐	☐	☐
53. Er prosedyrene brukervennlige og hensiktsmessige?	☐	☐	☐	☐	☐
54. Er det for mange ulike prosedyrer å forholde seg til?	☐	☐	☐	☐	☐

Har du andre kommentarer omkring prosedyrer? Skriv i boksen under.

TEKNISKE SYSTEMER

	meget sjelden eller aldri	nokså sjelden	av og til	nokså ofte	meget ofte eller alltid
55. Gir skjermbildene en god oversikt over operasjonen?	☐	☐	☐	☐	☐
56. Hender det at det er for mye informasjon å forholde seg til i skjermbildene?	☐	☐	☐	☐	☐
57. Må du forholde deg til bruk av ulike måleenheter (for eks.: meter/feet; Celsius/ Farenheit; kN/ Footpound)?	☐	☐	☐	☐	☐
58. Er det en blanding av nye og gamle systemer i boreområdet?	☐	☐	☐	☐	☐
59. Opplever du jobbsituasjonen som vanskelig ved innkjøring av nytt utstyr?	☐	☐	☐	☐	☐
60. Støtter boresystemet deg i kritiske situasjoner?	☐	☐	☐	☐	☐
61. Får du alarmer på ting som du ikke har bruk for?	☐	☐	☐	☐	☐
62. Er det enkelt å sile ut den informasjonen du har bruk for?	☐	☐	☐	☐	☐
63. Støtter skjermbildet deg i det du skal gjøre?	☐	☐	☐	☐	☐
64. Opplever du at boresystemet gir for stor mulighet til å endre variabler i skjermbildene?	☐	☐	☐	☐	☐
65. Blir innkjøring av nytt utstyr gjort på en tilfredsstillende måte?	☐	☐	☐	☐	☐
66. Gir boresystemene deg tidlig beskjed når noe er galt slik at du kan ta de rette avgjørelsene?	☐	☐	☐	☐	☐
67. Dersom du gjør kritiske aksjoner i borekabinen, må det bekreftes?	☐	☐	☐	☐	☐

Har du andre kommentarer omkring tekniske systemer i arbeidet ditt? Skriv i boksen under.

ROLLEKLARHET

	meget sjelden eller aldri	nokså sjelden	av og til	nokså ofte	meget ofte eller alltid
68. Vet du nøyaktig hva som forventes av deg i jobben?	☐	☐	☐	☐	☐
69. Er ansvarsområdet for stort i jobben din?	☐	☐	☐	☐	☐
70. Hender det at det blir mye når du også har ansvar for at daglig vedlikeholdsarbeid blir utført?	☐	☐	☐	☐	☐
71. Er ansvar og roller knyttet til kritiske arbeidsoperasjoner entydige?	☐	☐	☐	☐	☐

RISIKOFORSTÅELSE

	meget sjelden eller aldri	nokså sjelden	av og til	nokså ofte	meget ofte eller alltid
72. Føler du deg komfortabel med oppgavene dine?	☐	☐	☐	☐	☐
73. Tar dere en gjennomgang av oppgavene før dere går i gang?	☐	☐	☐	☐	☐
74. Når dere kjører SJA, hjelper det deg til å få oppmerksomhet på det som er viktig?	☐	☐	☐	☐	☐
75. Hender det at dere har for liten tid til å utføre SJA?	☐	☐	☐	☐	☐
76. Hvis det oppstår uforutsette ting eller endringer, tar dere da en stopp og vurdering?	☐	☐	☐	☐	☐
77. Ved vurdering av endringer tar dere direkte kontakt med boresjef?	☐	☐	☐	☐	☐
78. Har de ansatte i serviceselskapene god risikoforståelse?	☐	☐	☐	☐	☐

Har du andre kommentarer omkring rolleklarhet og risikoforståelse? Skriv i boksen under.

MØTER/PLANLEGGING

	meget sjelden eller aldri	nokså sjelden	av og til	nokså ofte	meget ofte eller alltid
79. Er utreisemøtene for generelle til at det er til hjelp i arbeidet ditt?	☐	☐	☐	☐	☐
80. Etter du har deltatt på utreisemøtene, føler du deg trygg på den jobben du skal gjøre som borer?	☐	☐	☐	☐	☐
81. Holdes det "før jobben-møter" før hver enkeltjobb?	☐	☐	☐	☐	☐
82. Bidrar "før jobben-møter" til sikker jobbutførelse?	☐	☐	☐	☐	☐
83. Får du den informasjonen du trenger i skiftmøtene for å gjøre en god jobb?	☐	☐	☐	☐	☐
84. Involveres alle som skal delta i arbeidsoppgavene ved gjennomføring av SJA	☐	☐	☐	☐	☐

KOMMUNIKASJON

	meget sjelden eller aldri	*nokså sjelden*	*av og til*	*nokså ofte*	*meget ofte eller alltid*
85. Får du mye informasjon på øret som du ikke har bruk for?	☐	☐	☐	☐	☐
86. Har du en jevn dialog med boresjef?	☐	☐	☐	☐	☐
87. Er operasjonsrommet på land til støtte og hjelp for deg?	☐	☐	☐	☐	☐
88. Har du nok tid til å snakke med boreleder/boresjef?	☐	☐	☐	☐	☐

Har du andre kommentarer omkring møter/planlegging og kommunikasjon i arbeidet ditt? Skriv i boksen under.

OPPLÆRING

	meget sjelden eller aldri	*nokså sjelden*	*av og til*	*nokså ofte*	*meget ofte eller alltid*
89. Legges det til rette slik at du kan holde deg faglig oppdatert?	☐	☐	☐	☐	☐
90. Får du trening på simulator (utover trening på trykkontrollsimulator)?	☐	☐	☐	☐	☐
91. Har dere seminarer hvor teamet trener sammen?	☐	☐	☐	☐	☐
92. Får du tilbud om fagrelaterte kurs?	☐	☐	☐	☐	☐
93. Får du opplæring i lokale forhold når du kommer på en ny innretning?	☐	☐	☐	☐	☐
94. Er det lagt opp til minst en ukes overlapp når du er på en ny innretning?	☐	☐	☐	☐	☐
95. Er trykkontrollopplæringen tilfredsstillende i forhold til arbeidet ditt?	☐	☐	☐	☐	☐
96. Er opplæringen du får rettet mot den jobben du *faktisk* gjør?	☐	☐	☐	☐	☐
97. Er opplæring av nyansatte tilfredsstillende?	☐	☐	☐	☐	☐
98. Følger boresjefene opp de nyansatte?	☐	☐	☐	☐	☐

Hvilke type opplæring trenger/savner du? Skriv i boksen under

FYSISKE FORHOLD

	meget sjelden eller aldri	nokså sjelden	av og til	nokså ofte	meget ofte eller alltid
99. Forekommer det sjenerende oljedampslukt i borekabinen?	☐	☐	☐	☐	☐
100. Hender det du får muskelsmerter ved operering av boresystemet?	☐	☐	☐	☐	☐
101. Er det irriterende støy i borekabin?	☐	☐	☐	☐	☐
102. Er du fornøyd med den fysiske utformingen av borekabinen?	☐	☐	☐	☐	☐
103. Har du mulighet for å veksle mellom stående og sittende arbeidsstilling i borekabinen?	☐	☐	☐	☐	☐
104. Er sikten fra borekabinen tilfredsstillende?	☐	☐	☐	☐	☐
105. Kan du fra normal arbeidsstilling se de ulike skjermene og monitorene?	☐	☐	☐	☐	☐
106. Er kommunikasjonsutstyret lett tilgjengelig fra borestolen?	☐	☐	☐	☐	☐

Har du andre kommentarer omkring fysiske forhold? Skriv i boksen under.

GENERELLE SPØRSMÅL

107. Hvor mange ganger har du vært sykmeldt i løpet av de siste 12 mnd?
(Skriv 0 i feltet hvis du ikke har vært sykmeldt siste år.) .... ☐☐ ganger

108. Hvor mange av disse sykmeldingene mener du skyldes forhold knyttet til jobben?
(Skriv 0 i feltet hvis du mener at ingen av sykmeldingene skyldes jobben.) .... ☐☐ stk.

Omtrent hvor mange ganger har du følt deg <u>utrygg</u> som følge av kritiske forhold under boreoperasjoner i løpet av de siste 12 mnd?

- Aldri ☐
- 1 - 5 ganger ☐
- 6 - 10 ganger ☐
- 11 - 15 ganger ☐
- 16 - 20 ganger ☐
- Mer enn 20 ganger ☐

Personlige opplysninger

1. Kjønn: Mann ☐ Kvinne ☐
2. Alder: ☐☐ år
3. Sivilstatus: Gift/samboer ☐ Enslig ☐

Hvilken skiftordning går du?

- Fast dagskift ☐
- Fast nattskift ☐
- Helskift (1 natt/14 dag annenhver tur) ☐
- Svingskift med 7 natt først så syv dag ☐
- Skiftordningen varierer ☐

Installasjon

Hva slags installasjon arbeider du på? Fast ☐ Flytende ☐

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