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The effect of human factors on safety related to barrier management

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Summary: The aim of this thesis is to establish information on barrier elements where human errors take place and to establish proactive measures to eliminate these errors. The three main objectives for this project is to review the current safety and barrier management approach in Equinor, identify to what degree human factors have an impact on safety and make recommendations for improvements on safety and barrier management.

Keywords: Human factors, human engineering, barrier management, safety, TIMP, Equinor, accidents, human impact.

Summary

The aim of this thesis is to establish information on barrier elements where human errors take place and to establish proactive measures to eliminate these errors. The three main objectives for this project is to review the current safety and barrier management approach in Equinor, identify to what degree human factors have an impact on safety and make recommendations for improvements on safety and barrier management.

The subject of human factors is an important part of this project. By studying accidents that has happened in the past, it was possible to identify many underlying reasons leading to the accidents that were related to both human behaviour and factors impacting on the course of events.

The first part of the thesis is an extensive theoretical part. It covers the introduction, literature review with definitions on human factors, human errors and human engineering, and the different elements connected to barrier management. The research methodology provides information about the design and process of this paper, as well as the two different ways data have been collected.

The second part consists of analysis and evaluation of information and data obtained from reading the accidents reports and from a questionnaire sent out to employees in Equinor. The results from both are shown in different graphs in chapter 5. During the discussion chapter the aim is to discuss around and provide conclusions to the research questions.

The thesis concludes that an effort should be made to implement human factors, and that it should have a positive impact on both safety and barrier management in Equinor. The results show that the areas that would improve the most, when taking human factors into account, would be communication, competence, procedures, training and motivation.

Foreword

This thesis is written as a part of the requirements for the Master´s degree of Technology and Safety in the High North at the University of Tromsø – The Arctic University of Norway. It has been an on-going process starting before the summer break in 2018 and ending in May of 2019, a process that has taught us much and increased our interest in the subject.

Producing a Master´s thesis on any subject is, as many has stated before us, a lengthy process. It is strange to see how the work we have done materializes on the coming pages. All the pre-work with reading of theory, writing, deleting and rewriting which has provided the basis for the thesis is not shown in the final version of this paper. What started out as a small idea before the summer break has now, after nearly a year and many twists and turns, ended in a thesis that symbolizes the end to our educational years.

We would like to thank Equinor and the employees we have been in contact with there, for their information and feedback on different parts of the thesis. We would also like to express our thanks to our supervisor Javad Barabady, for his guidance and feedback throughout this project.

Tromsø, 1st of June 2019

Anders Bakkli

Anders Bakkli

Malene Tennfjord

Malene Tennfjord

Distribution of work

The thesis is written as cooperation between Bakkli and Tennfjord. The work has been divided between us, although it has to be noted that we both have cooperated on all parts. There has been a thorough discussion involving all sections, and both have contributed in the creative process of all sections regarding the structure, design and content of the paper.

We worked together in the selection of reports we needed to include in the document analysis. We divided the reports in half, writing and analysing 8 each. We discussed what to look for in the reports and reached an agreement on the structure of the chapter. As for the questionnaire, the preparation was done in cooperation between the both of us where we discussed questions, design and format.

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Abbreviations

B&B	Boring og brønn drift nord i Statoil
EERA	Emergency, Evacuation and Rescue Analysis
FMEA	Failure Mode and Effect Analysis
FMECA	Failure Mode, Effects and Criticality Analysis
FTA	Fault Tree Analysis
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HPES	Human Performance Enhancement System
HSE	Health and Safety Executive UK
HTA	Hierarchical Task Analysis
HTO	Human, Technology and Organization
ISO	International Organization for Standardization
IPL	Independent Protective Layers
LOPA	Layers of Protection Analysis
NCR	Non-Conformance Requests
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
NORSOK	Norsk Sokkels Konkurranseposisjon
OTS	Operasjonell Tilstands Sikkerhet (Operational Safety Conditions)
PS	Performance Standard
PSA	The Norwegian Petroleum Safety Authority
RBI	Risk Based Inspection
SJA	Safe Job Analysis
SOP	Standard Operating Procedures
TIMP	Technical Integrity Management Program

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Terms and definitions

Human factors	Human factors refer to environmental, organizational and job factors, and human and individual characteristics, which influence behavior at work in a way that can affect health and safety (Health and Safety Executive, 2019).
Human error	A failure of a planned action to achieve a desired outcome (NOPSEMA, 2019).
Human engineering	Is a discipline within organizational and work psychology that studies the interaction between human, technology and organization (Sagberg, 2018).
Barrier	Technical, operational and organizational elements that individually or together function to reduce the possibility of specific errors, hazards and accident situations occurring, or that limit or prevent injuries and/or disadvantages (Petroleumstilsynet, 2013).
Barrier management	Coordinated activities to establish and maintain barriers so that they maintain their function at all times (Petroleumstilsynet, 2013).
Methodology	Describes the general research strategy that outlines the way in which research is to be undertaken (Brookshier, 2018).
Method	Tool used to answer the research questions (Brookshier, 2018).
Triangulation	A process of verification that increases validity by incorporating several viewpoints and methods (Yeasmin & Rahman, 2012)

1 Introduction

A brief introduction is given in this chapter in order to introduce the problem. The first section covers the background and problem definition of the research project. Then it discusses the research project aim and objective, and finally the limitations of the thesis are specified.

1.1 Background and problem definition

Historically there has been disparity in major accident hazard safety reports and safety cases between the level of analysis of human failures and technical failures. Usually the analysis of the technical failures dominates even though the importance of human failure is well known. There is a widespread awareness in the oil and gas industry that human failures whilst performing safety critical tasks have contributed to major accidents, accidents like Piper Alpha, Chernobyl and Texas City, and these failures have been described in great detail in accident reports. Near misses and accidents where human actions have prevented major accidents through timely interventions are less well reported (Technical team of EI, 2011). Whilst progress has undoubtedly been made in recognizing the role of human factors in the intervening years, recent accidents demonstrate that there is still work to be done.

Equinor has a strong and stable focus on the technical integrity and barriers over a long period of time. Through their technical integrity management program (TIMP), Equinor has established a holistic and standardized approach on risk of failures. By connecting tools, competence and people to best practice work process, they can evaluate technical state of equipment, systems, barriers and installations and, when necessary, improve actions in order to achieve a desired technical/risk level. TIMP is a program that maintains and manages the technical integrity of barrier management, but it does not include those non-technical barriers. Oil and gas exploration and production activities are carried out in hazardous environments and events like Piper Alpha, Chernobyl and Texas City highlight those risks and underline the importance of considering human factors during facility design.

Traditionally, barrier management focuses on technical aspects and single barrier, and not so much on operational conditions. This focus on single barrier rather than the whole barrier system may fall short of preventing major accidents, since these major accidents are caused by multiple barrier failure. There is very much one would like to know about human reliability, and the lack of knowledge is not the main problem. The main problem is that one does not use the knowledge available and accidents occur.

The following story illustrates the focus of this thesis. A man went into a tailor´s shop for a ready-made suit. After a while he had tried on most of the stock without finding the one fitting him. Finally, the tailor said “I am sorry sir, but I can´t find a suit that fits you. You are the wrong shape”. So, should one expect people to change their shape, physical or mental, so that they fit into the plants or procedures one has designed or should one design to fit humans? If a person cannot reach a valve, we do not tell the person to try harder or grow taller. One provides a step, moves the valve or removes the need for the valve. Instead of expecting others to change their mental shape and never have slips or lapses of attention, one should change the design or method of working to reduce the possibility of human failure (Kletz, 2001). Within Equinor there are signs that this is beginning to change with higher volume of human factors analyses being conducted. There is also a growing awareness within the industry of how such studies lead to better management of the risk of human failures, and with this improvement in safety and reduction in losses.

As with change of focus related to human factors, investigation methods have also changed focus. There has been a change from focusing on a single cause to a complex cause, for example weaknesses in organization and management, and their interaction with work activities. Investigation reports from the industry now gives a better overview over human and technology factors in relation with unwanted events and subsequent accident investigations, but not sufficient enough on organizational factors. The Norwegian Petroleum Safety Authority (PSA) has experienced that organizational factors related to structural conditions (e.g. roles, responsibilities, procedures and training) is included, but factors more related to e.g. cultural conditions, management, power relations and framework conditions at different levels are not as clarified (Thunem, Kaarstad, & Thunem, 2009).

The motivation to write this thesis is a combination of the interest in the subject from the authors of the paper, and also the interest Equinor has expressed on the subject. The subject is very important in conjunction with the subjects of safety and barrier management. As of today, Equinor do not have much information about human factors and would really appreciate if this thesis could find good ways to both explain the term and how to best implement them into their safety and barrier management system.

1.2 Aim and objectives of the research

The aim of the thesis is to establish information on barrier elements where human errors take place and to establish proactive measures to eliminate these errors. It will also help to identify and implement the non-technical barrier elements. The subject of human factors will be an important part of this thesis. Therefore, it is important to look into how to manage operational barrier elements to increase the human reliability and reduce the human errors related to safety critical tasks. To find to what degree human factors has a part in safety issues, this thesis will look into major accident hazard and determine if there is room for improvement by implementing human factors.

The objectives of this research study are to:

- Review current approach to safety and barrier management
- Identify to what degree human factors have an impact on safety issues
- Provide recommendations and suggestions for improvement of safety and barrier management

1.3 Research questions

In order to meet the aim and objective of the study, the following research questions are defined.

RQ1: What is the current approach for safety and barrier management in Equinor?

RQ2: What are the challenges and weaknesses of the existing approach regarding non-technical barrier elements?

RQ3: What are the main human and organizational factors that plays a part in major accidents?

RQ4: What recommendations/suggestions are needed to improve the overall safety and barrier management?

RQ5: What areas of the overall system will improve the most, taking human factors into account?

1.4 Limitations

The barrier management approach in Equinor has a strong technical focus, and therefore has room for improvement within the human and organizational aspect. The limitations for this thesis are as follows:

- This thesis focuses on the non-technical barrier elements, which is human and organizational aspect of barrier management.

- Based on data from investigation reports limited to incidents regarding hydrocarbon leaks in Equinor and a questionnaire.

- A limitation to the questionnaire is that it will not give the level of detail in qualitative response one would get in an interview and the number of responses obtained is limited.

- Time aspect is only 5 months and therefore the thesis is limited to certain areas within the barrier management system. This is because the subject in this paper is quite big, and it is possible to use much more time to really go in depth about it. Also, by studying more specific areas, it will provide better solutions for those areas.

2 Literature review

In this chapter some basic definition of human factors, human error and human engineering will be presented. Also, a detailed review of important areas in barrier management for this thesis will be presented.

2.1 Human factors

There are a number of definitions for the term human factors. A report prepared by BAE Systems Defence Consultancy from 2002 states that human factors is a professional discipline concerned with improving the integration of human issues into the analysis, design, development, implementation, and the operational use of work systems (Carr & Widdowson, 2002). The definition from the Health and Safety Executive UK (HSE) focuses more on the different factors related to the work situation, and how they interrelate with human characteristics to affect safety and health in the work place.

The definition from HSE includes three different aspects that are interrelated and needs to be considered:

1. The job: This part includes areas such as the nature of the task, workload, the working environment, design of controls and displays and the role of procedures. A key part of this aspect is to match the job with the physical and mental characteristics of personnel.
2. The individual: Takes into account the competence, skills, personality, attitude and risk perception of personnel. In every area where you have multiple people working, you will have a wide range of personalities and characteristics within the group. The main thing to remember is that characteristics such as personality are fixed, while skills and attitude can be adjusted or enhanced through training and courses.
3. The organization: Factors that are often overlooked but have a huge impact on both individual and group behavior, are work patterns, the culture of the workplace, resources, communication, leadership and others.

The overall objectives of human factors are to design systems, jobs and organizations matching the human capabilities and limitations, and not the other way around. This applies for both definitions mentioned above. By applying a human factor approach it is possible to improve both human health and safety, but you will also get a better management and more effective organization (Health and Safety Executive, 2019).

2.2 Human errors

As with human factors, there are several definitions of human errors. An article from 2015 defines it as a mistake in the planning or execution of a task resulting in failure to meet a goal (Spacey, 2015). The two definitions for human factors are quite similar, but the term human errors are more general and must be broken down into several subcategories to better understand it. The National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) categorizes human errors into two different categories. The categories are skill-based errors and mistakes. Skill-based errors are given two new subcategories, slip of action and memory lapse, while mistakes cover rule-based and knowledge-based errors (NOPSEMA, 2019).

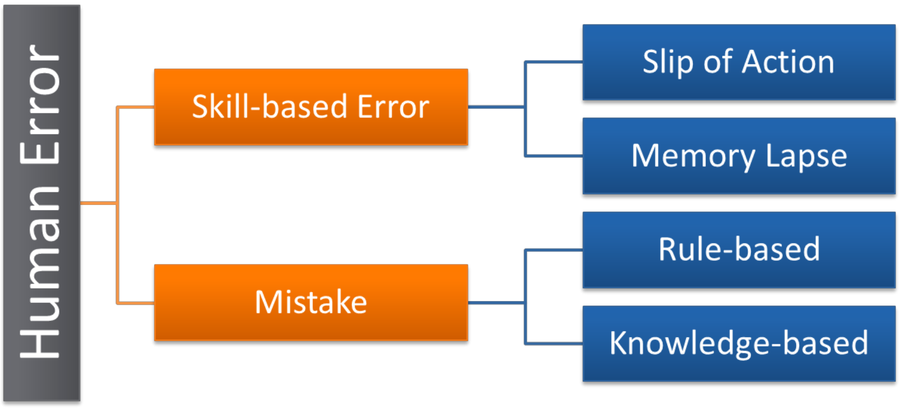

Figure 1 - Diagram of human errors (NOPSEMA, 2019)

Skill-based errors are often related to highly routine activities. The individual has done the task correctly so many times that the focus on the task at hand decreases, and an error occurs. This could happen to anyone, even the most experienced, highly skilled personnel. In fact, they are even more exposed to this type of error, because of their experience in doing the task. A memory lapse refers to errors related to forgetting something. This could be a step in a process, parts of a plan or even the entire plan. Slips of action are errors that are unintentional. Typical errors belonging in this category are doing tasks on autopilot, performing right action on wrong object and copying wrong when writing numbers. For instance, writing 0.31 instead of 0.13 would be a typical error (NOPSEMA, 2019).

Mistakes are errors that are not done on purpose. Typically, personnel with less knowledge and experience make mistakes. They can often be traced back to the original plan, which purpose is to achieve some desired outcome. But because of inexperience or poor information, the plan is not appropriate. According to NOPSEMA, mistakes can be rule-based or knowledge-based. Knowledge-based mistakes are the result of a “trial and error” approach.

Rule-based mistakes describe when rules are applied incorrectly, not at all or when bad rules are put to use. NOPSEMA states three different categories to rule-based mistake, which are incorrect application of a good rule, application of a bad rule and failure to apply a good rule. If one or more of the three are applied, a desired outcome is not achieved (NOPSEMA, 2019).

2.3 Human engineering

Human engineering is closely related to human factors. In English, the discipline is sometimes referred to as human factors. Human engineering is how to design systems with factors such as abilities, skills, habits and needs at the centre. The goal of human engineering is to make sure working conditions are as safe, health friendly and efficient as possible. One central aspect of the discipline is the facilitation of work methods, jobs, technology and equipment in accordance with cognitive psychology and ergonomics. It is also important to understand how larger organizational systems, for example training, risk management and safety culture is a part of this interaction (Sagberg, 2018).

When an accident has occurred, a human engineering analysis can be conducted. In this type of analysis, the basis is that human, technical and organizational factors (HTO-analysis) are treated equally. The method is based on the Human Performance Enhancement System (HPES), which comes from the nuclear industry. There are three methods included in such an analysis, and they are (Tinmannsvik, Sklet, & Jersin, 2004):

1. Structured analysis by use of an event- and cause-diagram.
2. Change analysis by describing how events have deviated from earlier events or common practice.
3. Barrier analysis by identifying technological and administrative barriers that has failed or is missing.

The first thing to do in a human engineering analysis is to develop the sequence of events longitudinally and illustrate them in a block diagram. Figure 2 illustrates a standard human engineering diagram. Then, the analyst will try to identify technical and human causes of each event and draw them vertically to the events in the diagram. The next step is to make a change analysis. This means to assess how the events in the accident process have deviated from normal situations and operations, or common practice (Tinmannsvik, Sklet, & Jersin, 2004).

The third step will be to find and analyse which technical, human or organizational barriers that have failed or were completely missing during the accident development. All missing or failed barriers are arranged below the events in the diagram, as shown in Figure 2. There are some basic questions to think about while doing this, and they are (Tinmannsvik, Sklet, & Jersin, 2004):

- What may have prevented the continuation of the accident sequence?
- What may the organization have done in the past in order to prevent the accident?

Finally, the last step would be to identify and make recommendations. It is important that the recommendations are as realistic and specific as possible. This is to ensure that it is actually possible to implement the proposals. The recommendations can be anything within the technical, human or organizational category (Tinmannsvik, Sklet, & Jersin, 2004).

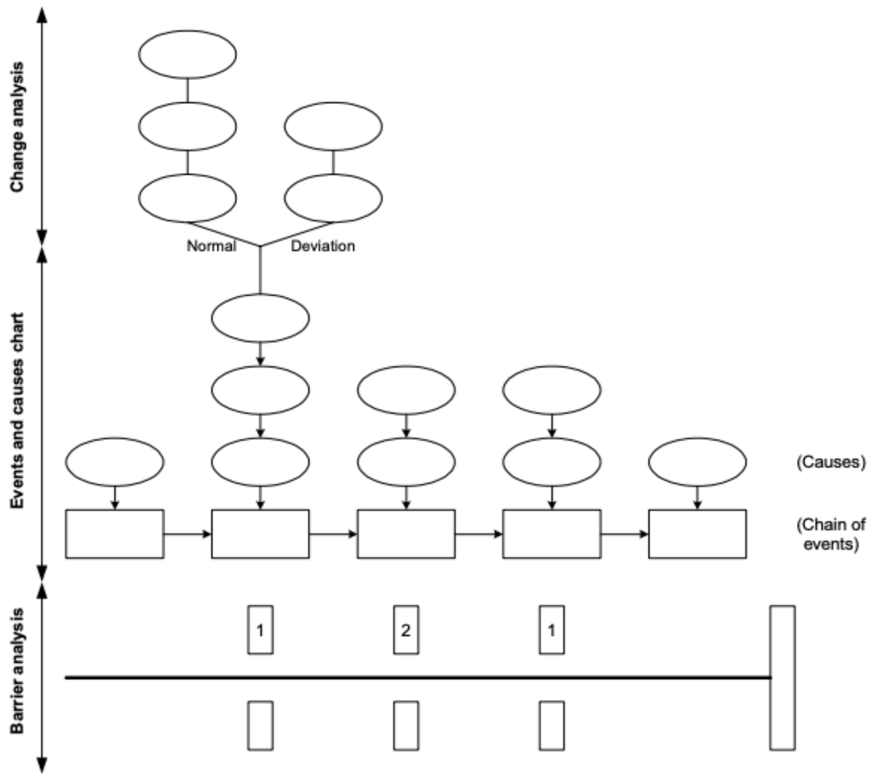

Figure 2 - Standard human engineering diagram (Tinmannsvik, Sklet, & Jersin, 2004)

2.4 Barrier management

Every safety and barrier management system consists of different barrier elements. The three main categories are technical, operational and organizational. PSA has defined the operational barriers as *"the actions or activities that the personnel must perform to realize a barrier function"* (Petroleumstilsynet, 2017). The organizational barriers are defined as *"personnel with defined roles or functions and specific competence included in the realization of a barrier function"* (Petroleumstilsynet, 2017). Technical barrier elements are defined as *"equipment and systems included in the realization of a barrier function"* (Petroleumstilsynet, 2017). In other words, who is doing what with what equipment in error, danger and incident situations (Petroleumstilsynet, 2017).

Two other, more underlying factors playing a part on a barrier and its ability to function properly are called performance requirements and factors affecting performance. Performance requirements are verifiable requirements for barrier element properties to ensure the barrier is effective. Factors affecting performance are conditions identified to have significant impact on barrier functions and barrier elements´ ability to function as intended (Petroleumstilsynet, 2017). Figure 3 illustrates how barrier functions are implemented through barrier elements.

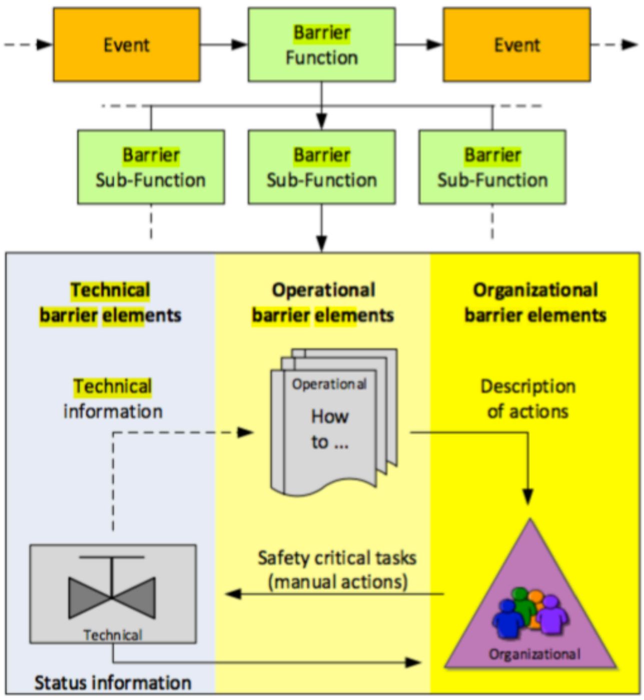

Figure 3 - Barrier functions implemented through barrier elements (Hauge & Øien, 2016)

The following table shows an illustration of the interaction between the different categories of barrier elements, performance requirements and factors affecting performance, and how they work together to ensure a barrier function.

Table 1 - Illustration of the interaction between technical, organizational and operational barrier elements, performance requirements and factors affecting performance (Petroleumstilsynet, 2017)

	Barrier function		
Barrier elements	**Technical:** Which equipment and systems is a part of the realization of a barrier function?	**Organizational:** Which personnel have defined roles or functions and specific competence to be able to realize a barrier function?	**Operational:** What safety critical tasks must be done to ensure that the barrier function works as intended?
Performance requirements	Which requirements must be made to equipment and systems e.g. in the shape of functionality, integrity and robustness?	Which requirements must be made to e.g. specific competence, availability, exercises and joint training?	Which requirements must be made to carrying out tasks e.g. response time, action criteria, communication requirements and checkout?
Factors affecting performance	What affects the performance of different technical elements? E.g. design and material quality, maintenance management, environmental factors etc.	What affects the performance of the personnel? E.g. work load, human-machine interface, familiarizing, responsibilities, organizational complexity etc.	What affects the possibility to perform tasks correctly and on time? E.g. availability and quality of procedures, quality and scope of exercises and training, design of facility and equipment, noise, weather etc.

2.4.1 Technical barrier elements

Drilling rigs and ships are equipped with a wide range of systems, structures and other design features that have barrier functions. This is referred to as technical barrier elements. Technical barrier elements are further divided in two main categories – those that do and those that do not alter shape state or condition in order to perform a barrier function. Those technical barrier elements that do alter shape state or condition are called active or functional barrier elements, while those that do not alter are called passive or structural barriers (Øie, Wahlstrøm, Fløtaker, & Rørkjær, 2014).

What constitute these barriers are based on assessments of the hazards involved, and the level of detail on which technical barrier elements are identified depends much on the system in question. Some systems are large and complex, while others are made up of fewer parts and therefore are simpler. An important factor when deciding detail level is for which purpose each barrier are identified. Therefore, knowing the barrier elements function, requirements for performance and how they can be weakened are important for identifying barriers.

Using standard engineering documentation, the identification of the technical barrier elements realizing a barrier sub-function is relatively straightforward. One uses a top-down approach to make sure all relevant elements are captured. This is important considering that technical barrier elements typically have an extensive amount of technical barrier elements required. Therefore the top-down approach should be followed up by a bottom-up verification approach. This could then be mapped against existing performance standards, relevant NORSOK standards, or some logical model showing the relations between all barrier elements within a barrier function (Hauge & Øien, 2016).

For a barrier to function optimal it will depend on both technical elements and operational or human elements. To ensure that barriers functions optimal Equinor has established a technical integrity management program (TIMP), by combining tools, competence and people they can evaluate the technical integrity of the plants (Equinor, 2018).

2.4.2 Operational and organizational barrier elements

There are many documents and standards that determine how to maintain and ensure operational barrier elements. Both NORSOK and ISO standards are very important in the oil and gas industry. Standards can also provide performance standards for different barrier elements, as well as requirements to them. A pre-requisite for managing operational barriers is identifying them. Key sources for doing this are:

- Risk documentation
- Safety critical task analysis
- Non-conformance requests and deviations
- Operations procedure and personnel

2.4.2.1 Risk documentation

Examples to sources for risk documentation can be analyses such as hazard identification (HAZID), hazard and operability (HAZOP) and layers of protection (LOPA). These are just examples, and there are other analyses that can give information about risk in a company or industry. This chapter will give information about some of these analyses, what they are, and the purpose of them.

HAZID

A HAZID analysis is a hazard identification analysis, and the name is more or less self-explanatory. It's a systematic method which purpose is to evaluate and identify risk with a system or an activity. The method is used in advance of a planned activity, in order to prevent and reduce unwanted events affecting personnel, material and the environment. The principles of using HAZID are considered to be relatively simple and unlikely to reveal all risk factors. It is still a widely used method and will often give useful results (Pedersen & Hofstad, 2017).

HAZOP

HAZOP is an acronym for hazard and operability analysis that has a documented and systematic method where the purpose is to identify safety-related hazards and challenges in conjunction with execution, maintenance and operation of a process facility. What separates a HAZOP analysis from a HAZID is that a HAZOP analysis is performed during the design phase to identify risk factors in the process design. The process facility is evaluated and analysed with possible hazards in mind. Typically, it is normal to study the consequences of possible deviations from planned design. The analysis is finished when a report has been made, which describes the studied themes and contains the identified hazards (Hofstad & Halbo, 2017).

LOPA

LOPA is short for layers of protection analysis, and it is a simplified, semi-quantifiable risk assessment method. The main purpose for the analysis is to see if there are sufficient layers of protection against a defined accident scenario. A scenario could require several layers of protection, dependent on the complexity and potential severity of consequences. When conducting this kind of analysis, you will only be interested in IPLs, independent protective layers. An IPL is a device, system or action that is capable of preventing an accident scenario when they occur (Ouazraoui, Nait-Said, Bourareche, & Sellami, 2012).

The study itself is based on information gathered from such analyses as HAZID and HAZOP. Normally, a LOPA is applied on systems already in place, with the safeguards installed. As with many other risk assessment analyses, there is a stepwise way of approaching it, and they are (Franks, 1999):

1. Establish consequence screening criteria
2. Develop accident scenarios
3. First scenario
4. Identify initiating event and frequency
5. Identify IPLs and associated probability of failure on demand
6. Estimate risk
7. Evaluate risk
8. Consider if the risk is acceptable
9. Consider options to reduce risk

There are other methods to document risk, and those mentioned above are just some examples. Other methods are also good both for evaluating risk and identify potential hazards in the workplace. You could do emergency, evacuation and rescue analysis (EERA) to study if the evacuation system in place will function as intended if an incident were to occur. To identify potential failures and the effect of them within a system, a failure mode and effect analysis (FMEA) or failure mode, effects and criticality analysis (FMECA) would be effective. If the goal were to identify all the things that could lead to a potential hazardous event, you would use a fault tree analysis (FTA). It really comes down to what a company, researcher or analyst wants to find out and the chosen method should be of such that the main goal of the analysis is achieved.

2.4.2.2 Safety critical task analysis

A safety critical task is defined as tasks where human performance contributes positively or negatively to major accident risk, through either initiation of events, detection and prevention, control and mitigation or emergency response (Øie, 2016). A task analysis is broadly defined as the study of what an individual is required to do to reach a certain goal. A critical task analysis has the purpose of facilitating the identity of uncontrolled or poorly controlled error risk. This is done through the application of task analysis techniques on tasks which are critical to safety, integrity and environment. NOPSEMA describes one method that is useful, and it is the hierarchical task analysis (HTA). This method provides a framework for different task analyses and is a useful general guide. There are six steps involved with the method, and they are (NOPSEMA, 2017):

1. Task definition – determines which critical task that are going to be analysed and describes the purpose of the analysis.
2. Data collection – to ensure comprehensive coverage of the task in question
3. Determine the goal – define the main goal of the analysis
4. Determine sub-goals – the goal in step 3 is broken down into smaller, meaningful sub-goals. The list of sub-goals should represent the necessary steps needed to achieve the overall goal.
5. Sub-goal decomposition – This step is a continuation of step 4, where sub-goals are further broken down into a new set of sub-goals and operations. It is important that the bottom level of each nested hierarchy within an HTA contains an operation, while each superordinate contains a goal.
6. Plans analysis – The last step of the analysis is to add a plan that dictates how to achieve the goals in the analysis. The purpose of such plans is to specify the order in which the different goals and operations are to be performed. Plans exists in many forms, such as linear (do 1, then 2, then 3 etc.), non-linear (do 1, 2 and 3 in any order), cyclical (do 1, then 2, then 3, repeat until x) and selection (do 1 then 2 or 3). The following figure shows an example of such an analysis.

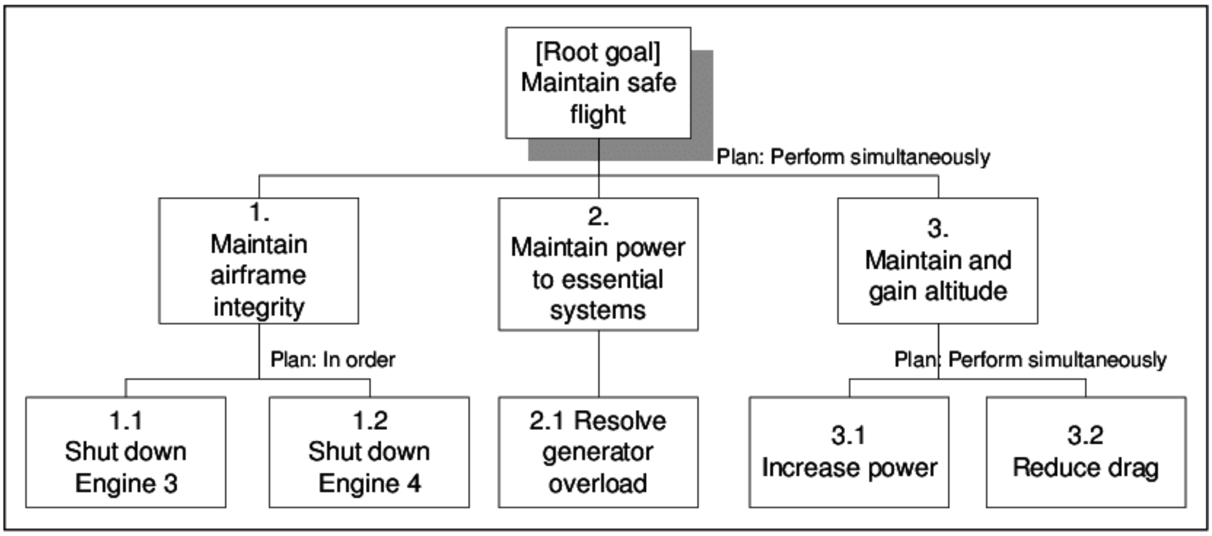

Figure 4 - Example of safety critical task analysis (Fields, Pocock, Wright, & Harrison, 2001)

2.4.2.3 Non-conformance requests and deviations

Non-conformance requests (NCR) and deviations are very similar in comparison, but there is an important difference in how they are to be understood and used. A non-conformance is an occasion when a product does not meet product specification and don't conform to requirements. NCRs are a tool to track defect categories, defect types, frequency, counts and so on. Primarily it is a tracking tool to be able to have control over products that have not met requirements, and what has been done with them, e.g. were they scrapped, reworked, used as is and so on. A company can use this to make informed production and efficiency decisions (Boudreaux, 2012).

A deviation could mean any number of things. The word alone is very wide and covers both statistical and normative deviations. A statistical deviation means something is different from the norm. Normative deviations can be both negative and positive, e.g. crime or misuse of drugs (negative), or about unusually gifted people (positive) (Tjora, 2016). In conjunction with the subject of this paper, the definition from the Norwegian Labour Inspection (Arbeidstilsynet) will be used. They state that any incident breaking HSE regulations are to be treated as deviations. Examples of deviations will be lack of personal protection equipment, wrongful storage of chemicals and work-related injuries. Breaches of important procedures, instructions or routines in the workplace are other examples of deviations that should be reported (Arbeidstilsynet, 2019).

2.4.2.4 Operations procedure and personnel

Another way to manage the operational and organizational barrier elements are by implementing operating procedures and the personnel. Standard operating procedures (SOP) are a tool that can be very effective in many departments and could bring consistency and efficiency into performing tasks within a company.

SOPs are written, step-by-step instructions describing how to perform an activity. This will, alongside training of personnel, ensure that personnel perform activities in the same way every time. SOPs will help maintain safety and efficiency in multiple departments such as production/operations, employee training and finance. As long as an SOP is short, to the point and easy to understand it will be very helpful for both new and more experienced personnel. When a company decides to implement SOPs at their workplace, it demands a lot of planning and preparation. There is a 5-step procedure to this, and they are (Johnson, 2019):

1. Develop a list of the business process: Managers will talk to the employees about their everyday duties and will be able to discover which activities need an SOP.
2. Plan the process: Determine a format for the SOP, e.g. if it is going to be a step-by-step guide or workflow diagram. Also, decide how the SOP will be visible for employees, in written format or possibly online.
3. Talk with employees: This is an important step in the SOP making process. Only by talking to the employees it will be possible to fully understand the process.
4. Write and review the process: Write and review the SOP with both employees and management input. It is important to then assign personnel to be responsible for oversight and maintenance of the SOP.
5. Maintain the process: In order for the SOPs to stay relevant and useful, it is important that they are maintained and updated regularly, at least once a year.

3 Research methodology

This chapter discusses the underlying reasoning for why particular methods were used. This discussion includes description of the theoretical concepts that inform the choice of methods within the academic work and reviewing its relevance to examining research questions. It also includes a thorough review of the literature about different analysis that is carried out.

3.1 Research design

The overall methodology approach for investigating research questions is to determine if the study is qualitative or quantitative or a combination of both (mixed methods). A research is considered to be qualitative when it is based on non-numerical information, oriented to discover or refine research questions. Quantitative research is based on mathematical or numerical data, statistical or computational techniques to determine patterns of behavior or test theories. This is supported by Leppink (2017) and Denscomb (2017) and describes two different approaches to analysis. In this study the approach is a combination of qualitative and quantitative methods of safety and risk analysis and their applications in complex operating environments.

The approach of mixing qualitative and quantitative method gives benefits to the study. The first, and perhaps the most frequently discussed, is the benefit of triangulation. Second, mixing research methods provide a more holistic picture of how human factor effect the barrier management in different ways. Third, a mixed-methods approach may lend itself a strong explanation of human factors. Since this is the study of human factors in barrier management, it is important to understand the human aspects – the thoughts, feelings, and perspectives – behind barriers. Adding a qualitative study could help better understand the human factors and using those qualitative findings as a starting point for designing a quantitative system to quantify those findings.

3.2 Research process

The process of this thesis started before the summer vacation of 2018 when it was decided the thesis would be a group project. During the summer, Malene was in contact with Equinor, and the main subject for the thesis was ready when the fall semester started. Since barrier management is a very large subject, it was necessary to narrow it down. During the planning period in January, and after talks with Equinor, it was agreed that the focus would be human factors and how it affected safety and barrier management.

Below is the developed time schedule that has been a good tool to have, in order to keep control over the progress of the thesis. There have been some minor changes to the plan, but overall the plan has been more or less followed.

Activity	Plan Start	Plan Duration
Planning	07.01.19	31.01.19
Project description	07.01.19	10.01.19
Research question	07.01.19	31.01.19
Table of contents	27.01.19	31.01.19
Data collection	01.02.19	12.03.19
Writing of thesis	16.02.19	30.04.19
Theory part	16.02.19	03.03.19
Main part	26.02.19	31.03.19
Analysis, results	18.03.19	12.04.19
Discussion, conclusion	09.04.19	09.05.19
Review period	28.04.19	31.05.19
Final delivery	31.05.19	01.06.19

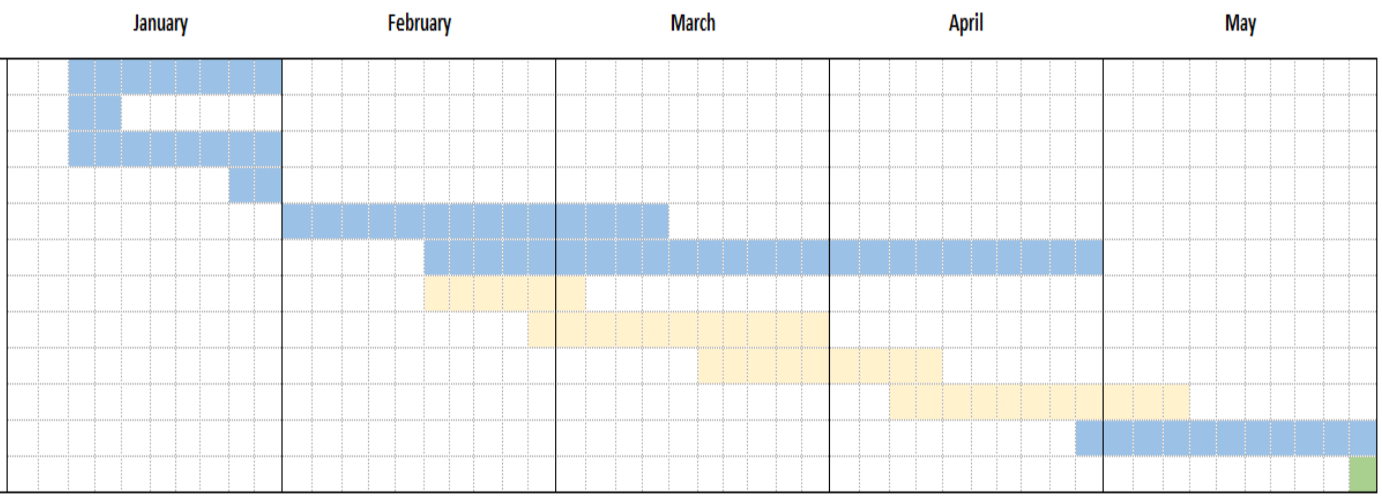

Figure 5 - Time schedule for thesis project

3.3 Data collection and analysis

It has been a good collaboration with Equinor throughout the project, mainly with the technical safety department. They have been welcoming and trusting when it comes to this project. Also, freedom was given to select theme and research problem that was found most interesting for the thesis.

In this project the data collection is based on a combination of different methods, with the purpose to place high reliance on this research. The data collections are from investigation reports, written sources and a questionnaire, and this combination is mentioned above as the triangulation. Concerning the research subject, two methods have been chosen in this project, documentary analysis and questionnaire.

3.3.1 Documentary analysis

Documentary analysis involves obtaining data from existing documents without having to question people through interview, questionnaires or observe their behaviour. This is the main way data is obtained about the research subject. In this study, both external and internal documents have been evaluated with the purpose to acquire knowledge about Equinor and barrier management. Oil and gas laws and regulations are easily accessible, and this is combined with information from investigation reports, public letters and other materials from Equinor.

The method used for data collection is based on the use of someone else´s already-published information for analysis, known as secondary data. Secondary data may include eyewitness accounts, contemporary reports of events, or later reports (SkillsYouNeed, 2017) (Denscombe, 2010). The quality of such data depends on the size of the sample and the quality of the data collection and sets requirements to credibility and source criticism. Independent of Equinor's internal investigations, PSA initiate their own investigation after any accident and evaluate the quality of the company's investigation. With this in mind and the fact that the data collection is gathered from a highly reputable company and government, this is data with a high level of reliance.

As mentioned before, the study has been limited to human factors in barrier management with data from investigation reports limited to hydrocarbon leaks. This gave us the opportunity to go in depth on each incident and give us a better understanding on how these incidents are related to human and organizational factors. The main material is from 16 investigations reports in the period 2008-2018.

The following incidents are analysed:

Table 2 - Investigation reports from PSA analysed in chapter 4

Place	Date	Type
Hammerfest LNG Melkøya	17.06.18	LNG-leakage
Mongstad	24.10.17	Naphtha leakage
Åsgård A	10.03.17	HC-leakage
Mongstad	25.10.16	Gas leakage
Stureterminalen	12.10.16	H2S-exposure
Kårstø	07.01.16	HC-leakage
Gudrun	18.02.15	HC-leakage
Statfjord C	26.01.14	HC-leakage
Hammerfest LNG Melkøya	05.01.14	HC-leakage
Oseberg A	17.06.13	HC-leakage
Heimdal	26.02.12	HC-leakage
Gullfaks B	04.12.10	Gas leakage
Mongstad	08.02.10	Gas leakage
Kollsnes	19.05.09	Condensate leakage
Oseberg C	12.09.08	HC-leakage
Statfjord A	24.05.08	HC-leakage

3.3.2 Questionnaires

To better understand and strengthen the already existing data from documentary analysis, a questionnaire has been implemented in the study. The purpose of the questionnaire is to measure some parameters in regard to the human aspects on a group of people and to make comparisons between groups of people. Questionnaires require a great deal of care in their design and delivery, but with a well-developed questionnaire it is possible to reach a much larger number of people than interviews would. A limitation to this approach is that the questionnaire will not give the level of detail in qualitative response one would get in an interview and the number of responses obtained could vary (SkillsYouNeed, 2017) (Denscombe, 2010).

Questionnaires, which are also called surveys, are one of the key ways to gather quantitative data for analysis. The method used for the questionnaire refers to the first hand data gathered by the researcher, known as the primary data (Surbhi, 2016). It relies on asking the same questions in the same way to a large number of people and obtaining a lot of responses. These responses are then analysed using statistical techniques to obtain the information on the study subject. There are two main types of surveys, self-completed and interview-administrated surveys (SkillsYouNeed, 2017) (Denscombe, 2010). As mentioned above this study will not focus on interview, therefore a self-completed questionnaire is the used method. The reason for choosing this method is that it is possible to reach a large number of people, it will give data accuracy and the time limit is a crucial part of the choice.

The quality of the survey data is a vital issue and there are pros and cons when it comes to questionnaire surveys. To justify the value of the collected data, two basic criteria for evaluating a research questionnaire is taken into account. The first of these concerns, are the likelihood that the questionnaire will provide full information on the research problem. The value of the questionnaire will depend on the extent to which it includes coverage of all vital information pertaining to the area of human factors. The second criterion concerns likelihood that the questionnaire will provide accurate information. This means with what level of confidence is it certain the responses are honest – free from mischievous attempts to scupper the research or errors arising through questions, etc. (Denscombe, 2010). Based on the objectives and research questions a questionnaire has been prepared that are supported by the checklist made by Denscombe (2010) and experienced personnel in the study area.

4 Empiricism

This chapter summarises the incident description and report analysis of the 16 investigation reports. For more information see the reference for the reports.

4.1 Report analysis of the 16 investigation reports

After an apparent peak in number of incidents in 2008, there has been a gradual reduction in number of leaks. Number of reported incidents in 2012 was the lowest the registered in this period.

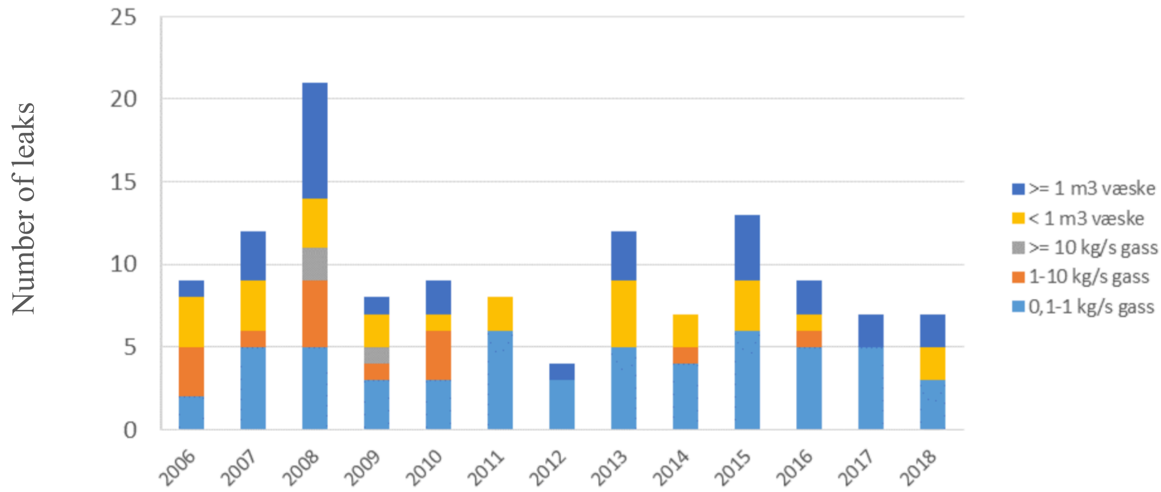

Figure 6 - Non-ignited hydrocarbon leaks from 2006 to 2018 (Huseb & Lauridsen, 2018)

This chapter has 16 sections and each section gives a short description of the investigation report followed by the analysis of the incident. The reports selected are incidents that are mainly involved with hydrocarbon leaks in the period from 2008 to 2018. Figure 6 shows how many leaks that have occurred and the level of leakage. The main incident causes connected to human and organizational factors of each report are listed in this chapter.

4.1.1 LNG leak from tanker truck during filling, 17.06.18

Incident description

In connection with filling of a tanker truck a LNG leak occurred on Equinor's facility Hammerfest LNG on Melkøya. The leak occurred from a direct cause, because a valve on the tanker truck where left in open position. The actual consequence of the incident was the leak of LNG to the surrounding environment. Equinor has estimated the leakage to be approximately 996 kg, with an initial rate of 0.06 kg/s and have considered the release to have small environmental consequences. Also, the incident did not result in any material damage or production shutdown (Hallan, 2018).

Report analysis

A thorough report has been carried out and the investigation gives an overall impression of the incident through a short summary and a timeline lasting for ten ours, but do not include an HTO-analysis. Further it is discussed if there has been deviation from requirements and procedure. Barrier elements that failed and worked are identified, as well as direct and underlying causes. In the end an assessment of the potential of the incident are carried out and some areas that need to be improved are recommended. The most important human and organizational factors from the report includes:

1. <u>Deficiencies in information management and expertise:</u> The personnel did not know safety features. Equinor has not followed up that Barents Naturgass met the requirements for material and competence to the drivers. It emerged though interview that they had not carried out follow-up beyond ensuring the drivers had a valid HMS24 course and a valid admission course.
2. <u>Lack of technical document:</u> Under operations technical documents should be updated, available and known to operation personnel. Relevant technical documentation for handling the incident was not available or sufficiently detailed and was as well not known to the personnel.
3. <u>Inadequate risk analysis connected to design:</u> The system for overflow protection was designed so that a simple wrong action could lead to unacceptable consequences. The chosen solution for the overfill protection is not robust with regard to any errors, and the possibility of correcting an error. The only barrier against larger leaks is a vent. If the valve is left in an open position it is not possible to close off from other locations and the leak will continue until the level is below a certain point for the valve. There are not any position indicators on the vent, and it is not easy to see if the valve is open or closed.

4.1.2 Naphtha leak on cracker plant, 24.10.17

Incident description

On 24.10.2017 a Naphtha leak on Mongstad occurred. The leak was detected by an operator who was investigating the area based on oral information of unusual amount of smell. The leakage was caused by inner corrosion in a pump fuse in the cracker plant. Statoil estimated the leak rate to be approximately 0.01 kg/s. The process part with leakage was isolated, emergency response established, and activation of the factory alarm made sure the personnel evacuated the plant (Langøy M. A., 2018).

Report analysis

This report appears to have been thoroughly prepared but an HTO-analysis were not used. The report concludes with the direct cause for the leak and has a chapter for deviation and recommendation for improvements. The direct cause of the incident was described as an internal corrosion caused by changes in operation conditions. Changes in operation conditions and inspection findings should from the risk based inspection method (RBI) entail in closer follow-up. Human and organizational factors are mentioned as a part of the direct cause for the leak, even though they are not categorised as organizational. The most important human and organizational factors from the report includes:

1. Deficient assessment when changing operating conditions: An overall review has not been carried out with all relevant disciplines to assess whether the increased salt in the oil could affect the integrity of the facility and whether the inspection programs must be changed due to the changed operating conditions.
2. Deficiencies in inspection and maintenance: No changes have been made in the maintenance routines in the form of the inspection program (RBI) following corrosion findings in the Naphtha loop.
3. Insufficient compliance of routines: Personnel did not follow their own daily routine. For example, a logging system was established in which different points in the cracker plant were to be checked and acknowledged at fixed intervals. The procedure for carrying out the check rounds was different from person to person, and all checkpoints were not always implemented.
4. Deficiencies in information management: Personnel at night had noticed a strong smell in the cracker plant before the leak where discovered. This observation where

communicated orally, but not delivered written to the day shift. It seems it was a coincident that the day shift had perceived the night shift smell observation.

5. Insufficient understanding of the risk and lack of identification of the associated risks: There was insufficient understanding of risk and lack of identification of risk factors in connection with the preparation and control of work permit for the stripping of Naphtha contaminated material. It was not executed a safe job analysis (SJA) to identify the associated risks.

4.1.3 Hydrocarbon leak on template S, 10.03.17

Incident description

In March 2017 a leak occurred in connection with removal of the blind flange. At initial activity for removal of the blind flange, no leak was discovered. Because of this the blind flange were removed. When the clock was 20:07 the blind flange was blown off the end flange and gas and condensate could stream freely to the sea. Deepsea Bergen contacted the control room on Åsgard A and both wells that were producing on the template were closed at 20:14. The alarm was activated. There were observed gas in the sea under the moon pool, but none of the gas sensors in the area triggered the alarm. At 20:27 it was reported that the leak had stopped (Gundersen, 2017).

Report analysis

A thorough report has been carried out and the investigation gives an overall impression of the incident through a short summary. There is also a thorough description of event from before operation in 2016 and until the incident had occurred in 2017. Further it is discussed if there has been deviation from requirements and procedure. Barrier elements that failed and worked are identified, as well as direct and underlying causes are addressed and discussed in great detail. In the end an assessment of the potential of the incident were carried out and some areas that need to be improved are recommended. The most important human and organizational factors from the report includes:

1. Deficiencies in risk assessments: In connection with planning and implementation of operation on the well, important contributors to risk and change in risk were not identified and treated. The risk assessment that was carried out with risk reducing measures bears a mark of being predefined. Also, it was an insecurity related to the position of the valve that was not mentioned in the risk assessment.

2. Uncertainties regarding responsibility and role: The responsibility for testing of the barrier were not clearly placed or coordinated, and it was not clear whom was the responsible for testing the valve before the disassembly of the blind flange.
3. Inadequate communication and cooperation: There was limited communication between operation and B&B with regard to operations that were going to be carried out after B&B had taken over. They both expected the other part to have executed the testing of all of the barrier valves. Better communication and cooperation could have clarified the uncertainties regarding barrier and the status of the isolation vent.
4. Lack of knowledge regarding technical documents: Management has not ensured that personnel have sufficient knowledge to the current governing document and that internal requirement were followed.

4.1.4 Gas leak in connection with maintenance, 25.10.16

Incident description

On Mongstad a gas leak occurred when an operator tried to operate on a valve after gas were detected in the area. This was due to corrosion under the isolation leading the socket pipe to rust, and the socket with the valve broke off so gas flowed freely. Emergency shut down and manual depressurization was implemented immediately, and personnel evacuated the plant. Under different circumstances the gas leak could have led to loss of personnel. The actual consequence was the release of hydrogen and hydrocarbon gas to the environment and production stop in the affected facility (Langøy M. A., 2017).

Report analysis

The investigation team has conducted a thorough analysis. A description of the sequence of events of the incident is well documented. For the incident, the associated conditions are identified. The conditions are further studied to determine if they are the cause of the incident. The analysis has direct references to structural organizational factors. All the causes identified are rooted in organizational factors:

1. Inadequate risk assessment before starting the activity: In connection with planning and start-up of the surface program in the plant, important contributors to risk and change in risk were insufficiently secured. They have not sufficiently considered the need for compensatory measures to handle known plant impairments in combination with risks arising from planned activities in connection with stripping and inspection.

2. Insufficient information about risk and lack of communication: Risk connected to the work with stripping of the plant was not communicated to the operators. For example, which precautions the operators should take due to the plants weakened conditions was not communicated to them.
3. The plant has not been proper maintained: The long-term planning and prioritization of the maintenance work has been inadequate and does not reflect the prevalence and risk associated with corrosion under insulation. There are no operational or capacity restrictions to prevent the maintenance work, so it seems that the knowledge regarding the risk connected with poor maintenance are not communicated.

4.1.5 Personal injury caused by H_2S exposure, 12.10.16

Incident description

In the afternoon, October 12th, five people went to blow air into the bottom of the H_2S reactor at Sture. Two internship students from a secondary school participated in the work. Sludge had built up in the reactor over time causing operational problems (Ellingsen, 2016).

The operators opened valves to allow air to enter the reactor and walked up the tank ladder to inspect the top of the reactor. When they came up, they noticed that it was uncomfortable and difficult to breathe. Within a short time three people lost consciousness. The other two managed to get down from the tank and shut off the air supply (Ellingsen, 2016).

Emergency response (Line 1) was notified and life-saving first aid was performed. Four people managed to get down from the reactor on their own. One person had to be lifted on a stretcher by crane (Ellingsen, 2016).

Report analysis

A thorough report has been carried out and the investigation goes in depth of the incident through a short summary, background information and a detailed course of event. Further it is discussed in detail the deviations from requirements and procedure. Barrier elements that failed and worked are identified, as well as direct and underlying causes through an HTO-analysis. In the end an assessment of the potential of the incident are carried out and areas that need to be improved are recommended. The most important human and organizational factors from the report includes:

1. Lack of risk assessment prior to operation: The risk potential associated with the H_2S reactor was not identified and documented during installation in 1994. This has led to knowledge gaps in the organization related to the H_2S reactor.
2. Inadequate labelling of hazards associated with H_2S: There has not been executed an HAZOP or similar to identify risk. Because the hazards connected to the H_2S reactor were not identified and documented in design phase it contributed to inadequate follow up of the barrier state.
3. Lack of detection of H_2S gas: There were shown through the investigation that the personnel did not use the portable H_2S-meter, and the routine for the use of this H_2S-meter varied. A portable gas measurement would notify personnel if the value were too high. On the day of the incident it was reported that there were missing portable H_2S-meters and therefore the personnel chose to go without.
4. Personnel protection was not used: Operators did not use respiratory protection and escape masks were not used in the facility.
5. Insufficient competence and being understaffed with respect to the workload: Normally there are three outdoor operators at Sture, but that afternoon there was only one. This combined with the insufficient information exchange during shift handover and lack of planning of the work led to the risk not being identified.

4.1.6 Gas leak in Statpipe reception area, 07.01.16

Incident description

During normal operation on January 7th a gas leak was detected in Statpipe reception area on Karstø. Multiple alarms went off and that initiated automatic disconnecting of ignition sources for Statpipe and Sleipner. In total five gas detectors gave high alarm while the leak took place. Emergency close off were implemented manually from CAP panel in the control room. In addition, the panel leader in cooperation with the shift leader decided to conduct a controlled descent of the process trains T-100 and T-200. The pressure dropped due to the leak, and personnel decided to send one person to go in the facility to manually open the valve against flare. This led to the pressure to drop faster. The initial rate of the leak is estimated to be 1.3 kg/s and duration of 9.5 hours with the amount of around 22 ton (Sande, 2016).

The leakage occurred due to a duplex fatigue failure in the connection to the male adapter. The fatigue failure is due to inadequate mechanical bias in combination with the systems natural frequencies coinciding with vortex release frequencies in normal wind speeds (Sande, 2016).

Report analysis

The reporting of the sequence of events indicates technical factors to be of great importance to the incident. Even though the sequence of event immediately seems to address the technical aspect, there are a few references to the human factor. The chronological, detailed review of the sequence of event gives a relatively good picture of the context between different factors and their contribution to the incident. The following shows the organizational and human factors in this report analysis:

1. Lack of learning and communication: They have not made sure there has been adequate learning and improvement after several registered similar incident. Several incidents have occurred across the company that could have given them the basis for learning and integrity assessment of the facility.

4.1.7 Hydrocarbon leak from a process module, 18.02.15

Incident description

On the early morning of February 18th personnel in the control room on Gudrun registered strong vibration. This ceased after about a minute without any cause being identified. At 06.23 the same morning gas was detected in the M30 process module on Gudrun. A general alarm was automatically activated, and the plant was automatically shut down and depressurised. Within a few minutes, gas had spread to most of the M30 module. All personnel mustered pursuant to the alarm instructions and were accounted for in the space of 11 minutes on Gudrun and 16 on West Epsilon (Wiger, 2015).

The direct cause of the incident was a leak from a rupture in a two-inch pipe in the bypass line for the ESD valve on the liquid outlet from the first-stage separator as a result of powerful vibration in the liquid piping system downstream of this separator. Statoil estimated the initial leak rate at 8 kg/s, and condensate from the first-stage separator leaked to open air. The total emission/discharge is estimated at 2800 kg/4 m^3 of condensate, and more than 1 m^3 is estimated to have been discharged to the sea (Wiger, 2015).

Report analysis

The report appears to have been thoroughly prepared. Reporting of the sequence of events shows a serious incident that could have evolved into a major accident. It also indicates that almost all triggering and underlying causes, as well as weaknesses or failures observed with barrier elements, are related to organizational factors. The report is thorough with detailed analysis of the sequence of events, assessment of consequences, risk factors, potential and actual consequences, as well as a review of relevant documentation. The most important conditions are as follows:

1. Deficiencies in information management and expertise: The information required to maintain the plant in an acceptable condition was not communicated and processed so that adequate measures could be taken. Important contributors to risk were not identified.
2. Inadequate information at shift and crew changes: The instruction on continuous monitoring until the replacement in March was not clearly conveyed at the next shift change. The personnel present at the incident were not aware of the need to monitor the valve.
3. Weakness in information transfer and learning: The last breach shows that the communication both internally in Statoil and between Statoil and the sub-contractors were insufficient. During the building phase, important operation experiences were not passed along from Statoil to the contractors as a base for design. Statoil has good knowledge about vibration and the risk of fatigue in systems.
4. Weakness in Statoil's exercise of its responsibility: The valve was not suited to the loads it would be exposed to.
5. Lack of understanding and compliance for risk factors: During the operational phase, knowledge about failure in regulation valves or risk associated with vibration were not forwarded and used by relevant personnel responsible for technical integrity.

4.1.8 Hydrocarbon leak from an isolation valve, 26.01.14

Incident description

On Sunday January 26th a hydrocarbon leak occurred at Statfjord C. When the incident occurred, they were about to transfer stabilised oil from Statfjord A to Statfjord C. At the same time, preparation for maintenance of a load pump in the shaft took place. An isolation valve to the load pump was not airtight, which resulted in oil filling up the pump house. The valve for regulation of the level on the tank did not open, and there was a leak of oil on the basement deck. The transfer of stabilised oil from Statfjord A was stopped at the same time the shut-down of the process facility happened. The emergency preparedness organization mobilised, and remaining personnel evacuated to the lifeboats. No personnel were reported injured during this incident (Lauridsen, 2014).

Report analysis

In connection to the investigation there is conducted an HTO-analysis, where they have identified barriers that have failed, as well as the direct and underlying causes to the incident. The sequence of event is chronological described in great detail. When considering the direct and underlying causes, they have emphasized human, technical, operational and organizational factors in a barrier perspective. The following shows the organizational and human factors in this report analysis:

1. <u>Inadequate planning, execution, testing and monitoring of the work</u>: Isolation of load pump A was not executed in a way that took care of the internal requirements and secured properly implementation of the work.
2. <u>Lack of knowledge</u>: Statoil has not made sure that the personnel have adequate knowledge to preparation and setting of the isolation plan. Personnel with a central role in preparation and implementation of the isolation plan lacked mandatory courses in valve technique.
3. <u>Inadequate management of simultaneous activities</u>: It was not considered which consequences the transfer of oil could have while load pump A was isolated for maintenance.
4. <u>Inadequate qualification and follow up of competence</u>: Operators executing the maintenance on Fire Seals had inadequate mechanical expertise.

4.1.9 Hydrocarbon leak in process facility, 05.01.14

Incident description

During normal operations on January 5th, a sudden hydrocarbon leak occurred on Equinor's facility Hammerfest LNG Melkøya. The initial alarms vent off at 09:20 PM, and the area was declared gas free at 10:13 PM. The actual consequences of the leak were no personnel injuries and no material damage. The production was shut down for three days after the incident. It was hard to establish an accurate leak rate and amount, but simulations showed that the leak rate was in the area of 0,1-0,3 kg/s, and that the amount was in the area of 250-750 kg. PSA assumes the leak had no effect on the environment (Thorsen A. J., 2014).

Report analysis

An incident report was conducted by the PSA. The report covers the incident with a summary and a more detailed description of the incident, with a timeline lasting for 5 hours. Also included in the report is both actual and potential consequences, as well as deviations and suggestions to improvements. The root causes for the incident were not discovered, but the leak happened because of wear on a gasket connected to the stuffing box. Barriers that worked are mentioned. All things considered, the PSA has concluded the leak occurred due to a technical element that failed, and the actions taken when the leak started was performed correctly. The only thing they mentioned as a deviation was the time it took from detection of gas too depressurization started, which was approximately 25 minutes. There are, however, some important points mentioned in the report:

1) Understanding of risk: When the operator discovered the leak, he immediately told the control room about it, and was told to evacuate the area. Instead, the operator chose to walk around the area for some time, before evacuating to the administration building. By doing so, the operator was unnecessary exposed to a potential explosion and fire hazard longer than he had to be.
2) Establishment of coordination point (CO): The response team chose to establish CO near the point of leakage. This does not reflect the tasks that the team should perform. During the situation, no personnel were missing or injured, and the only personnel within the facility were the eight people within the response team.

4.1.10 Hydrocarbon leak during gas injection to well, 17.06.13

Incident description

Early in the morning on June 17th there was a hydrocarbon leak at the Oseberg A platform. Well B-45 was producing to a test separator, while gas injection was performed on well B-41. The two wells are tandem wells, which means that they are connected to the same plug and valve on both test and production manifold. Slugging from well B-45 caused the test manifold to shut down because of high pressure. The gas injection operation was not adequately isolated from the test manifold, which led to the manifold being pushed up further by the injection system. Statoil has estimated an initial leak rate of 0,1 kg/s, and that 85 kg of gas and 15 liter of oil leaked out. The actual consequences of the incident were leaking of process fluid and material damage to a 90-degree bend (Lauridsen, 2013).

Report analysis

The PSA conducted a report on the incident. The report covers the incident in detail, and includes a timeline lasting for just over 2 hours. The report discusses the actual and potential consequences and looks into deviations and improvements. The root cause for the incident was concluded to be sand within the gas stream hitting a 90-degree bend at high speed. This resulted in sand erosion, which in the end eroded a hole in the bend where gas and oil leaked out. The main reason this happened was that the facility had not been verified to handle the production of sand, and over time this resulted in a gas leak. The PSA list a number of deviations in the report, and some of the most important are:

1. <u>Lack of risk assessment:</u> During the investigation, PSA learned that during previous gas injection operations, it was necessary to connect to the wells via the kill line on the valve tree. This is a method described in Equinor's System and Operations manual (SO). Later, the method was changed so that the pressure equalization and pressure relief system is used. The amount of work is reduced with this method, because it does not require extra connections to the valve tree. The method is not described in the SO, and it is not documented that a risk assessment has been conducted to ensure the system would work during gas injection.
2. <u>Inadequate work processes:</u> Through interviews with personnel and review of documents, PSA discovered that there are not established or updated work processes for the following operations:
    - Use of pressure equalization and pressure relief system during gas injection

- Start of well in low pressure mode after shut-down
- Bleeding of pressure on test manifold
- How to handle slugging
- Bullheading of tandem well

Several of these are performed during normal operations and have been conducted over several years without procedures being established or updated.

3. Lack of inspection: Inspection of the pressure relief line from test manifold is not conducted, including the 90-degree bend, which was eroded through. However, the pressure relief valve up stream of the bend is tested frequently. Equinor informed PSA that the line had been used about 40 times the last year. In other words, the line is used often, but there has not been evaluated if there is a need for change in the inspection program nor has it been performed analyses connected to the pressure relief valve being used as a bleed valve.

4.1.11 Hydrocarbon leak during testing of ESDV, 26.05.12

Incident description

At 12:41 PM, during testing of two emergency shut down valves, a hydrocarbon leak occurred on Equinor's platform Heimdal. Preparations to the test involved depressurization of a pipeline against flare. This pipeline consisted of a control valve with a pressure class of 180 bar, and three manual valves, where the last valve was designed for 16 bars. The last manual valve was in closed position, and when the depressurization was initiated, the valve was exposed to 129 bars. This led to the gasket, isolation material and enclosure around the flange was blown off. The production operator alerted the control room, which closed the control valve. This took 4 minutes, and the leak stopped at 12:45 PM. Gas was present in the area about 30 minutes after the leak was stopped. Equinor has calculated that over a period of 252 seconds, the initial leak rate was 16,9 kg/s, and the amount was 3500 kg of gas. Actual consequence of the incident, apart from the leak, was operator exposed to gas and material damage to manual valve (Sandvik, 2012).

Report analysis

The PSA conducted an investigation and made a report of the incident. The report covers the incident in detail and has a timeline of about 4 hours. The report covers actual and potential consequences, triggering and underlying causes, as well as deviations and suggestions to improvements. The direct reason for this incident was that a valve designed for 16 bar, were exposed to a pressure of 129 bar while being in the closed position. The high pressure exerted on the valve then blew off the gasket, isolation material and the enclosure around the flange. PSA listed a number of deviations in their report, and the most important human and organizational factors were:

1. Understanding of risk: Through analyses, operations and maintenance, Equinor has not discovered that the design of the system has flaws which makes it not suited to this kind of testing. Risk connected to change in operating of the pipeline has not been identified or evaluated.
2. Job description: The level of detail in the job description was not adequate. The procedures were not unambiguous and user friendly. According to plan, testing of the two ESDVs was to be done once every year. Because the line rarely was used, last in 2004, PSA discovered that location and design of the pipeline were to a limited extent known by the personnel on board.
3. Communication and information sharing: It have not been done enough to ensure incidents in the past was documented, and that information from these were shared to make sure everyone was aware of how often leaks occurred on Heimdal. The information was also not used as a tool to learn how to handle incidents in the future.
4. Understanding of risk: Equinor had not ensured that both onshore and offshore personnel had the necessary competence and understanding of risk to be able to do their work in a safe way.

4.1.12 Gas leak after maintenance on production well, 04.12.10

Incident description

After maintenance on a throttle valve connected to a production well, an incident involving leaking of gas occurred on Equinor's platform Gullfaks B. It happened during a planned test to check for leaks. The leak rate was estimated to be 1,3 kg/s, and the amount of leaked gas was approximately 800 kg. The leak lasted for about 1 hour, because the emergency shut down system was not working at the time. Normally, this test was conducted using a diesel pump to pressurize the pipe system. In this case, the pump was unavailable, and it was decided to use injection water from another well as a pressure source. Because of this, it was necessary to open a wing valve to make sure the water would reach both the production pipe and the throttle valve. Then the main valve was closed, and both the wing valve and a hydraulic valve were opened. This led to gas streaming by the main valve, which was not properly closed, and the leak happened. The leak could have been over after just 1-2 minutes, but because the emergency system was out of order, it lasted for 1 hour. Actual consequences besides the leak were one technician exposed to hydrocarbon gas, and it is estimated that 48 m^3 Arctic Foam and 25 liter oil spilled to the sea (Laruidsen, 2011).

Report analysis

The PSA has conducted a report on the incident, including detailed description of both actions taken before the incident, and what personnel were doing just before the leak started. Included in the report are also actual and potential consequences, and the identified deviations leading to the incident. The PSA also includes their suggestions to improvements that could help avoid such incidents in the future. The main points from the report regarding human and organizational factors are:

1. Planning of work: The isolation plan used is a central part of the basis for safety while working on a pressurized system. It was found that several of the documents included in the plan was not used and lacked a signature of approval. PSA means this indicates a lack of understanding and competence connected to the requirements when working with a pressurized system.
2. Evaluation of risk: Risk related to build-up of pressure during planning and execution of the test was not identified or evaluated.
3. Barrier strategy: On Gullfaks B, there is not established specific strategies or principles for the design of barriers. Through interviews with personnel onshore, PSA discovered that none of them knew of any specific barrier strategy or performance requirements for barriers on Gullfaks B.

4.1.13 LPG leak after drilling hole in pipeline, 08.02.10

Incident description

In conjunction with isolation of pipelines an incident occurred at Equinor's onshore facility, Mongstad. One isolator was using an electric drill to drill holes through a couple of plates used as an enclosure for the isolation. While doing this, the isolator also drilled straight through the pipeline. This created a 3,3 mm hole in the pipeline, where gas leaked out. There were no personnel damage during the incident, and only the damaged pipeline was considered as material damage. The leak rate was calculated to be 0,08 kg/s, and it lasted for 72 minutes. The total amount of gas that leaked out was estimated to be approximately 300 kg. The PSA assumed it made no damage to the environment (Thorsen A. J., 2010).

Report analysis

The PSA travelled to Mongstad the same day of the incident and conducted an investigation the following day. The report they made describes the chain of events in detail. Included in the report are the actual and potential consequences, as well as deviations and suggestions to improvements. They found three important points regarding both human and organizational factors, and they were:

1. Risk assessment: It was not conducted any form of risk assessment in the planning of the isolation job. There was no consideration given to the risk of using a powerful electric drill around pressurized equipment.
2. Understanding of risk and competence: It was not ensured that executing personnel had adequate competence and understanding of risk in order to do their job safely. None of Kaefer, Statoil or the isolators identified any risk of using a drill while the pipeline was pressurized.
3. Communication: At the Mongstad facility, there are requirements to be fluent in the Scandinavian or English language. Kaefer are the company who verifies if the foreign personnel have good enough knowledge of the English language to be able to communicate and make them understood at the facility. During interviews, it was discovered that the language skills varied greatly. This could affect both work environment and safety at the work place.

4.1.14 Condensate leak during normal operations, 19.05.09

Incident description

During normal operations, at approximately 13:30 PM, an incident occurred at Equinor's onshore facility Kollsnes. The main reason for the leak was loose bolts in the flange connection to a valve. The bolt used on the opposite flange was measured to have too little torque, with values between 80-100 Nm. It was assumed same values for the bolts on the flange where the leak occurred. Proper values for tightening of bolts were approximately 300 Nm. This resulted in the gasket breaking because of the pressure, and condensate leaked out. The leak rate was estimated to 22 kg/s, and the total amount to 12 tons. The consequences from the incident were no personnel injury, very limited material damage and stop in production for three days. There was also nothing that leaked into the sea, the majority of the condensate evaporated to air (Kalberg, 2009).

Report analysis

The PSA conducted an investigation on the incident and made a detailed report. The report includes description of the Kollsnes facility, and details about the chain of events from the point of the incident and to the danger was declared over. They also mention they are generally satisfied with how the incident was handled. Both evacuation and foaming of the incident area where the leak occurred worked according to plan. The main points regarding human and organizational factors were:

1. Governing documents: Torque for tightening of bolts is given in Equinor's documents for this kind of work. The procedure describes valve mounting, torque et cetera which has not been followed.
2. Responsibility: On two occasions, once from sub-contractor and once from Equinor, it is confirmed that the system, including the valve, is ready to hand over. In both cases there is a lack of verification of tightening of bolts on the flanges connected to the valve.
3. Procedure: Equinor has not followed up its own management system to ensure compliance with the requirements given in governing documents.

4.1.15 Hydrocarbon leak during maintenance, 12.09.08

Incident description

During maintenance on a valve an incident occurred on the offshore platform Oseberg C. The triggering cause for the incident was sudden and unintentional opening of a test manifold valve towards depressurized test manifold. The pressure shock tore off a 2-inch pressure equalization pipeline between test and production manifold which created a 2-inch hole in the production manifold. The leak rate has been calculated to 26 kg/s, with an amount of 1500 kg. There were no personnel injuries and small material damage (Thorsen A. J., 2008).

Report analysis

The PSA conducted an investigation into the incident and made a report. The report covers the incident in detail, and takes a look at both root and direct causes for the incident to happen. They also discuss the actual and potential consequences and look at some of the deviations that occurred. They do not, however, mention any suggestions to improvements. The main human and organizational factors were:

1. Competence and experience: Between the personnel working with hydraulic systems on Oseberg C, there was a clear lack of competence and experience. During interviews it was discovered the personnel had not received additional education or courses in hydraulics.
2. Risk assessment: There was not conducted any risk assessment working with a valve with 70 bar differential pressure. This shows there is a clear lack of understanding of risk.
3. Procedures: There were no work procedures available for the job that was to be executed. Both for working on hydraulic systems and on valves with differential pressure there were no specific work procedures on how to do the job.

4.1.16 Hydrocarbon leak in gear shaft, 24.05.08

Incident description

During a 14-day work period in May, there were four elbow bends that were to be isolated and cut, and then blinded off. After the cutting was done, a steel brush was prepared to clean the pipe on the inside. The two saw supports were slightly screwed out, because the personnel were of the impression the steel brush could damage them. During the cleaning process, one of the supports fell out of position, and created a hole leading to a large spill of oil. The actual consequences of the leak were spill of 156 m^3 oil, evaporation of hydrocarbon gas and personnel exposed to both oil spill and gas. There was not registered any personnel injury because of this. It was also estimated that about 70 m^3 of oil spilled into the sea (Etterlid, 2008).

Report analysis

The PSA started an investigation into the incident and wrote a report. The report covers background information on the gear shaft at Statfjord A, chain of events, actual and potential consequences, as well as deviations and suggestions to improvements. The report also includes the direct and root causes for the incident to take place. The main human and organizational factors were:

1. Project management: The operation was not executed in a way that meets requirements to management. Roles and responsibility between involved personnel were not clear.
2. Risk assessment: Prior to the job, there was not conducted any risk assessment. Measures to limit or stop such a leak were also not considered.
3. Knowledge: No routines have been established to ensure personnel who performed the job have sufficient knowledge of current procedures relevant to the operation.
4. Competence: Equinor has not ensured involved personnel have process safety competence and adequate risk understanding to maintain safe operation and maintenance.

5 Analysis and evaluation

This chapter describes and presents the findings from the investigation reports and questionnaire, which was conducted to answer the research questions. It also discusses safety measures to improve human factors.

5.1 Investigation reports

This section gives a short review of the 16 selected reports and look at them across of each other. Then the categories of human and organizational factors and measures that have been the main focus of the reports are summarized.

5.1.1 Review of the selected investigation reports

The reports in chapter 4 are considered to be representative with regards to the thesis main focus, human factors, and are listed in Table 3. All incidents are hydrocarbon leakages that happened either offshore or onshore. They were all incidents with a potential to lead to a more catastrophic accident, but there were not any incidents resulting in fatality. However, there were one accident that just by luck ended in only personal injury and not fatality (see section 4.1.5).

Most of the reports appear to have been thoroughly prepared, but often with a main focus on technical factors. This was also the case even though human and organizational factors had great importance to the cause of the accident. The description for the sequence of event and level of detail are varying, especially with regards to human, organizational and operational factors (HTO).

Independent on how in depth the investigations of the incidents are executed, direct and underlying causes are identified, and barrier elements that failed and worked are also identified. What varies is how the human and organizational factors are identified as the cause or part of the underlying cause for the incident. In some reports an HTO-analysis are conducted, but mostly this is not done. The reports give a good basis for theoretical and model based assessment around technical and some organizational factors, and suggested actions found in the investigation reports.

Following is a list over selected reports:

Table 3 - Incidents selected to better understand human factors relation to accidents.

Report no.	Incident	Date
4.1.1	LNG leak from tanker truck during filling	17.06.18
4.1.2	Naphtha leak on cracker plant	24.10.17
4.1.3	Hydrocarbon leak on template S	10.03.17
4.1.4	Gas leak in connection with maintenance	25.10.16
4.1.5	Personal injury caused by H_2S exposure	12.10.16
4.1.6	Gas leak in Statpipe reception area	07.01.16
4.1.7	Hydrocarbon leak from a process module	18.02.15
4.1.8	Hydrocarbon leak from an isolation valve	16.01.14
4.1.9	Hydrocarbon leak in process facility	05.01.14
4.1.10	Hydrocarbon leak during gas injection to well	17.06.13
4.1.11	Hydrocarbon leak during testing of ESDV	26.05.12
4.1.12	Gas leak after maintenance on production well	04.12.10
4.1.13	LPG leak after drilling hole in pipeline	08.02.10
4.1.14	Condensate leak during normal operations	19.05.09
4.1.15	Hydrocarbon leak during maintenance	12.09.08
4.1.16	Hydrocarbon leak in gear shift	24.05.08

Analysis of the report for these 16 incidents are found in chapter 4.

5.1.2 Common features of human and organizational factors

When reviewing the 16 reports, there were a number of common features of human and organizational factors that were identified as well as their recommended measures. The factors, which often are mentioned in the reports, can be categorised as follows:

- Competence, experience and knowledge
- Procedure and governing documents
- Understanding and compliance of safety and risk assessment
- Communication
- Maintenance
- Work routines and habits
- Responsibility, role and leadership
- Barrier management

Categories that have been chosen for the human and organizational factors in each report are subjective. They are not based on rules or any other information than what the PSA discovered during their investigations and wrote in the reports. While reading the reports, each factor has been evaluated solely on the description of errors and contributing factors. Below is the result from categorising the factors.

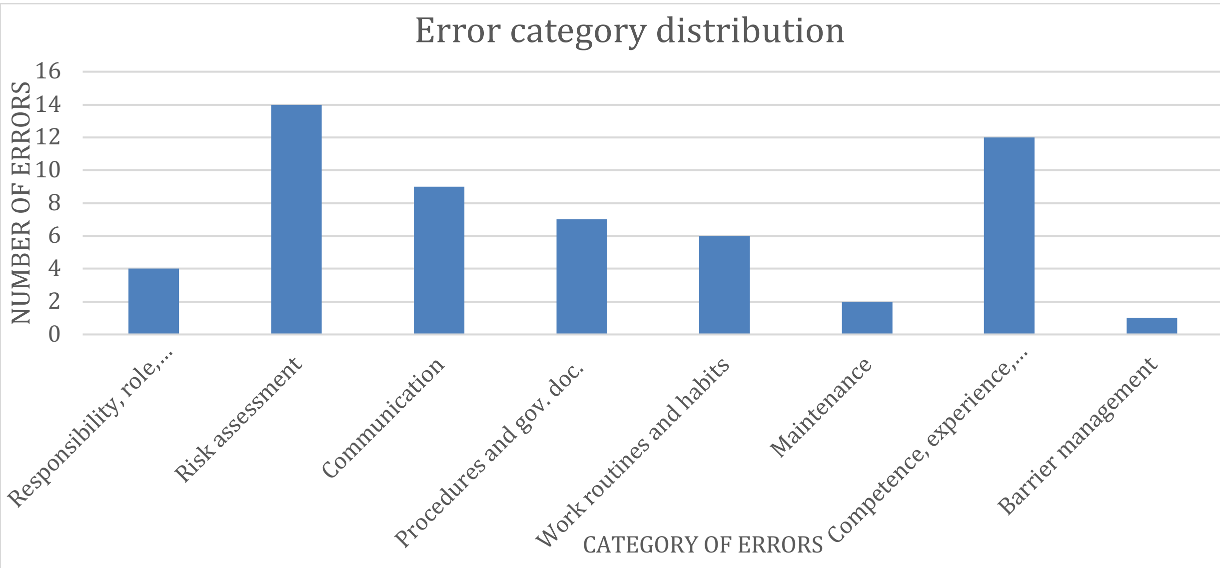

Figure 7 – A subjective view of errors from accidents within Equinor

In chapter 4 a total of 55 different factors have been categorized. From the graph, it is clear to see there are some categories that differ more from the other. Both the bar for risk assessment and competence, experience and knowledge scores high compared to the other bars. Even though the bars are separated in the graph, it is important to understand that the categories also blend into each other. For instance, lack of risk assessment and general understanding of risk does not solely mean personnel know they should perform risk assessments, but just do not bother to do it. It could be they do not have the right competence or experience on the subject, or that the procedures and governing documents do not explain the importance or approach adequately enough.

Competence, experience and knowledge

When analysing the incidents there were a few common features when it comes to personnel competence, experience and knowledge, and these are training in work processes and procedures, knowledge to equipment, knowledge about the associated risks and experience transfer. In many of the reports lack of competence and experience are categorised, and in most of the cases it emerges that necessary training is not executed. In some cases, no routines have been established to ensure personnel who perform work have sufficient knowledge of current procedures relevant to the work. This has occurred on multiple occasions and are outlined in some reports, see chapter 4. When this has occurred, on multiple occasions on different facilities, one can come to the conclusion that this is more than just lack of competence and experience on an individual level. These factors are to blame on an organizational plan, more specific lack of leadership.

In some cases, it is hard to distinguish between when it is on an individual level or on an organizational level since each individual has a certain responsibility to know their own tasks and make sure they have the necessary knowledge. But when this is said, it is the organizations main responsibility to facilitate good routines for capacity building and training, and good routines for experience transfer. For example, it emerged though investigation of a LNG leak from a tanker truck in 2018 that Equinor had not followed up that Barents Naturgass drivers met the requirements for material and competence, see section 4.1.1. They had not carried out follow-up beyond ensuring the drivers had a valid HMS24 course and a valid admission course. Equinor is a complex company and are daily working with challenging work tasks and cooperating with other companies. Therefore, one need to recognize the importance of competent personnel if one wants to avoid or minimize human and organizational errors.

Some of the measures recommended in the reports are not specific enough in regard to the competence to the personnel, and how the training to build up the competence is to be executed. Since the measures are not specific enough it is hard for the company to address the issues and how to get them implemented.

Procedure and governing documents

From the reports analysed the reports uses expressions as procedures are not been followed, no work procedures available or not sufficient knowledge to current governing documents. In some cases, following procedures could lead to extra challenges, if the procedure is designed in a way that makes the work process inconvenient or unclear. Again, it is possible to categorise these factors on an individual plan, however one can come to the conclusion that personnel do not want to break procedures but wish to execute them in a safe and secure way. As documented in the reports in section 4.1.1 and 4.1.3, one can see the importance of technical documents being updated, available and known to operation personnel. Relevant technical documentation for handling the incident was not available or sufficiently detailed and was as well not known to the personnel. Here the breach in the procedure is higher up in the hierarchy, at a point where the organization has not followed up on the operation.

Typical actions in this category are more concrete and are not as relevant for the human aspect that are in focus in this project. What is relevant is if the reason for why procedures are not being followed are because employees experience a pronounced expectation from management and the organization about effectiveness, and in some cases not using procedures can make the job go faster. This pressure for effectiveness may lead to human errors occurring.

Understanding and compliance of safety and risk assessment

The reports show there are important risk analysis and assessment that is not implemented and used, knowledge and compliance are lacking, as well as inadequate barriers. It varies from deficient risk analysis in the design phase to inadequate risk assessment in planning of work operations, and further to insufficient understanding of safety and risk where the operation is actually executed. Out of all of the reports analysed in this project there were only tree reports that did not have deficiencies in safety and risk assessment, see reports in section 4.1.6, 4.1.8 and 4.1.14. Reasons for human error are the insufficient understanding of the risk and the lack of identification of the associated risks. When the personnel lack knowledge regarding what they observe, the chance for an accident to occur is even higher.

Complex and safety critical operations will always depend on human actions, and people are the very basis for good decisions, safe operations and handling of nonconformities. Even though people make mistakes, people involved in these operations are still a source of security (Petroleumstilsynet, 2013). Thus, personnel's compliance and understanding of risks are central in restoring safe conditions at unforeseen events. When executing risk assessment, one should emphasise on human behaviour as a positive safety factor and take into account human abilities, limitations and needs.

Communication

Communication plays a big part between operators, both in a team and across teams. Lack of learning and communication especially when conditions have changed have several times led to human errors. Often operators have not used information from previous incidents to improve and learn. For example, the gas leak in Statpipe, section 4.1.6, there were several registered similar incident across the company that could have given the operators the basis for learning and integrity assessment of the facility. Or when there was a hydrocarbon leak from a process module in Gudrun, section 4.1.7, there were inadequate information at shift and crew changes. It is extremely important to communicate when there have been changes in the facility. This is easy to understand but very hard to control and conduct. A good way to avoid underlying causes for human and organizational errors is by training on how to communicate and to whom the information reaches.

Maintenance

There are a few cases of deficiencies in inspection and maintenance when reviewing the reports in this project, for example the Naphtha leak at Mongstad, section 4.1.2. Lack of routines, unfeasible interval and insufficient maintenance, are all factors in connection with the understanding of safety and risk, routines and with inadequate procedures. It seems the lack of maintenance is a result of operators not having the knowledge about the associated risk that comes with it, and this reflects on the organization not having a safety focus in general.

Work routines and habits

There are a few cases of faulty work routines and habits in the investigation reports, for instance, during the Naphtha leak on Mongstad, section 4.1.2. A logging system had been implemented and the purpose was to check different points in the cracker plant at fixed intervals. According to technical and operational regulations, paragraph 45, it is stated that procedures must be designed and used so they fulfill their intended functions. Even so, the procedures for the check rounds at Mongstad were different from person to person, and all checkpoints were not always implemented.

Another case involving work routines and habits is the one from Stureterminalen, section 4.1.5. This case shows that there are sometimes mitigating circumstances. During the accident at Sture, several experienced personnel were absent, while the one experienced field operator left had the responsibility for both an apprentice and two high school students with little to no experience. This clearly is a change in work routines for the experienced operator, which led to this person having too high a workload. However, when the accident happened, neither of the involved personnel was using any form of respiratory mask. It was not usual to bring escape masks when performing work on the reactor, which goes under the category of habits. The reactor was not equipped with gas detectors either. This has nothing to do with routines or habits but would have alarmed the personnel of the gas concentration.

In both of the cases above, the procedures at the workplace were not good enough. Either, because the procedures were not clear on how to perform the job, or they were hard to find or understand. This has led to a general acceptance that operators do the same job in different ways, and that procedures are not followed, as they should be. Because the routines were so heavily imbedded in the way the operators worked, this opened for the accidents to take place.

Responsibility, role and leadership

Whenever a job is being performed, independent of it is during normal operation or not, it is of great importance that the responsibility, roles of the personnel and the leadership is clearly defined. When people do not know who´s in charge, or what they are expected to do, accident and unwanted events have a greater chance of happening. In the 16 reports in chapter 4, there are at least 4 times confusion about responsibility, roles and leadership have played a part in the accident taking place. The reports are found in section 4.1.3, 4.1.7, 4.1.14 and 4.1.16, and involve personnel at different levels in the Equinor hierarchy.

The accidents show the importance of having clear, defined roles during operations. This could be during testing of valves before certain operations or signing of on documents stating a certain module is ready for operation, when they in fact are not ready. Both of these are mentioned in the reports and have contributed to the accidents taking place. Another accident points out that the job was not performed according to requirements, and that the responsibility between the involved personnel was not clear. When an accident happens, personnel have no one to turn to, which in turn leads to an escalation of the accident. If roles and responsibility are defined before executing a job, personnel know whom to turn to in case of an emergency, and they know what´s expected of them in such a case.

Barrier management

In all of the reports, there is an element of barrier management or strategy that has not worked according to plan. This can be for many reasons and includes all of the chapters above. Whether it is risk understanding, poor communication between personnel or competence and experience, there are barriers in place that have been breached.

There is, however, on case that sticks out. On Gullfaks B, section 4.1.12, it was discovered that personnel had no knowledge of any specific barrier strategy or performance requirements to the barriers on the platform. Barrier management is one of the most important tools to ensure the safety at the workplace. When not one of the involved personnel, both onshore and offshore, know of any strategy which is supposed to ensure their safety while performing their job, it is clear there is something very important missing in the organization. When personnel do not know of any strategy, they also do not know what function the barriers or barrier elements are supposed to safeguard.

5.1.3 Safety measures to improve human factors

After accidents there is an investigation into the causes and contributing factors. From analysing the investigation reports, many accidents involve human failures and very often little attempt is made to understand why the human failures occurred. However, recent investigations have a higher focus on human factors through HTO-analysis than before. Typical examples of immediate causes and contributing factors for human failures can be categorised into three categories: job factors, individual factors, and organizational and management factors. The most common factors from incidents investigated are discussed above, section 5.1.2. Figure 8 illustrates how holes in human factor barriers allow hazards to penetrate the system with the Swiss cheese model.

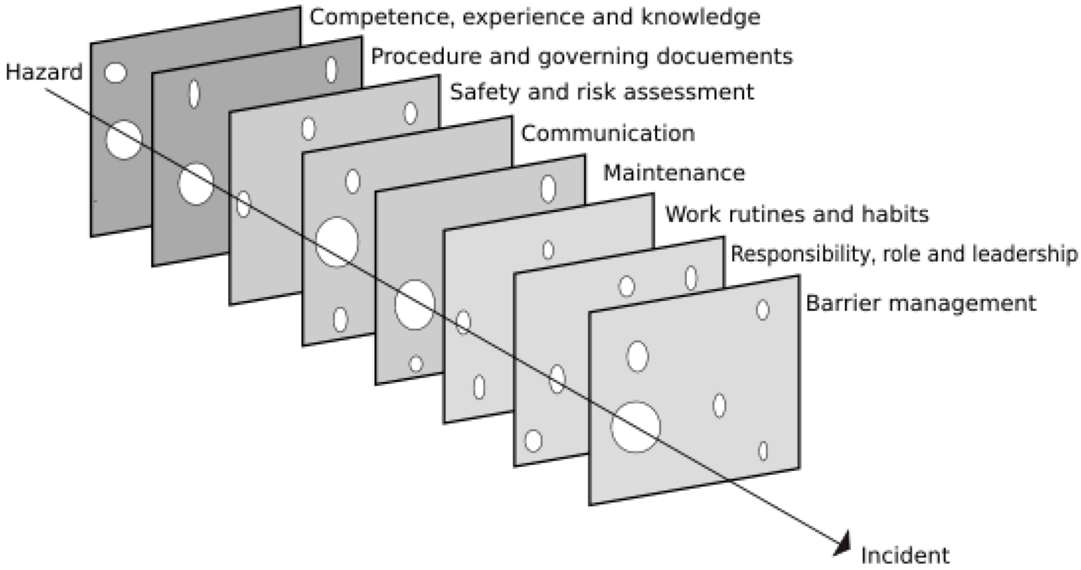

Figure 8 – Swiss cheese model for human factors found from analysing investigation reports

The discovery of these frequently absent human factors barriers provides important information on what to focus on when improving safety as well as productivity. By eliminating these common weaknesses, one could potentially affect the outcomes of future incidents. To improve risk management on site one should start with reducing the human failures (John, 2017).

5.2 Questionnaire

This section will show the results obtained from the questionnaire sent to Equinor. From the demographic of the respondents, information about gender, working place and role in Equinor was found. The distribution of gender was that 83.3% where male and 16.7% where female. The same goes for the working place for the personnel, where 83.3% works onshore and 16.7% works offshore. Half of the respondents said they had a managerial position. All of the respondents have some or very good knowledge about the term human factors, which gives them good basis to answer the questions later in the survey.

Further in the questionnaire the personnel were asked to choose different job, personal and organizational factors needing improvement to prevent human failure. Later, the questionnaire asks about different subjects and they are quality of procedures, how well training/courses/exercise gives necessary knowledge, ergonomically design of workplace and equipment and how well the information sharing is on the different levels in the organization. Then a question was given to rate four different factors that can have an influence on human performance. The factors were workload, working time arrangements, training/courses/exercises and competence. To finish the questionnaire, respondents were asked to give their thoughts and ideas on what could help improve safety and barrier management.

Figure 9 and Figure 10 shows the distribution of age group for the respondents and how long they have been working in Equinor.

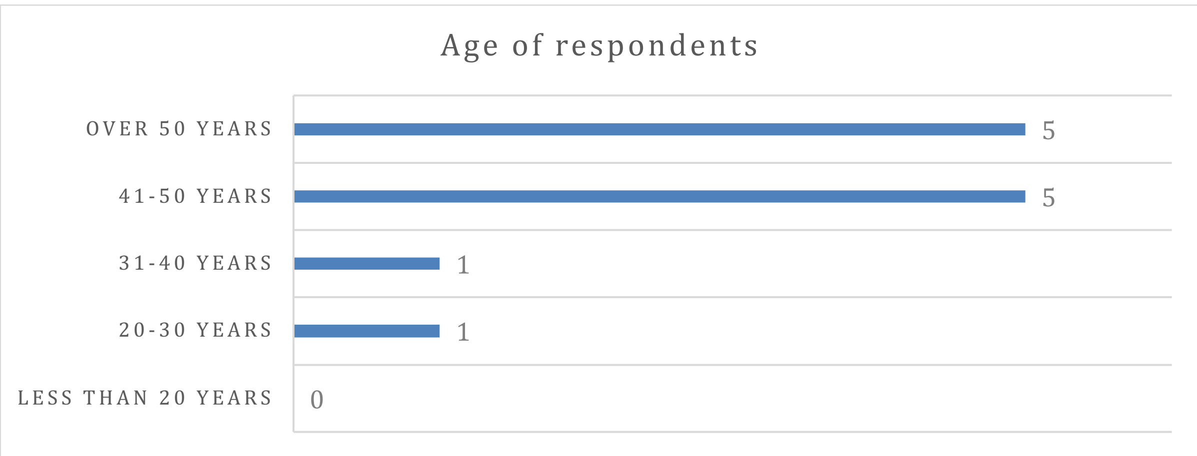

Figure 9 - Distribution of respondents in age groups

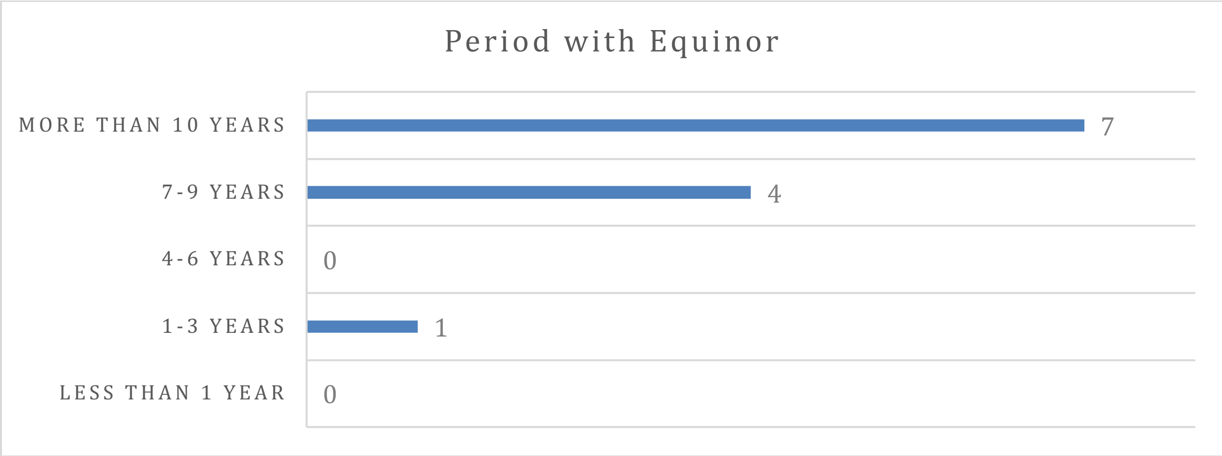

Figure 10 - Time respondents have been working for Equinor

The respondents were then asked to choose between job factors, which need improvement to help prevent human failure. The results from this are shown in Figure 11. The four categories that was chosen the most were clarity of signals, sign, instructions and other information, interaction between system/equipment and operator, preparation of tasks including permits, risk assessments et cetera and communication with colleagues, managers and others. Nobody thinks difficulty of tasks should be improved. This could be because most of the respondents have been working for a long time and have gained much experience and competence related to their job tasks.

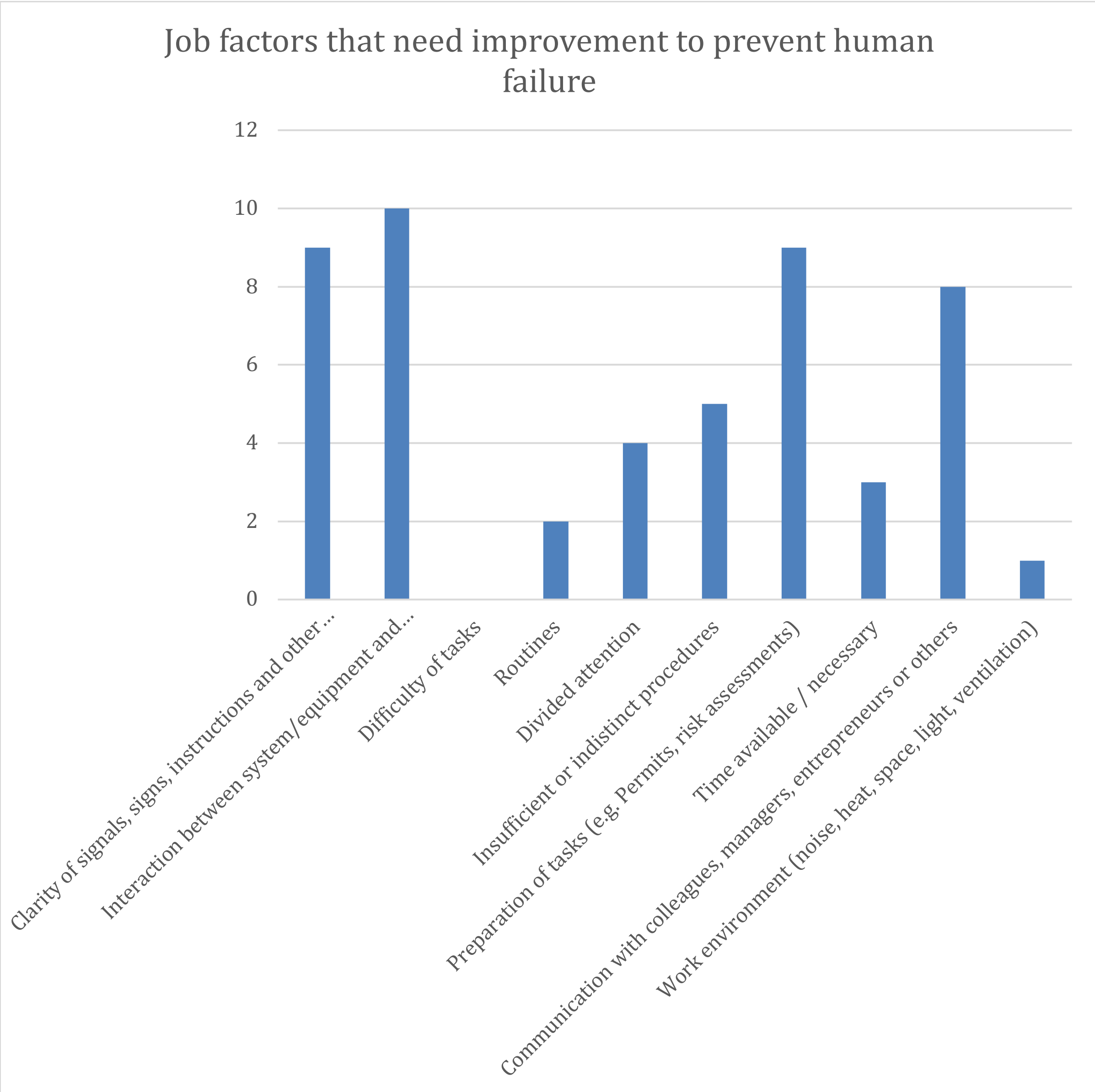

Figure 11 - Selection of job factors from respondents

The next question was similar, just with personal factors. One can clearly see that competence and motivation are the two factors the respondents consider need to be most improved to be able to prevent human failure. Aside from these two factors, the numbers are evenly divided between the other four factors. Figure 12 shows that most of the respondents agrees that competence and motivation are highly important in prevention of human failure.

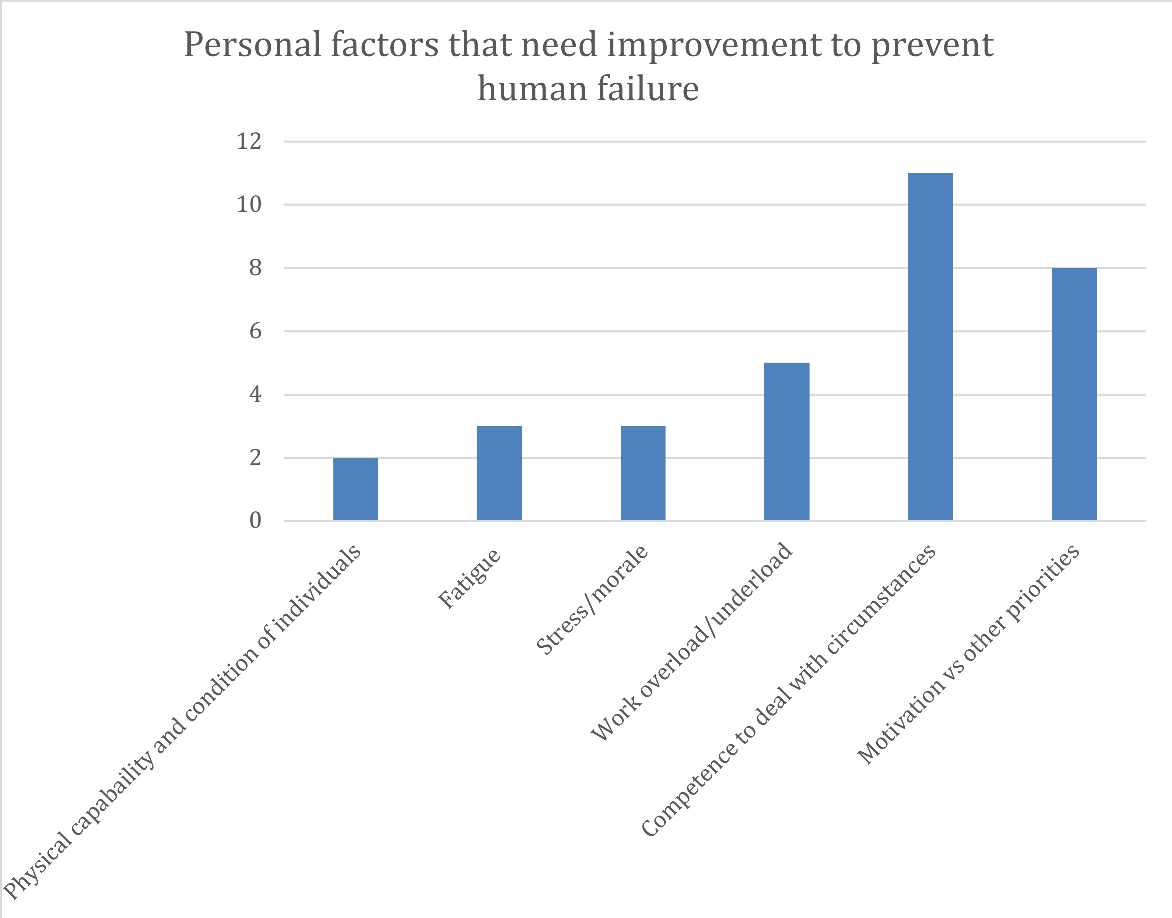

Figure 12 - Selection of personal factors from respondents

Figure 13 is in the same category as Figure 11 and Figure 12, but with focus on organizational factors. Here, the three factors standing out are communication and information sharing, clarity of roles and responsibility and the effect of organizational learning such as courses, training and exercises. The numbers are evenly divided between the remaining factors. Interestingly one person has said peer pressure is a factor that needs to be improved.

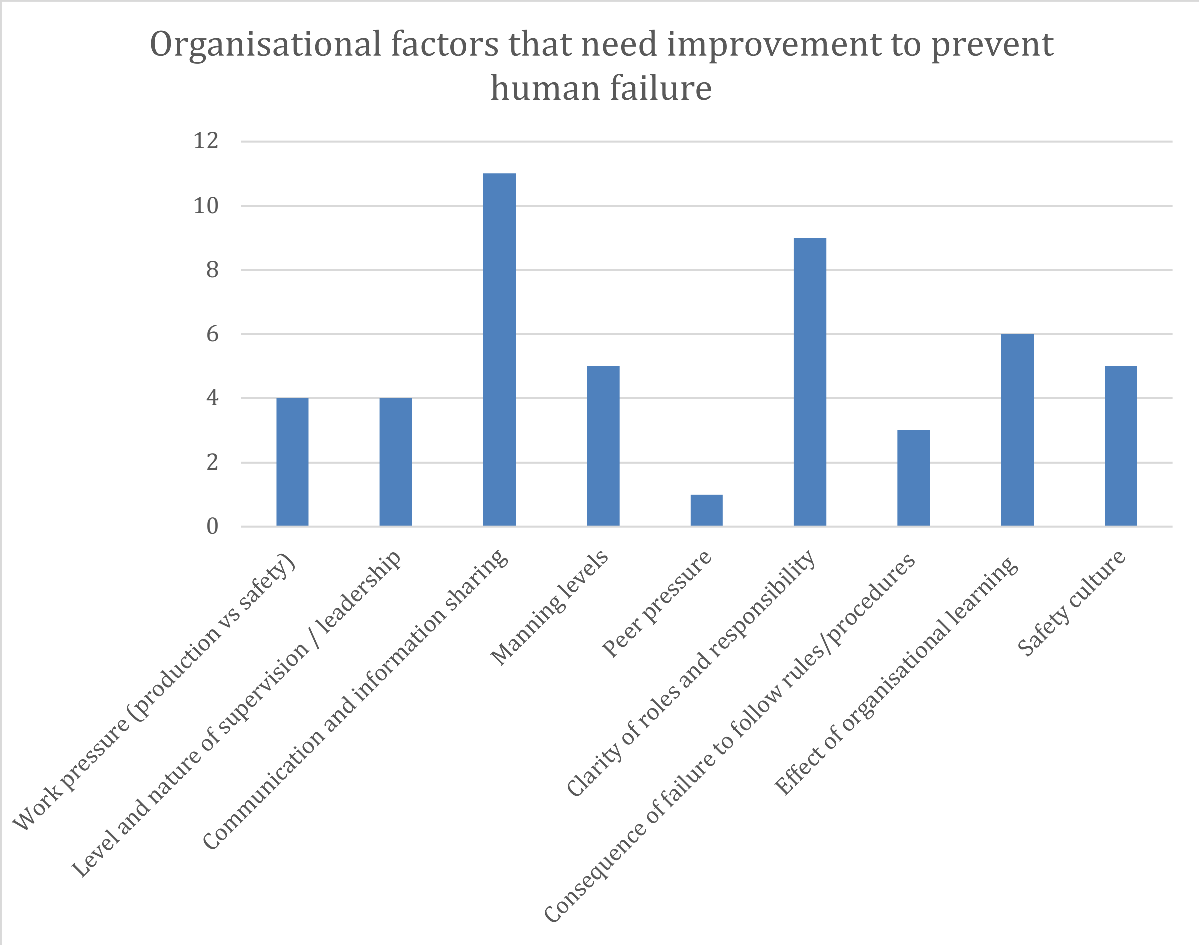

Figure 13 - Selection of organizational factors from respondents

In Figure 14, one can see that for question 1, 3 and 4 the respondents more or less agree, but they also disagree on question 2 and 5. 67 % of the respondents think operators don't follow the given procedures, but 83 % mean operators know where to find the procedures. Because there only are twelve respondents to the survey, it is difficult to see a clear tendency in the questions were the answers are very varying on both the positive and negative side. This is also the reason for the high percentage values when most of the respondents agree.

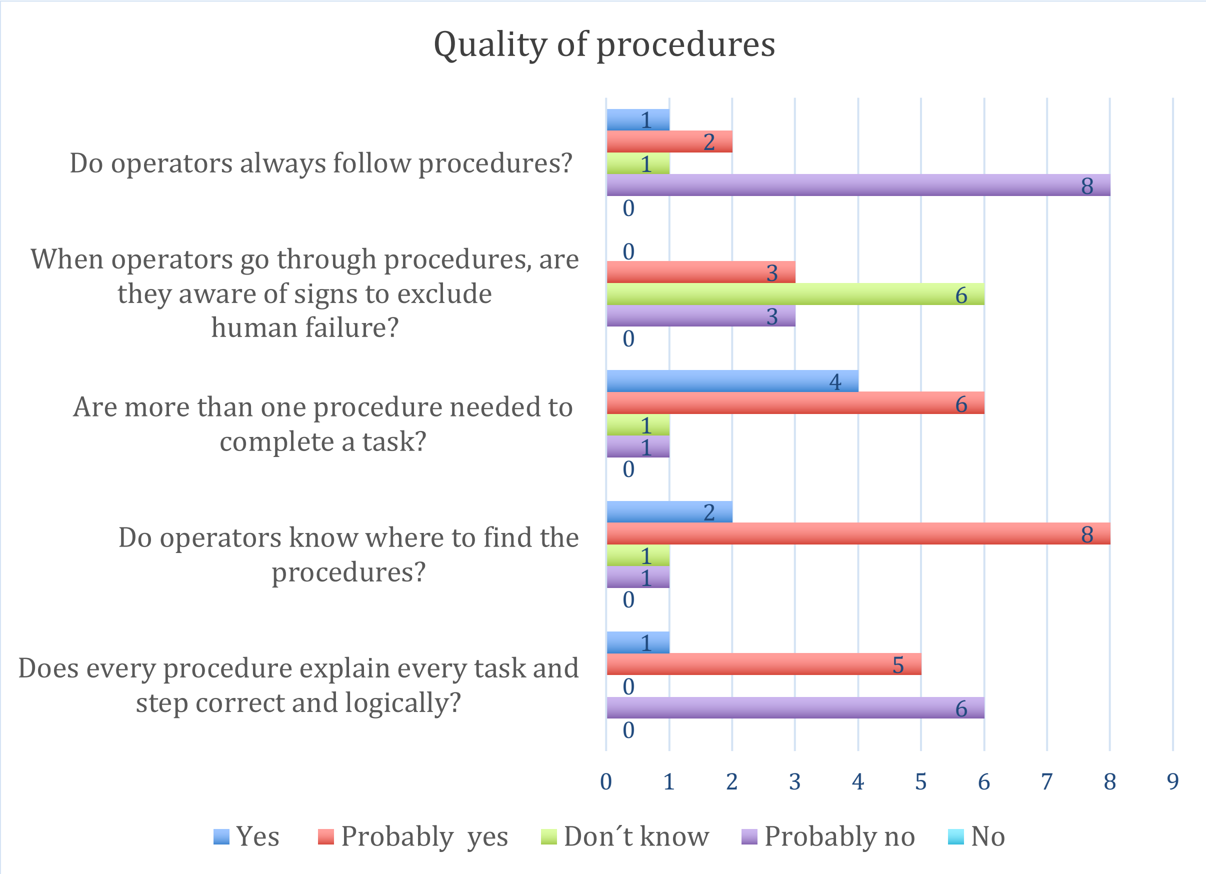

Figure 14 - Different questions regarding quality of procedures

Figure 15 shows that the respondents agree on most of the questions related to courses, training and exercises and their influence on knowledge. The exception is question 4, where the numbers are more evenly divided. The low number of respondents does not provide a good basis to discuss why some thinks the courses and training are sufficient, and some think not.

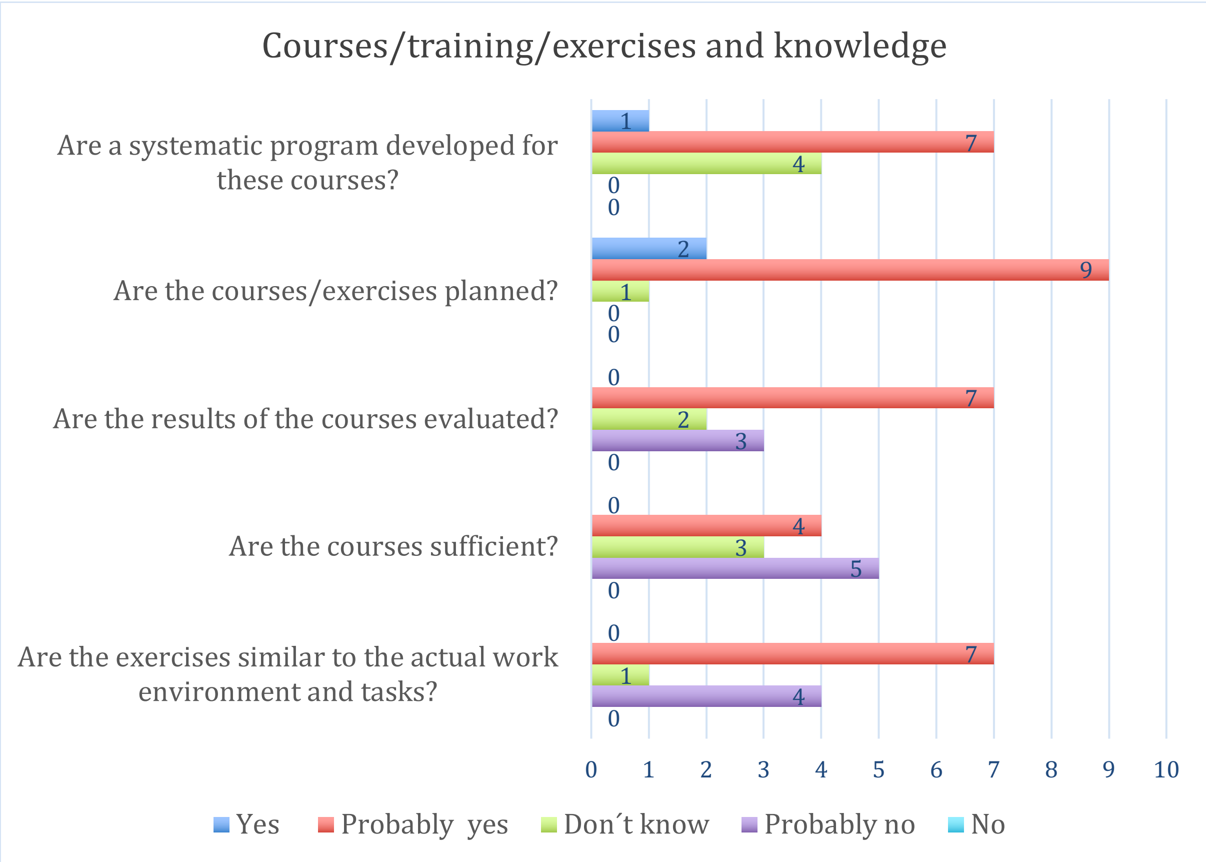

Figure 15 - Different questions regarding courses, training and exercises and how they give necessary knowledge

Figure 16 shows the respondents evaluation of their working environment and equipment. Overall, most of the respondents are generally satisfied with the design of their workplace, stating they are able to work in ergonomically positions and that equipment and the system around them do not cause discomfort when being used over time. Approximately 42 % are not satisfied with the design of their workplace and 33 % say equipment and system around them cause discomfort over time.

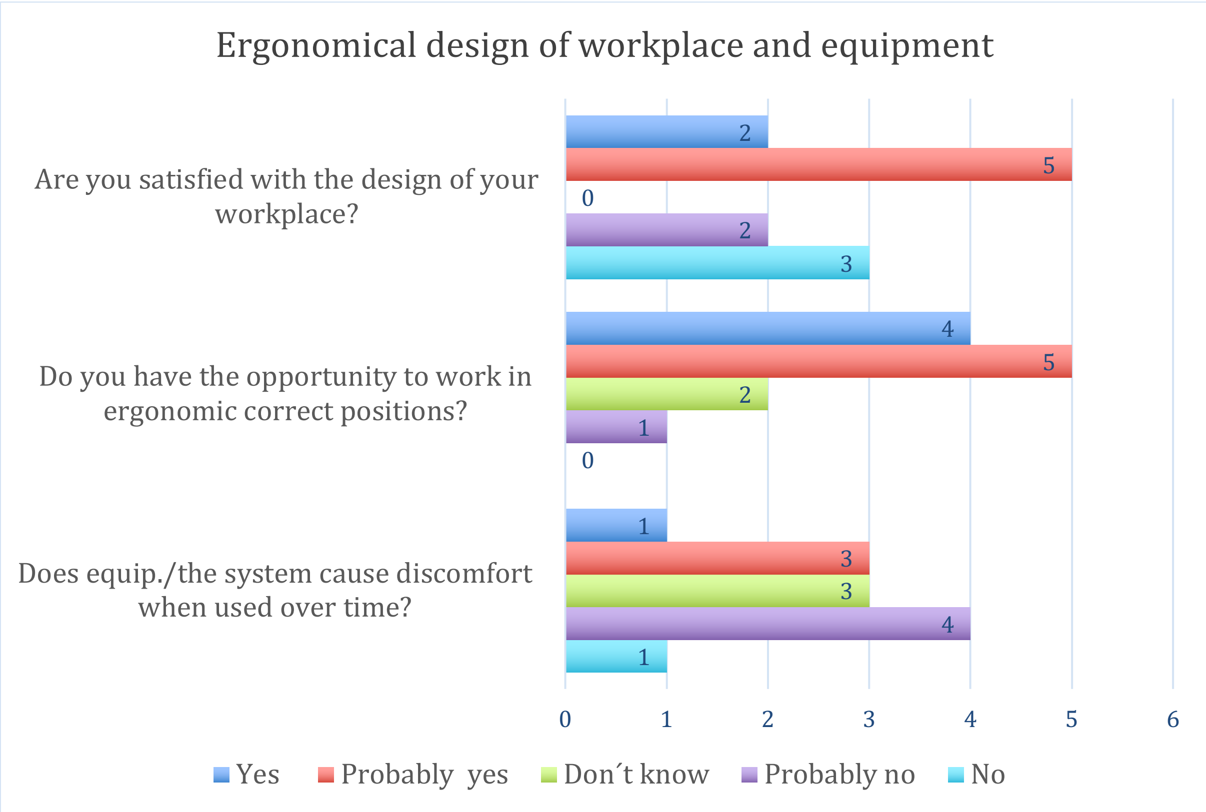

Figure 16 - Different questions regarding ergonomic design of workplace and equipment

Figure 17 and Figure 18 show how the respondents have answered to the subject of information sharing in the organization. The figures show that most of the respondents either responds somewhat positive or negative to the questions. Overall, for Figure 17, most of the respondents answers positively (Yes or Probably yes) when asked about utilization of experience from other situations, communication between shifts and communication at different levels in the organization.

As for Figure 18, many say they do not know if information is given in the right amount, in the right format, to the right person or in the right time. Here, the respondents are more divided between probably yes, do not know and probably no. There seems to be some uncertainty within the organization regarding information transfer and sharing.

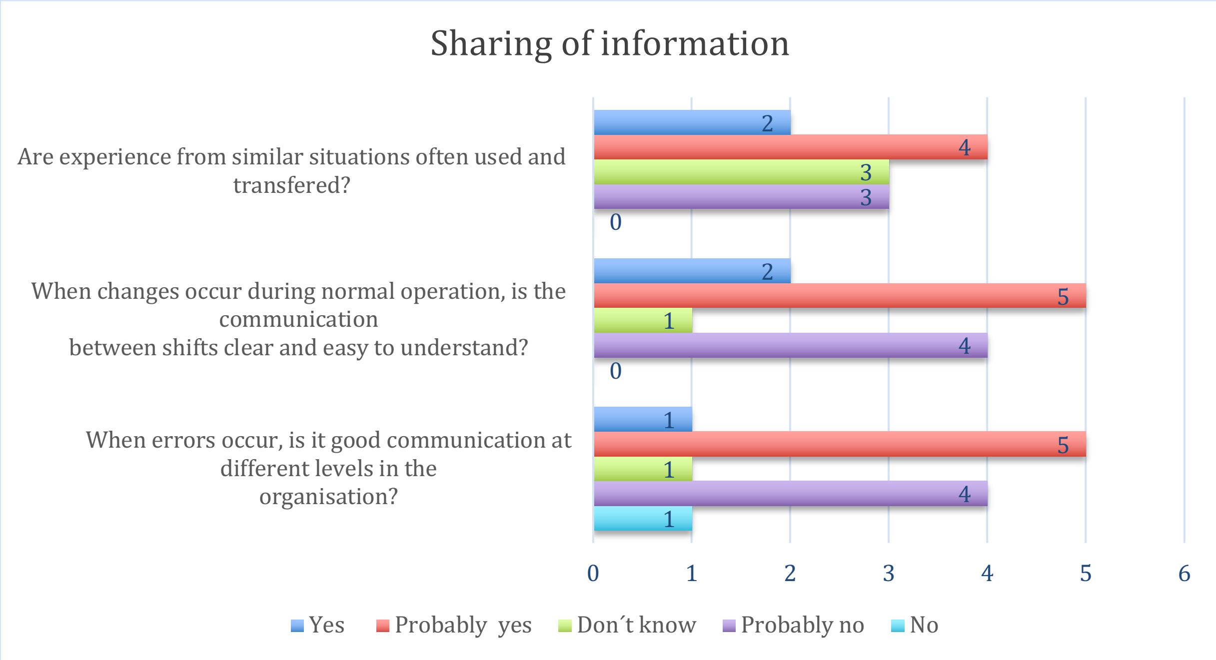

Figure 17 - Different questions regarding information sharing in the organization

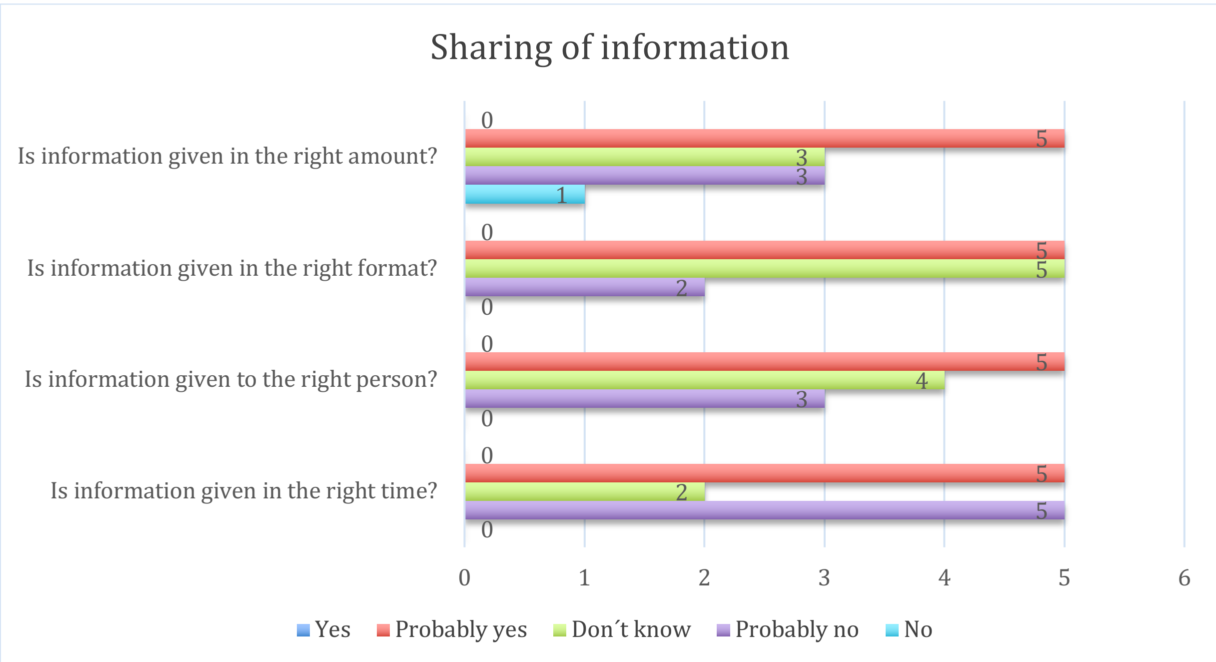

Figure 18 - Different questions regarding information sharing in the organization

Figure 19 shows the result of the respondent's evaluation of different factors that have an impact on human performance. They were told to rate the different factors from 1 to 4, where 4 were said to have the most impact in performance. The factor that was given the highest grade of influence by most respondents was competence. Both workload and training, courses and exercises were given the second highest rating. Most of the respondents think working time arrangements have the least influence on human performance.

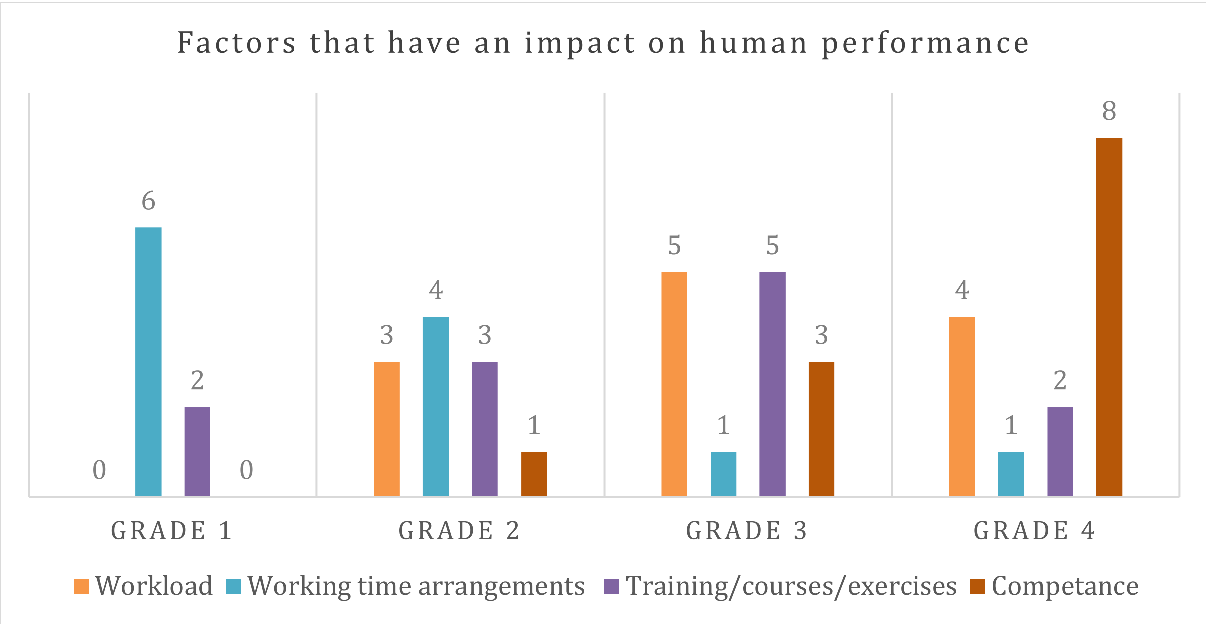

Figure 19 - Respondents evaluation of which factors to have most impact on human performance

6 Discussion

This chapter has four sections, where each research question is discussed. The first section gives a review of the current approach in safety and barrier management in Equinor. The next section discusses the challenges and weaknesses of the current safety and barrier management of Equinor and the main human and organization factors in relation to major accident hazard are discussed in section 6.3. In the last section, suggestions for improvement for safety and barrier management in Equinor are discussed.

6.1 Safety and barrier management in Equinor

Technical safety management in a project development comprises activities to identify risks, develop safety strategies and performance requirements for safety systems and barriers (Endrese, 2018). In order to manage safety and risk, there are principals and corporate safety requirements to technical systems and barriers. The main objectives for the requirements are to ensure the safety of personnel, protection of the environment and protection of assets and minimisation of financial consequences of safety incidents. The main technical safety management activities of Equinor are shown in Figure 20 and show how the different safety performance standards are developed.

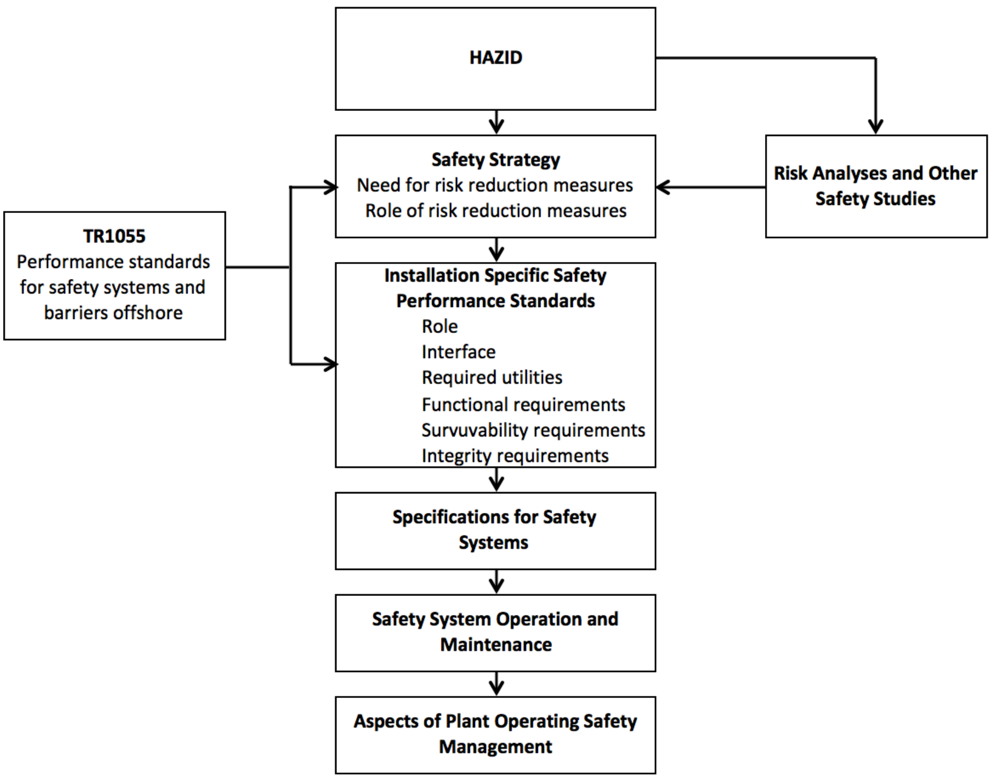

Figure 20 - Activities related to safety (Endrese, 2018).

The safety performance standards form the basis for barrier/system specifications and integrity verification through the lifecycle of the installation. For a barrier to function optimal it will depend on both technical elements and operational and human elements. Verification systems has been developed to capture threats to the barriers that may gradually develop over some time and present barrier status information in a monthly or bi-monthly perspective (Hauge & Øien, 2016).

To ensure barriers functions optimal, Equinor has established a technical integrity management program (TIMP), by combining tools, competence and people they can evaluate the technical integrity of the plants. In this way one can prioritise and implement risk reducing measures (Equinor, 2018). TIMP do not directly assess the risk level on the facility but assess the condition of the technical barriers. Since the process consist of barrier status information, updated monthly or bimonthly, it gives a continuous monitoring of the technical integrity to safety critical tasks which is an important part in reducing major accident in the daily operation. TIMP consist of the work process, a method for condition-based evaluation, and a tool for follow-up and visualizing the technical integrity. Figure 21 below show TIMP work process/flow.

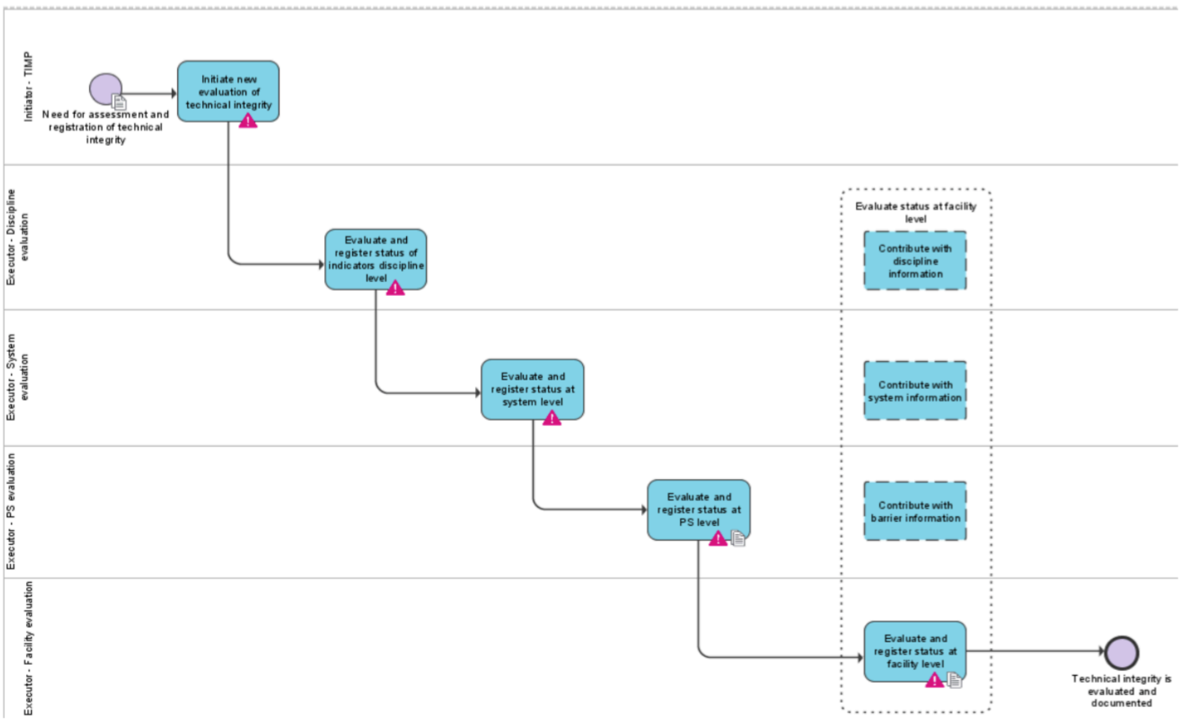

Figure 21 - ARIS - Management System, Process/Workflow (Cock, 2018)

The evaluation of the technical integrity gives information about to what degree tools and equipment's achieve desired function. To conduct the evaluation on the facility indicators are collected from various sources internally in Equinor.

Evaluate and register status of indicators discipline level

When evaluating and registering the status based on indicators, all indicators presented must be considered. Gap represented through indicators is assessed and categories in tools for following up technical integrity. Indicators are evaluated with regards to GL0313 – Guidelines for TIMP-evaluation, and status is addressed to the correct system, performance standard (PS) and location (Cock, 2018). Not all indicators are relevant for all installations, since they have different functions (equipment and systems). It is therefore made an assessment on which predefined indicators that are relevant to the current installation.

The condition of the indicators is evaluated and categorised based on a grading scale, from B-F shown in Figure 23. Also, a description of the shortcomings and weaknesses, and measures if there is compensate for deficiencies are given.

Evaluate and register status at system level

Based on the evaluated indicators and incoming equipment assessment against the actual system, status on system is evaluated and documented in the tool for technical integrity. If there are any known conditions that are not caught up through indicators, this must be included in the holistic system assessment (Cock, 2018). Status then addresses against the right performance standard (PS) (only for safety evaluations). The system evaluation should reflect the most severe gaps that are registered in the evaluation of the discipline and system level indicators and the knowledge the system otherwise have about the system (Equinor, 2018). The systems integrity is evaluated after function, reliability, maintenance and condition monitoring and management.

Criteria for setting status for indicators, systems and PS are given in Figure 22 and Figure 23 for following up and visualize technical integrity.

B	- No significant defect or deficiency in the equipment. All safety functions are ensured. - Maintenance and condition control is carried out according to the requirements and plans ensuring the reliability of the safety systems. - Management: Handling of dispensation, changes and important technical documentation is mainly in accordance with the applicable procedures. Any minor failure does not affect the equipment's main functions in its expected lifespan.
C	- Minor damage, wear or deficiencies in the equipment that may affect the main function of the equipment to a small extent. - Maintenance and condition control are performed and documented, however there are minor shortcomings in relation to requirements and plans. The availability of the equipment is affected to a minor extent in its expected lifespan. - Management: Handling of dispensation, changes and technical documentation is mainly in accordance with the applicable procedures, but has certain deficiencies that in special situations can reduce the equipment's functionality and availability.
D	- Defect or deficiency in the equipment that can eventually lead to failure of main key functions or reduced availability. Failure evolution must be assessed. - Maintenance and condition control is inadequately performed and documented. The deficiency can lead to a function failure. The equipment has somewhat reduced availability. - Management: Handling of dispensation, changes and technical documentation has significant deficiencies in accordance with the applicable procedures. This can reduce the equipment's functionality and availability.
E	- Severe defects or deficiency in the equipment that causes failure of certain main functions, reduced capacity or within a short period of time can lead to serious failure of critical main functions. - Critical maintenance and condition control is not performed or has major shortcomings. The equipment has failures that cause equipment or part of the equipment to not meet the requirements for capacity and availability. - Management: Handling of dispensation, changes and technical documentation have severe deficiency and have not been implemented in accordance with the applicable procedures. The deficiency leads to a significantly increased chance of function failure.
F	- The equipment has severe defects or deficiencies. The equipment is not able to function.

Figure 23 - Evaluation of condition, indicator level - Production (Equinor, 2018)

B	- All essential functional requirements of the system are fulfilled. - All vulnerability requirements are met. The system will perform its main function in the event of any severe accidents. - Maintenance and condition monitoring is performed according to requirements and plans so that the reliability requirement for the system is fulfilled. - Management: Handling of dispensation, changes and important technical documentation is mainly in accordance with the applicable practices. Any deficiencies do not affect the safety system's main functions in either short or long term.
C	- Functional requirements are substantially fulfilled - All significant vulnerability requirements are met. The system is under detrimental conditions making it somewhat more vulnerable to failures, but will normally perform its main function in the event of any severe accidents. - Maintenance and condition control is carried out and documented, but has some deficiencies in relation to requirements and plans. The capacity and reliability of safety systems are within acceptable limits. - Management: Handling of dispensation, changes and technical documentation are mainly according to the applicable practices, but has some deficiencies that in certain situations can reduce the system's functionality and reliability.
D	- Defects or deficiencies in the system that can eventually lead to failure of certain safety functions or reduced reliability. - The system is more vulnerable to failure during severe accident situations. - Maintenance and condition control is inadequately performed and documented. The system's reliability cannot be documented or is reduced in relation to requirements. The deficiency can eventually lead to function failure. - Management: Handling of dispensations, changes and technical documentation has significant deficiencies in accordance with the applicable procedures. This can reduce the system's functionality and reliability.
E	- Severe defects or deficiencies in the system leading to the failure of certain safety functions, reduced capacity or within a short period of time can lead to serious failure of critical safety functions. - The system is vulnerable and vital functional requirements may fail during a severe accident situation. - Critical maintenance and condition control is not performed or has major defects that cause the safety system or part of the system to deviate from the requirements for capacity and reliability. - Management: Handling of dispensations, changes and technical documentation have serious deficiencies and have not been implemented in accordance with the applicable procedures. The deficiencies lead to a significantly increased risk of system failure.
F	- The equipment has severe defects or deficiency. The critical safety functions will not work in the event of an accident situation.

Figure 22 - Evaluation of condition, system/PS level – Safety (Equinor, 2018)

Evaluate and register status at PS level

PS evaluator shall perform both indicator evaluation and PS-evaluations. PS evaluations should reflect the most severe gaps that are registered in the evaluation of the indicators and the knowledge the PS evaluator otherwise have about the PS (Equinor, 2018). Criteria for the grading is shown in Figure 22 same as for system evaluation. In the PS evaluation, the location should also be included. If there were measures to consider from the indicator evaluations in terms of how important it is to initiate mitigation action, then these should be considered in the PS evaluation (Cock, 2018).

Once every calendar year, an extended review of the barrier function´s integrity should also be carried out using the relevant performance standard and associated checklists (Cock, 2018). The integrity of the barrier should be evaluated after functional requirements, vulnerability requirements, reliability, maintenance and condition monitoring and management. The different performance standards and their technical barriers are listed in the table below.

Table 4 - Performance Standards - Technical Barriers

PS	Barriers	PS	Barriers
1	Containment	13	Alarm and communication system for use in emergency situations
2	Natural ventilation and HVAC	14	Escape, evacuation and rescue (EER)
3	Gas detection	15	Layout design principle and explosion barriers
4	Emergency shut down (ESD)	16A	Offshore cranes
5	Open drain	16B	Drilling Hoisting system
6	Ignition Source control	17	Well integrity
7	Fire detection	18	Ballast water and position keeping
8	Emergency Depressurisation and Flare/Vent system	19	Ship collision barriers
9	Active fire protection	20	Structural integrity
10	Passive fire protection	21	Transportation control centre (not included)
11	Emergency power and lightning	22	Human machine interface & alarm management
12	Process safety	23	IT security

Evaluate and register status at facility level

From the status on indicator level, system level and PS level, a total assessment of the plants technical integrity are carried out. The overall assessment made should contain deficiencies and discoveries, and how they affect the level of risk with regard to major accidents and possible downtime (Cock, 2018). It should also be seen in a relation that may affect the level of risk within some areas. The responsible for technical integrity conducts the evaluation in a meeting where the responsible calls in the following as needed (Equinor, 2018): performing indicator evaluation, performing system evaluation, performing PS evaluation, operational responsible, maintenance management and main safety representative from the platform. This is to ensure there is a common understanding of the plant's evaluation.

The assessment made by the professionals above secures the plants technical integrity described in the company's tools for following up on technical integrity. They are using the GL0313-TIMP evaluation guidelines for guidance (Cock, 2018). A portal visualized the status of technical barriers in form of a bow tie model and makes the foundation for the evaluations at facility level. This is illustrated in Figure 24.

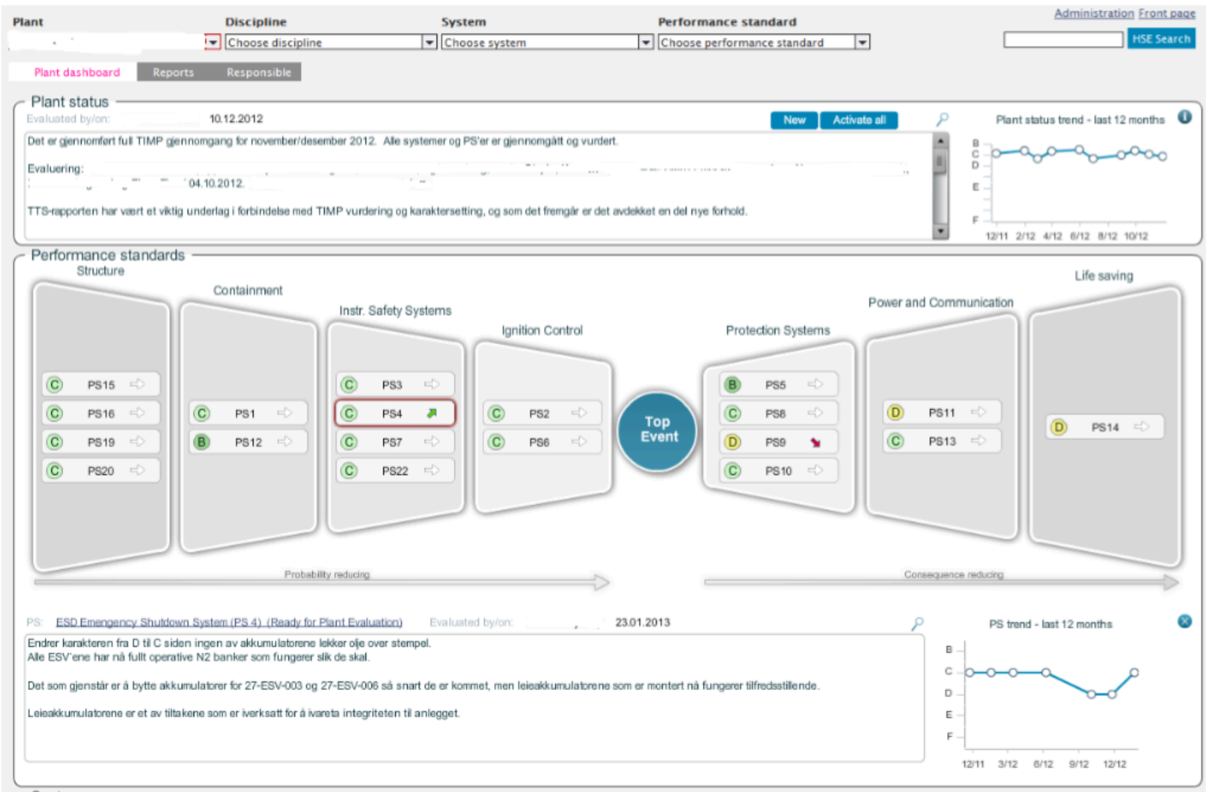

Figure 24 - Plant status in technical integrity management portal (Equinor, 2018)

In the bow tie model one has an overview of the different PS and their grade, as well as the PS trend over the last 12 months.

6.2 Challenges and weaknesses of the safety and barrier management in Equinor

The fundamental challenge for TIMP is operationalizing. The main focus in TIMP is to describe the state of the barrier and what it takes to raise the condition and character to gain control of the situation. Underlying causes are not fully elucidated in TIMP. Based on a presentation by Refsdal (2011), technical integrity indicators may camouflage important issues through aggregation. This could lead to the focus turning to the indicator itself rather than underlying issues and improvement actions.

The technical integrity management program addresses important physical barriers and as a result of its application, the annual number of hydrocarbon leaks has reduced over the period 2008 to 2018. However, to be able to implement adequate risk reducing measures, monitoring the above precursors is not sufficient and it is also important to understand why hydrocarbon leaks occur. According to a study performed in 2012 by the Norwegian Oil Industry Association on behalf of the operators on the Norwegian continental shelf, it concludes that a substantial part of the hydrocarbon leaks is related to human intervention on process equipment. Based on this, attention should be paid on activities able to support human areas, to reduce the probability of human error (Røed, Vinnem, & Nistov, 2012). To be able to reduce the probability of human error there is a need to expand the programme to address technical, human and organizational factors.

Technical, operational and organizational barriers should in interaction prevent or prohibit specified unwanted events to occur. Human factors act as a barrier against poor decisions and important factors are attentive, non-fatigued operators, good situation awareness data and representations, and good team communication skills. But if the human factors are weak one allows poor decisions to be made and accidents may occur (John, 2017). Through the technical integrity management program, Equinor has a strong physical barrier control. Identifying weakness in the non-technical barrier management is an important step for improvement of the safety and barrier management.

A challenge with the safety and barrier management is the need to address important failure modes in personnel and business areas. Purely technical solutions do not address all important failure modes and therefore it is a need to expand the technical integrity to include the whole HTO-area (Sørum, 2012). A change will require finding human and organizational indicators and adjusting them to the different levels in the organization. These indicators can be based on 7 defined operational performance standards developed for operational safety conditions, which are competence, procedures, roles and responsibilities, management etc. The challenge lies on how one measure such conditions.

6.3 Human and organizational factors in major accidents

In order to identify human and organizational factors, the primary focus of the master thesis has been on categorization of the circumstances of the accident. This means that the focus has been on which human and organizational factors took place in the work process leading to the accident, rather than the direct cause of the accident. A historical perspective considering some of the major catastrophic accidents over the last 20-30 years supports our focus. The outcomes are mainly a result of long event sequences where there are usually opportunities where the control might have been regained, if one had understanding and awareness of the underlying causes. The same are observed for some of the more recent events that have been extensively investigated.

After reading through 16 different accident reports written by the PSA, it became clear that many of the underlying reasons for the accidents taking place was down to both human and organizational factors. As already stated in chapter 5.1.2, the graph in Figure 7 shows a subjective selection of factors involved in the different accidents. This was done because the reports from the PSA often focused on the technical elements that failed, and for the most part did not specifically mention or look into human or organizational factors.

A total of 55 factors were found from reading the reports and Figure 7 shows the factors are divided between 8 different categories. The categories are very important in regard to both human and organizational factors in any company, and when they are given a chance to fail simultaneously, they create a basis for accidents to take place.

Some of the categories are more represented than others. Understanding and compliance of safety and risk assessment is one of them. Out of the 16 reports, there were only in 3 of them where understanding and compliance of safety and risk assessment was not found to be one of the reasons leading to the accident. The deficiencies vary from design phase to actual execution of different operations and show that without a proper understanding of safety and risk assessment, accidents will occur.

Another factor identified in several of the reports were the one considering competence, experience and knowledge. A variety of reasons to why accidents occurred because of this factor were identified. Personnel had not received necessary training; they did not have proper knowledge about equipment; procedures and work processes were not undergone properly and so on. When this happens several times on different sites, it clearly is a much larger problem that must be handled on an organizational level. Operators and personnel in general need to be trained properly, and the more experienced personnel should share what they know with personnel who are new to the industry or job in order to make them as good as they can be. When this does not happen, inexperienced personnel are performing jobs as best they know, but it increases the risk of failure and accidents. To be able to reduce the risk of failure and accidents, proper routines and procedures must be in place. In some of the cases that was not even the case. This corresponds with Figure 7 which show that on several cases procedures, governing documents, work routines and habits plays a part in accidents taking place.

When combining all of the factors mentioned in chapter 4.1, it is easy to understand that accidents can happen. Lack of proper understanding of risk by workers may lead to new types of hazards which is not being identified. For example, due to the lack of proper communication between shifts and colleagues, important information about a plant or platform may not be shared and maybe the wrong valve is opened or a module that is disconnected from the process is being used (example Piper Alpha). Procedures and routines can be very important assets in any working environment, but when they aren't properly explaining what to do in different work situations, or are non-existent, they become a liability. If there is any room for misinterpreting or misunderstanding procedures, or a possibility to perform a job outside of the framework of the procedures, it creates opportunities for accidents to happen. Not following procedures can work out, of course. Maybe 5 times, 10 times or even 100 times, it is possible to achieve what you want. The problem is, it only requires an operation to go wrong one time to create a major accident with large consequences.

In the questionnaire there were a couple of questions related to the subject of this chapter. Respondents were asked to answer questions about:

- In order to prevent human failure there is a need of improving personal factors
- Organizational factors that needs improvement in order to prevent human failure
- Rate factors which could have an impact on human performance

As Figure 12 shows, the two important human factors the respondents think needs to be improved the most are competence to deal with circumstances and motivation vs. other priorities. Competence to deal with circumstances corresponds with the discoveries from the accident reports, where lack of competence on different subjects often was one of the reasons for accidents taking place. Although they are important factors, workload, stress, fatigue and physical capability of personnel were not considered to be as important as the two mentioned above. The results can indicate that personnel need to raise their competence and focus while working in the organization.

The results for the organizational factors are a bit more divided, see Figure 13. However, here there are also two factors that have been chosen the most. Communication and information sharing, and clarity of roles and responsibility are two very important factors within an organization. According to the respondents, communication and information sharing needs to be improved, which can indicate it is not good enough as it is today. Again, this corresponds with the findings from the accident reports. Lack of improper communication, as well as information sharing, played a part in several of the accidents. The same goes for clarity of roles and responsibility. When personnel know who´s in charge and have the responsibility, one could assume it would create a much clearer working environment. Having personnel with dedicated roles and responsibility would give a company the opportunity to maintain control over operations and personnel. Without it, any working environment could possibly end up being very chaotic, which will increase the chance of failures and accidents.

When asked which factors would have the most impact on human performance, most of the respondents said that competence was the most important one. This has, as already mentioned, been the returning topic in this section. They also more or less agree that working time arrangements have the least impact on how personnel perform while being at work. However, as the factors to have the second most impact on human performance, both workload and courses, training and exercises have been chosen. Sending personnel to courses, train them and put them through exercises should be a good way to improve their abilities and competence. But if the consequence of doing that is increased workload, it could be important to look at how often personnel are sent on courses or performing exercises, compared to how much they already work under normal circumstances.

When comparing the results found in this thesis with articles written earlier, it is found that the most important factors in this thesis coincide with earlier results. Back in 2012, Fred Nickols wrote a short article about seven important factors that affect human performance. Listed in the article, among others, were motivation, feedback and knowledge of structures. These are important personal factors, which could affect the performance of employees if not maintained properly (Nickols, 2012).

6.4 Improvement of safety and barrier management

In the questionnaire, the respondents were asked to make suggestions to improve the safety and barrier management system. There were many answers, and they were quite varied. Some of the respondents mentioned the same things, such as training of personnel, better and more focus on procedures and competence and experience. Other suggestions that was mentioned were:

- Motivation
- Better organizational learning
- Understanding of risk and consequence
- Better quality control of performed work
- Better risk assessment
- Increased focus on tasks at work
- Communication and supervision
- Less administrative tasks which takes focus from operation
- Less noise in working environment
- Management focus and support

Many of these suggestions can improve the safety in the company. By increasing employees understanding of risk and consequences and improve the quality of risk assessments, it could have a significant impact on safety. Barrier management would benefit from more focus and better procedures, as well as improving employees´ ability and competence from training. As mentioned early in this paper, barrier management is defined as coordinated activities to establish and maintain barriers so that they maintain their functions at all times (Petroleumstilsynet, 2013). In order for this to happen, the main elements of barrier management must be present. The three elements, and their definition, is:

- Operational barrier elements: *"The actions or activities that the personnel must perform to realize a barrier function"* (Petroleumstilsynet, 2017).
- Organizational barrier elements: *"Personnel with defined roles or functions and specific competence included in the realization of a barrier function"* (Petroleumstilsynet, 2017).
- Technical barrier elements: *"Equipment and systems included in the realization of a barrier function"* (Petroleumstilsynet, 2017).

In other words, who is doing what with what equipment in error, danger and incident situations (Petroleumstilsynet, 2017). When all of these are working together, they constitute different parts of realizing barrier functions. To be able to improve barrier management, a company needs to understand the definitions of the elements and ensure that both personnel and management are on the same page to create the best possible barrier management system. Giving personnel defined roles and specific competence, in form of having dedicated personnel in positions of responsibility and train personnel will ensure higher quality on organizational elements. By improving and simplifying procedures, and making sure everyone involved follows procedures, can provide the basis for personnel to make fewer mistakes and errors. As a result, operational elements will maintain their function better. The technical elements must be of such a nature that the interaction between operators and equipment and/or system does not become a liability. Personnel must have a good understanding of what the equipment they use are supposed to do, as well as the possible consequences of misuse.

All of this is supported by the results from the questionnaire. The results show that the answers from the respondents correspond with what is needed to improve safety and barrier management. Combining the results with the list of suggestions in this chapter would, per definition, have a positive impact on the organization and its safety and barrier management.

Below is a table with human factors that can be improved, and we believe would have a positive impact on organizational safety and barrier management. From the incident reports there are incidents that were continually happening which are to be linked to either behavior or error. The table includes several important factors considering individual and organizational factors involved with accidents. We have also made some suggestions to measures which could reduce the possibility of human error.

Table 5 – Human factors affecting organizational safety

FACTOR	CHALLENGES	MEASURES
Communication	Sharing of information and knowledge Not understanding information that is given Loss of information between personnel Communication between company and entrepreneurs/sub-contractors Not proper or adequate enough	Learning from other companies, both domestic and international Having good routines on information sharing, decrease chance of information loss and misunderstanding Give information in right amount, to right personnel and in the right time
Competence	Many employees with good theoretical background hired directly from university which have less practical knowledge and understanding Less experienced personnel at work because of absence	Hiring from both groups to utilize the best from them. Both theoretical and practical approaches to challenges are important Making sure enough personnel have sufficient training and are comfortable covering for others when necessary.
Procedures	Sometimes inadequate Can be too technical and difficult Time demanding to go through before doing tasks Too little focus on human factors May require more than one procedure to finish tasks	Ensure procedures fully describe tasks and doing so in a way that is easy to understand and not confuses or demotivates personnel Implement human factors in risk assessment to make personnel aware of factors that could lead to mistakes

Training/courses	Can be too little specific training Can take a physical strain on employees Better knowledge and understanding of human factors	Giving individuals specific training and defined roles within their working environment Work to ensure that personnel are not overloaded with courses and exercises Have courses with human factor specialists to increase knowledge about the subject
Motivation	Personnel not knowing what goals they are working towards Not being focused on their job, other things are prioritized	Setting clear goals will help on motivation. One can measure progress, and personnel know when the task is finished Always have good communication between colleagues and management to make sure that personnel are focused and ready when at work

When improving safety these human factors are of high importance. By eliminating common weaknesses there is a possibility to affect the outcomes of future incidents. To improve risk management on site one should start with reducing the human failures, by implementing the measures shown in Table 5. An article written in 2017 by Mark F. St. John also supports this. Improvements can come from (John, 2017):

1. Redefining specific procedures to enhance information access
2. Increasing across-training to enhance cross-team knowledge of skills and responsibilities
3. Standardizing display configurations to support collaboration

7 Concluding remarks

In this chapter the conclusion to the thesis will be presented along with suggestions for further research in regards to the subject of this thesis.

7.1 Conclusions

In the industry there is a growing awareness of how studies on human factors could lead to better barrier management and with this improve the safety and at the same time reduce the losses. There is need of continuous work on how to measure conditions including the whole HTO-area. In regards to measuring human factors on safety and barrier management the following conclusion are made:

- The technical safety management in Equinor comprises of activities that measure the technical barriers in a good way and have reduced accidents over the last decade.

- Through TIMP Equinor has a good way to evaluate the technical integrity of the plants and with this capture threats to the barriers. However, there are challenges with the program when it comes to capturing human failures.

- The approach is very technical and should implement human and organizational factors to increase the barrier management. This change will require finding indicators on these factors and adjusting them to different levels in the organization.

- The human and organizational factors appear to be divided between several areas. The main factors are the understanding of risk assessment, communication, competence, experience and knowledge.

- By analysing the questionnaire the most important personal and organizational factors that was emphasised and in need of improvement were competence, motivation, communication and information sharing, and clarity of roles and responsibilities.

- Studies have shown that organizational culture, communication and commitment could have an impact on worker performance. Other human and organizational factors which are important in regard to human performance are training of personnel, feedback and knowledge of structure.

- From the incidents report there are incidents that were continually happening which are linked to either behaviour or error. It appears that the risk influencing factors on human behaviour is a good place to start.

- The areas we believe would have the most impact on safety and barrier management, considering the human aspects, are communication, competence, procedures, training and motivation.

7.2 Suggestions for further research

Based on this thesis a few suggestions are made for further research.

- In regards to the technical safety management, further research on human and organizational factors is necessary. Especially on how to measure such conditions is the key challenge.

- Further research into human factors and engineering to get a better understanding of their impact on safety.

- Perform studies to find if communication, competence, procedures, training and motivation would have a positive impact on the overall safety and barrier management.

- Use time to create performance standards and requirements in regard to human, operational and organizational elements, and find risk indicators related to them to further this work.

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Appendix A – Questionnaire

Questions sent out to the organization in Equinor are listed below. The information we got from these questions provided the basis for the analysis in the project. On request from Equinor the questions are written in Norwegian.

Kjønn

- ○ Mann
- ○ Kvinne

Aldersgruppe

- ○ <20
- ○ 20-30
- ○ 31-40
- ○ 41-50
- ○ 51>

Jobber du onshore eller offshore?

- ○ Onshore
- ○ Offshore

Har du en lederstilling?

- ○ Ja
- ○ Nei

Hvor lenge har du jobbet for bedriften?

- ○ < 1år
- ○ 1-3 år
- ○ 4-6 år
- ○ 7-9 år
- ○ 10 år >

Hvor kjent er du med begrepet "human factors" (menneskelige faktorer)?

- ○ Veldig kjent
- ○ Litt kjent
- ○ Mindre kjent

Human Factors referer til miljø-, organisasjon- og arbeidsfaktorer samt menneskelige og individuelle egenskaper som påvirker atferd på jobben på en måte som kan påvirke helse og sikkerhet.

Dette spørsmålet omhandler hvilke faktorer som etter din mening bør forbedres på ditt arbeidssted for å redusere faren for menneskelige feil.

Hvilke av arbeidsfaktorene under trenger å bli forbedret for å unngå menneskelig feil? (Velg 4)

- ☐ Tydelighet av signaler, tegn, instruksjoner og annen informasjon
- ☐ Samhandling mellom system/utstyr og operatør
- ☐ Vanskelighetsgrad av oppgaver
- ☐ Rutiner
- ☐ Delt oppmerksomhet
- ☐ Utilstrekkelige eller utydelige prosedyrer
- ☐ Forbredelse av oppgave (eks. tillatelse, risikovurdering)
- ☐ Tid tilgjengelig/nødvendig
- ☐ Kommunikasjon med kollegaer, ledere, entreprenører eller andre
- ☐ Arbeidsmiljø (eks. støy, varme, plass, lys, ventilasjon)

Dette spørsmålet omhandler hvilke faktorer som etter din mening bør forbedres på ditt arbeidssted for å redusere faren for menneskelige feil.

Hvilke av de personlige faktorene under trenger å bli forbedret for å unngå menneskelige feil? (Velg 2)

- ☐ Fysisk evne og tilstand
- ☐ Utmattelse
- ☐ Stress/moral
- ☐ For mye/for lite arbeidsmengde
- ☐ Kompetanse til å håndtere ulike situasjoner
- ☐ Motivasjon vs. andre prioriteringer

Dette spørsmålet omhandler hvilke faktorer som etter din mening bør forbedres på ditt arbeidssted for å redusere faren for menneskelige feil.

Hvilke av de organisatoriske faktorene under trenger å bli forbedret for å unngå menneskelige feil? (Velg 4)

- ☐ Arbeidspress (eks. produksjon vs. sikkerhet)
- ☐ Nivå på ledelse/ledelsens egenskaper
- ☐ Kommunikasjon og informasjonsdeling
- ☐ Bemanningsnivå
- ☐ Gruppepress
- ☐ Tydelighet av rolle og ansvar
- ☐ Konsekvens av å ikke følge prosedyrer/regler
- ☐ Effektiviteten av organisatorisk læring (lære fra erfaring, øvelser, trening)
- ☐ Sikkerhetskulturen

For spørsmålene, tenk på en typisk oppgave som gjøres på din arbeidsplass og svar basert på denne.

Kvaliteten på prosedyrene

	Definitivt ja	Sannsynligvis ja	Vet ikke	Sannsynligvis nei	Definitivt nei
Forklarer prosedyrene hver eneste oppgave og hvert steg korrekt og logisk?	○	○	○	○	○
Vet operatører hvor de finner prosedyrene?	○	○	○	○	○
Må flere prosedyrer benyttes for å utføre oppgaven riktig?	○	○	○	○	○
Når operatører går gjennom prosedyrene, er de klar over tegn for å utelukke menneskelige feil?	○	○	○	○	○
Følger operatører alltid prosedyrer?	○	○	○	○	○

For spørsmålene, tenk på en typisk oppgave som gjøres på din arbeidsplass og svar basert på denne.

Hvor bra kurs/trening/øvelser gir nødvendig kunnskap

	Definitivt ja	Sannsynligvis ja	Vet ikke	Sannsynligvis nei	Definitivt nei
Er øvelsene/kursene lik det faktiske arbeidsmiljøet og arbeidsoppgavene?	○	○	○	○	○
Er kursene tilstrekkelige?	○	○	○	○	○
Blir resultatet av kursene evaluert?	○	○	○	○	○
Er kursene/øvelsene planlagt?	○	○	○	○	○
Er et systematisk program utviklet for disse kursene?	○	○	○	○	○

For spørsmålene, tenk på en typisk oppgave som gjøres på din arbeidsplass og svar basert på denne.

Ergonomisk utforming av arbeidsplass og utstyr

	Definitivt ja	Sannsynligvis ja	Vet ikke	Sannsynligvis nei	Definitivt nei
Oppstår feil ofte, og er de enkle å oppdage og fikse?	○	○	○	○	○
Gir utstyret eller systemet ubehag vis du bruker det i lengre tid?	○	○	○	○	○
Har du mulighet til å jobbe i god ergonomisk posisjon?	○	○	○	○	○
Er du fornøyd med designet av din arbeidsplass?	○	○	○	○	○

Hvor bra informasjonsoverføringen er på de forskjellige nivåene i organisasjonen

	Definitivt ja	Sannsynligvis ja	Vet ikke	Sannsynligvis nei	Definitivt nei
Når feil oppstår, er det god kommunikasjon på de ulike nivåene i organisasjonen?	○	○	○	○	○
Når endringer skjer under normal drift, er kommunikasjonen mellom de forskjellige skiftene tydelig og lett å forstå?	○	○	○	○	○
Er erfaring fra lignende situasjoner ofte brukt og videreført?	○	○	○	○	○
Blir informasjonen gitt på riktig tid?	○	○	○	○	○
Blir informasjonen gitt til den riktige personen?	○	○	○	○	○
Blir informasjonen gitt i det riktige format?	○	○	○	○	○
Blir informasjonen gitt i riktig mengde (ikke for mye / ikke for lite)?	○	○	○	○	○

Ranger de følgende faktorenes påvirkning på menneskelig ytelse fra 1-4 , 1 har minst påvirkning og 4 størst påvirkning

	1	2	3	4
Arbeidsmengde	○	○	○	○
Arbeidstidsordning	○	○	○	○
Trening/kurs/øvelse	○	○	○	○
Kompetanse	○	○	○	○

*Hvilke tanker/forslag har du som kan hjelpe til med å redusere menneskelige feil? Vær vennlig å skrive tre forslag(eller mer).