NTNU – Trondheim
Norwegian University of
Science and Technology

Maintenance and barriers

Principles for barrier management in the petroleum industry will be more and more important and It is fundamental to understand the maintenance function in the barrier management.

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Mechanical Engineering
Submission date: June 2014
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MASTER THESIS

TPK4900

Maintenance and barriers

Endre Fylling Moen

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for stud. techn. Endre Fylling Moen

Vedlikehold og barrierer

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Barrier management within maintenance is about ensuring, on a systematic and continuous basis, that the maintenance barriers are relevant, effective and robust.

In this thesis the candidate shall:

- Present the relation between maintenance and safety.
- Present the “state of the art” for barrier management in Petroleum Safety Authority Norway.
- Analyse the importance of maintenance in barrier management.
- Present some maintenance indicators in the barrier management. Analyse how the indicators can be measured (the state/condition of the indicator).
- Analyse how maintenance function and maintenance indicators can me technical, operational and organisational barriers elements.
- Present the next generation barrier management concept (focus on maintenance for DNV).

Within three weeks after the date of the task handout, a pre-study report shall be prepared. The report shall cover the following:

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The pre-study report is a part of the total task reporting. It shall be included in the final report. Progress reports made during the project period shall also be included in the final report.

The report should be edited as a research report with a summary, table of contents, conclusion, list of reference, list of literature etc. The text should be clear and concise, and include the necessary references to figures, tables, and diagrams. It is also important that exact references are given to any external source used in the text.

Equipment and software developed during the project is a part of the fulfilment of the task. Unless outside parties have exclusive property rights or the equipment is physically non-moveable, it should be handed in along with the final report. Suitable documentation for the correct use of such material is also required as part of the final report.

The student must cover travel expenses, telecommunication, and copying unless otherwise agreed.

If the candidate encounters unforeseen difficulties in the work, and if these difficulties warrant a reformation of the task, these problems should immediately be addressed to the Department.

The assignment text shall be enclosed and be placed immediately after the title page.

Deadline: 30 June 2014.

Two bound copies of the final report and one electronic (pdf-format) version are required according to the routines given in DAIM. Please see http://www.ntnu.edu/ivt/master-s-thesis-regulations regarding master thesis regulations and practical information, inclusive how to use DAIM.

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DEPARTMENT OF PRODUCTION

AND QUALITY ENGINEERING

Per Schjølberg

Associate Professor/Head of Department

Responsible Supervisor

Preface

This master thesis is written in accordance with the final course TPK4900 at The Norwegian University of Science and Technology - NTNU. It has been developed in cooperation with DNV GL and the department of Production and Quality Engineering - IPK. The final thesis comprises of 30 study points in the total of 300 in the 5 year MSc. program - Mechanical Engineering.

The master thesis is written by stud. techn. Endre Fylling Moen under the faculty of Engineering Science and Technology at NTNU. The thesis objectives and formulation is developed by Per Schjølberg - Associate Professor/Head of the Department of Production and Quality Engineering.

My greatest gratitude to Per Schjølberg (NTNU), John Kristijan Hermann (DNV GL) and Astrid Rydock (DNV GL) for their help and counselling throughout the work with this thesis. I am profoundly grateful to John Kristijan Hermann for his quick response and constructive guidance, especially during the last phase of the thesis. I also want to thank my friend Simen G. Hegdalstrand for his assistance in proofreading.

Trondheim, 30.06.2014

Endre Fylling Moen

Summary

This thesis' sets out to analyse and present the purpose and meaning of safety, maintenance functions and management, maintenance indicators, barrier management and the importance and dependency between those. In addition, this is done in relation to the petroleum industry in Norway, and in collaboration with DNV GL, to develop an improved concept of barrier management. The analyses, discussions and conclusions are done at the basis of earlier accident reports and relevant literature.

Safety is the overall process of ensuring a safe environment for every included and associated object. A function that is designed and developed to maintain safety is dependent on frequent maintenance in order to maintain its functionality and capability.

One of the four top priorities in the Petroleum Safety Authority Norway's future development program is the improved integration of barriers and barrier management. Barriers are often defined as an obstacle, or a function, to prevent any form of hazardous energy to penetrate at an unwanted area, process or situation. The present situation in the industry indicates deviations in the common understanding and usage of barriers, and there are several areas of potential improvement.

In barrier management and the phase of monitoring and improving existing solutions, maintenance has a significant role of making the barriers more *relevant, efficient and resilient* due to changes, time dependent wear and modifications in the systems. To utilize and control the barriers at the highest level possible, the need for an organised management is required. This includes maintenance, which is an essential process in barrier management of proactively ensure the barriers' continuous improvement and resilience.

Maintenance indicators in accordance to barriers could be integrated in barrier management with the purpose of revealing weaknesses and areas of improvement. *Backlogging* is a maintenance indicator, which reveals if planned and preventive maintenance activities are performed in accordance with the scheduled plan. Backlogging is often measured in days or weeks. Another maintenance indicator is *number of errors* revealed during maintenance and testing. This indicator measures the ratio of errors in a barrier, after performing a test or maintenance operation. A barrier function often consists of several barrier elements, in which the barrier elements could be both technical, operational and organisational. Thus, maintenance functions and indicators are necessary to maintain and improve the elements. It is important to note, however, that maintenance is not regarded as a direct barrier element in itself.

This survey has developed a concept suggestion in cooperation and relation to DNV GL, with the focus at future barrier management guidelines. The emphasis has been on implementing maintenance activities and potential maintenance procedures in the barrier management within areas where earlier/present weaknesses are identified. More specific, a DNV GL concept of internal cooperation and exchange of experience is presented.

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Abbreviations and definitions

BM -Barrier management
PM - Preventive maintenance
CM - Corrective maintenance
MM - Maintenance management
CL - Closed loop
PR - Performance requirements
PSAN - Petroleum Safety Authority Norway
NPD - Norwegian Petroleum Directorate
TPM - Total productive maintenance
WCM - World class maintenance
RCM - Reliable centred maintenance
RCA - Root cause analysis
ALARP - As low as reasonably possible
IAEA - International Atomic Energy Agency
NAT - Normal Accident Theory
HRO - Highly reliable organisations
KPI - Key performance indicator
BOP - Blowout preventer
BDV - Pressure Relief Valve
ESDV - Emergency Shutdown Valve
DHSV - Down-hole safety valve
DwH - Deepwater Horizon

1. Introduction

The introduction *section is designed to make the reader aware of several assumptions and limitations which are made both before and throughout the thesis. The purpose is to establish a common thread as early as possible. It is also meant as a brief guidance to the background and purpose of the work, in addition to what the results should be accomplishing.*

1.1 Thesis background

Barrier management in the petroleum industry is a relatively new area of focus, and some of the involved actors are still, to some extent, not sufficiently familiar with the concept. There are deviating definitions or interpretations from local organisational perspectives, making the enhancing of a common and collaborative approach absent.

The maintenance function in barrier management has also had a growing interest when developing procedures and regulations for the barrier management. The importance and influencing relation from maintenance is essential to classify, as well as clearly illustrate where, when and how to implement and utilize the maintenance functions.

The Petroleum Safety Authority Norway as the supreme department of regulations and monitoring within the petroleum industry in Norway, has also set barriers and barrier management as one out of four top priorities for further improvement of safety work in the industry.

Throughout this thesis, several analyses of apparent weaknesses and future priorities regarding barriers will be presented, to better illustrate the relation and importance of maintenance functions in barrier management.

A conceptual guideline for DNV GL's future work within barrier management and maintenance will also be presented, as part of a further discussion and fundamental basis for a potential more precise and specific concept development.

1.2 Involved actors

The sub-chapter of involved actors includes a short presentation of the most relevant actors who have or may have a direct influence regarding the thesis objectives and composition.

1.2.1 NTNU

The Norwegian University of Science and Technology - NTNU, is the second largest university in Norway, with an approximation of 22000 students. About 50 percent of the students are studying technical, or scientific subjects (NTNU, 2014), and around 3600 students yearly graduate from the university, including bachelor's-, master's- and doctoral candidates.

This master thesis is being written in collaboration with the Department of Production and Quality Engineering, which is under the faculty of Engineering Science and Technology at NTNU. The department has a well established relation within the petroleum industry, in addition to being closely involved with the leading research facility in Scandinavia, SINTEF (2014). This creates a well founded basis for the development of a relatively useful and up to date thesis.

1.2.2 DNV GL

Det Norske Veritas - DNV was founded in Oslo in 1864, and was established as a membership organisation to provide more reliable and uniform classification and taxation of Norwegian ships (DNV GL, 2014). The shipping industry in Norway was a growing commerce, making different classifications and international regulations more essential. In 2013, DNV and GL merged and formed the DNV GL Group, with employees and other operating assets within over 100 different countries.

DNV GL is a company which combines both technical and operating expertise, with the ambitions to optimize the safety in relation to the environment, society and the customers. DNV GL offers expertise consulting in several different industrial areas, with the main focus on maritime, oil and gas, energy industries as well as food and health care. Their general vision is *Safer, Smarter, Greener*. In this thesis, the collaboration is within the Oil & Gas industry, but the results could probably be used as general guidelines for any of the other disciplines.

1.3 Thesis description and problem formulation

Principles for barrier management in the petroleum industry will be more and more important and it is fundamental to understand the maintenance function in the barrier management. Barrier management within maintenance is about ensuring, on a systematic and continuous basis, that the maintenance barriers are relevant, effective and robust.

In this thesis the candidate shall:

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1.4 Thesis objectives

The master's thesis primary objective is to evaluate and analyse the importance and correlation regarding maintenance within the barrier management, using historical data of earlier incidents/accidents, literature from several of the related and required subjects, information about the present situation as well as the future ambitions in the Norwegian petroleum industry. This will be used to develop and contribute to a potentially new and improved barrier management concept for DNV GL, with the main focus at maintenance.

1.5 Workload and method

1.5.1 Workload

The workload distribution in affiliation to the subtasks size and weight has systematically been classified with the elements of cost, time and resources. This is presented in the several CTR- forms in appendix I (pre-study report). The subtasks are also divided into work packages with the corresponding time disposal, including the usage of a Gantt-diagram (also in the pre study report). Along with the submission of the thesis, two status reports are also included, where the progression and status at a given time period during the work is compared to the predetermined plan. Any deviations are commentated, as well as the general status of the work.

1.5.2 Limitations and terms

Time

The thesis was released 6th of February, 2014. The pre-study report was delivered within three weeks, i.e. 27th of February. The thesis original submission deadline was 10th of June, but since there was some delay on the release date, the final deadline is set to 30th of June, 2014. This is an approximation of 17 weeks. The thesis is a 30 study point subject, which in this case, indicates an estimated workload of 45 hours a week, making it in total of 765 working hours, excluding the pre-study report.

Literature

There is much available literature in relation to maintenance and barriers individually, but there is not a sufficient amount when it comes to the direct link between them. This will present challenges in locating the newest and most relevant literature, however, it is rewarding to write about something that is not "old and exhausted".

Recommended and consulted literature from both NTNU and DNV GL will particularly evaluated, in addition to potentially other people with appropriate and relevant expertise.

Scope and contribution to DNV GL

Since the field of this expertise is a relatively new and growing discipline, my highest aim is to develop, or at least highlight some new ideas or guidelines for DNV GL, regarding barrier management with focus at maintenance. The scope and time limitations of the thesis makes the concept development emphasis at a general approach, and not directly linked to one specific barrier or/and maintenance activity.

1.5.3 Method

This thesis is based on scientific literature regarding any necessary area of interest, when working towards the achievement of the thesis objectives. Analysis of data from earlier investigations report are used, in addition to developing a fictive industrial scenario, where actual and existing methods and approaches of maintenance activities and barriers are used.

This is done to endeavour the importance and affiliation of maintenance in barrier management, quantitatively from both a real and fictive situation and scenario. The results will hopefully contribute to elucidate other aspects of the same meaning or/and analysis perspectives.

1.6 Thesis structure

The thesis is structured like a research report in accordance with the thesis description and problem formulation. After the preface and list of content etc., the first chapter consists of an introduction, which also defines many of the assumptions and limitations.

Chapter 2 - The first major part of the theory section is presented throughout this chapter. The chapter is structured logically in relation to the subsequent part, where the thesis' topic issues are analysed and presented chronological, based on the subparagraphs in the problem formulation. The chapter first presents several aspects of maintenance, maintenance management and maintenance concepts. This is followed by the presentation of safety and safety culture.

Chapter 3 - In this chapter, the second major part of the theory is presented. The first part includes barriers and barrier management, with the emphasis at barrier management planning and monitoring. This is followed by a little theory section regarding some common and general barrier methods or concepts. The final part of this chapter includes a presentation of scorecard, indicators and general information about PSAN.

Chapter 4 - Here is the first part of the main task presented, namely the relation between maintenance and safety. Several methods of maintenance are analysed, as well as how different maintenance activities may influence the safety of an operation.

Chapter 5 - In this chapter, the present situation regarding barrier management in PSAN is described. This is followed by an analysis of how important maintenance is in barrier management, using data from the Deepwater Horizon accident. PSAN's future ambitions and areas of focus are compared (and discussed) to the results from the analysis.

Chapter 6 - A presentation and analysis of two different maintenance indicators which could be included in the barrier management.

Chapter 7 - Maintenance in relation to technical, operational and organisational barrier elements are analysed and discussed whether maintenance functions or indicators may be defined as a barrier elements.

Chapter 8 - Throughout this chapter is the future concept and guidelines for DNV GL discussed and presented. Since the last part of this thesis' objectives is to present a future concept, the chapter will merge and represent both the ***discussion part of the thesis,*** in addition to the basic analysis and answer of the final subtask in the problem formulation.

Chapter 9 - The conclusion summarizes the analyses and findings, concluding the most relevant and essential parts in accordance with the objectives.

2. Maintenance and safety

This chapter *will present relevant academic theory regarding maintenance, maintenance management and safety. This develops much of the basis of this thesis' objectives, and is an essential fundament for the analysis and argumentation which are made throughout the final chapters.*

2.1 Maintenance

2.1.1 Maintenance

Maintenance is a generic term for how to plan and execute administrative, technical and managerial processes to maintain or restore an item's function, so that it is able to perform its required function, as adapted from NS (13306, 2010). In general, maintenance can be described as the knowledge and method for ensuring a stable intact system, primarily before and after maintenance activities. This is performed to avoid major losses and injuries in relation to health, economy, society, aesthetics and any other relevant factors in an organisation that relies on the systems functionality.

By Wilson (2002), maintenance is divided into two main categories, namely preventive maintenance (PM) and corrective maintenance (CM), with the following subcategories:

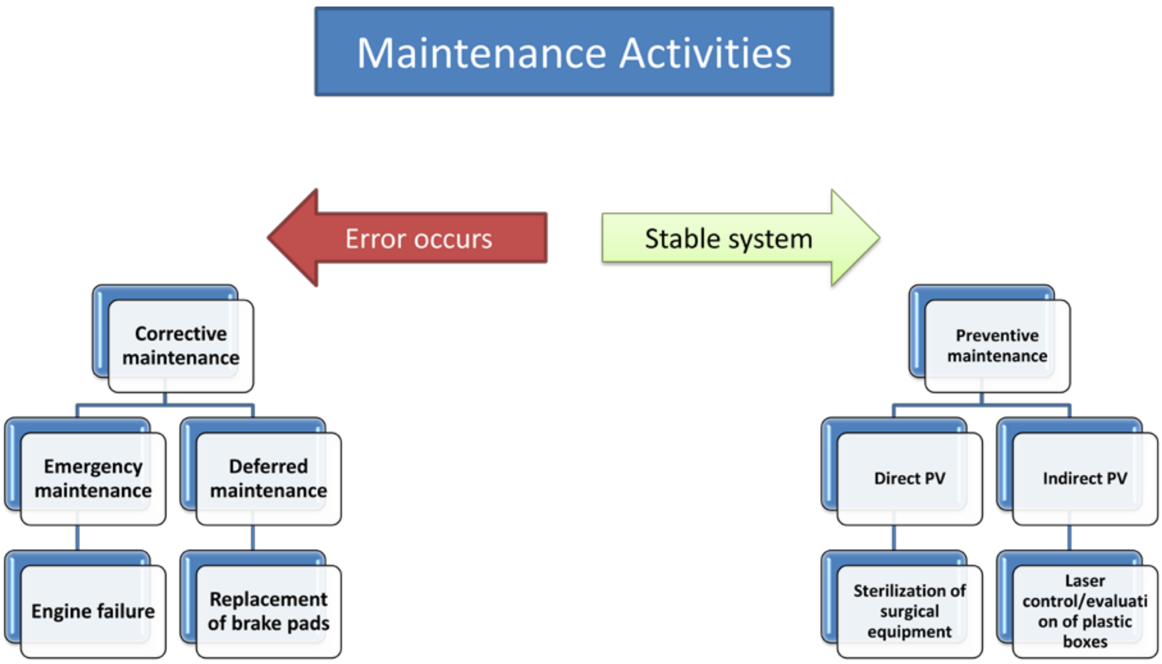


Figure 1 - Maintenance activities

Some examples of maintenance may be (NPD, 1998): Repair, overhaul, troubleshooting, removal, replacement, testing, adjustment, lubrication, cleaning and determination of the items/functions condition.

2.1.2 Preventive Maintenance

Preventive maintenance is performed before a potential failure of the system occurs, or a device function is inoperative. This is performed to prevent, or reduce the probability for any errors or failures (Øien, 2008). Preventive maintenance can be divided into two different categories, direct and indirect PM.

Direct PM is an interval, or sequence-based maintenance performance, basically to prevent that any errors occurs.

Examples of direct PM:

- Replacement of the breaks in a car after 20,000 km, which is made on the basis of recorded data for the number of miles driven, and the estimated durability of the device.

- Refill with chain oil on the chainsaw to prevent the chain of becoming too hot, and to wear prematurely.

Indirect PM is a more general form of maintenance, which is designed to identify possible errors at the earliest stage possible. This is often carried out through various forms of system monitoring and controls, primarily to prevent the error or the potentially next error, to cause any enlarged failure with more serious consequences at a later stage.

Examples of indirect PM:

- In an industrial process where various components are drilled out for the assembly of a larger object, the machine runs continuously until the monitoring system indicates a vibration level that approaches the specific limit of quality. It then requires a certain cooling period, ensuring that the machine produces quality assured products.

- A drill is identified to be 95% functional after a quality check. Quality regulations dictate that the drill delivers satisfactory results up to 90% functionality, suggesting that a maintenance execution must be planned.

2.1.3 Corrective Maintenance

Corrective maintenance is carried out after a failure is detected, with the main target to correct the errors and recover the systems functional normal state (Øien, 2008). This can either be acute and unplanned maintenance, or deferred planned maintenance.

Unplanned acute CM must be performed when an error causes an acute downtime and failure for a function. This is usually done the same day as the event occurs, but is ideally immediately implemented to get the unit functional again as quickly as possible. This often leads to negative economic consequences and repercussions for the system, since unplanned maintenance often requires additional time (Øien, 2008). Authorized personnel must be called, the errors and any potential physical damage etc. must be identified, and the associated maintenance parts must be obtained from either an internal stock, or ordered from an external source. All processes must also follow the specified procedure protocols, both to ensure the quality and safety of equipment and personnel.

<u>Unplanned acute CM:</u>

- Motor collapse in a running ship engine.

- Conveyor for a mass produced item wears off.

Planned deferred CM maintenance is a scheduled maintenance activity which is executed after the faults, or failures in the system, are identified. In case of deferred maintenance, any postponed corrective execution has to be postponed in accordance with the given maintenance protocols (Øien, 2008). A well prepared planned deferred CM follows all safety protocols, as well as minimizing the time spent in acquiring the necessary equipment, parts, personnel and installation.

<u>Planned exposed CM:</u>

- The indicator light on an industrial machine indicates that a hydraulic pump delivers a lower pressure than it should. The pump still delivers a sufficient pressure in accordance with the quality and production frameworks, but a maintenance operation is required.

- The operator of a forklift in a warehouse notices that the brake suddenly begins to emit abnormal sounds. After an inspection, it turns out that the brake discs soon will be exhausted. A maintenance performance is required and must be scheduled.

2.1.4 Reflection

Wilson (2002) points out that acute CM-activities are much more expensive than indirect PM. Acute CM causes a malfunction to the system or device, resulting in an unplanned downtime, and increases the likelihood of losing both time and money in potentially lost production and related maintenance. From another point of view, it is limited how much one can invest in monitoring and control, before one probably will lose money on the usage of surveillance systems. It is all about running a proactive maintenance philosophy, where the organisation is well prepared with identified and classified uncertainties and risks, responsibilities are clearly delegated and appropriate measures and systems are integrated in areas where it is deemed necessary (this will be discussed and defined in the next chapter).

Optimization: Cost Minimum preventive efforts

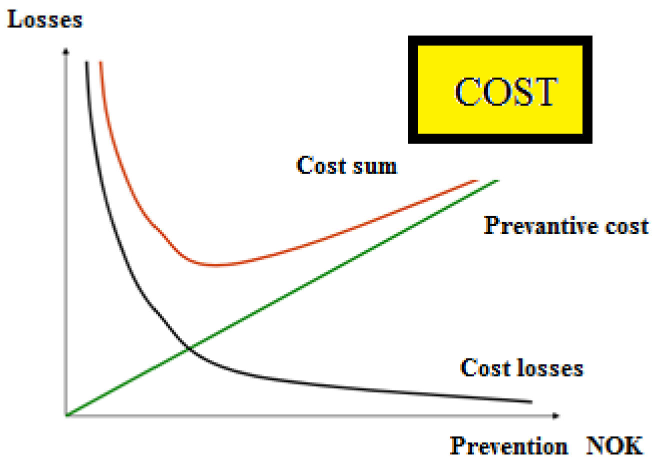


Figure 2 - Graphing the relationship between loss and prevention (HOVDEN, 2013a).

Figure 2 above illustrates how the relationship between CM costs (loss costs) and PM costs (cost of prevention) refers to the total cost sum (Hovden, 2013a). John Day and Alumax California was certified as one of the first companies in achieving World Class Maintenance (see chapter 2.3.2), and developed the 6:1 ratio between PM and CM for an optimised cost benefit maintenance program (LCE, 2007). LCE argues that the value in the maintenance strategy development lies in determining the ratio individually for every function which requires maintenance, based on several different variables:

- **Asset** criticality, age, history and technology.
- **The** trust in the asset to perform.
- **Percentage** of delegated resources on PM, CM and emergencies.
- **Change** the PM frequencies within the already established guidelines (ISO etc.).

2.2 Maintenance Management

***Maintenance management** is crucial to any industrial company, when it controls and determines how maintenance is performed. This is particularly important in the proactive phase of maintenance and how to continuously improve existing maintenance functions.*

2.2.1 Maintenance Management

Under the standard NS-EN 13306 (13306, 2010), maintenance management (MM) is defined as:

".. *all management activities that determine the maintenance objectives, strategies, responsibilities, and implement them through initiatives such as maintenance planning, control and supervision. This is done with a continuous improvement of the organisational methods, including financial aspects*".

In general, MM is presented as the way the system's maintenance functions are analyzed, improved, controlled, planned and strategically executed to ensure a stable and secure system in relation to the objectives.

A system is considered as ideally stable and safe when only preventive maintenance is performed without any incidents of emergency maintenance, as with unplanned failure which could lead to serious accidents and/or death. Should an unplanned and sudden event occur immediately after a CM maintenance operation is completed, the involved and responsible actors are obliged to perform proactively work to prevent recurrence of both the direct and underlying cause of the incident (NPD, 1998). Proactive is described by Bokmålsordboka (2014) as to something that prevents undesirable incidents to happen.

It is consistent with the theoretical definition of maintenance management, also developed various models to illustrate how the relationship between the various phases of MM must be related. This is designed to ensure that the objectives are achieved, as well as to ensure a proactive and progressive MM. In Figure 3, the control loop from the basic study (NPD, 1998) is illustrated.

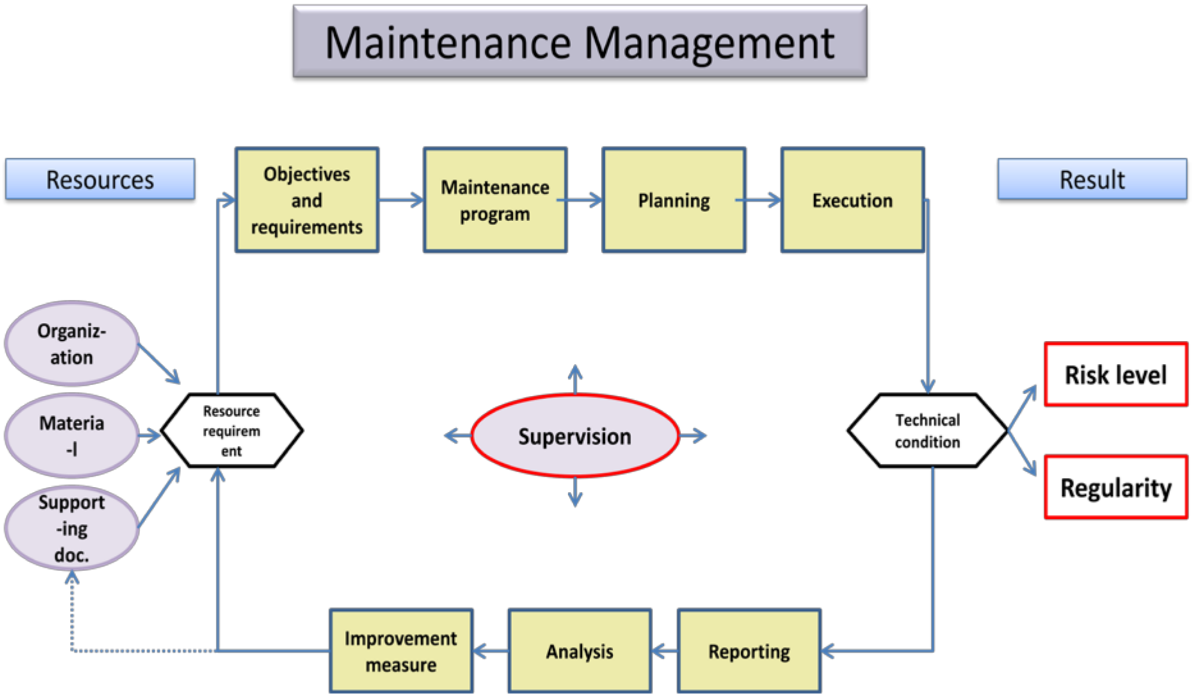


Figure 3 - Adapted control loop for maintenance (NPD, 1998).

It is developed several regulations which set the framework for how the maintenance management shall be controlled. From the *Activities Regulations* (NPD, 2001), a few sections are described as follows:

§ 45 Planning and Priorities: "*It shall be prepared an overall plan for conducting maintenance program and corrective maintenance activities*."

§ 46 Maintenance Efficiency: "*The effectiveness of maintenance should be systematically evaluated on the basis of recorded data for performance and technical condition of facilities or parts thereof. Evaluation will be used for continuous improvement of the maintenance program*."

The control loop (CL) is constructed in such a way, that it proactively seeks to constantly optimize the maintenance performance, with an effective usage of MM. This is done by continuously analysing the maintenance condition, where valuable data are collected as a basis in improving identified weaknesses.

Risk evaluation and *risk management* are not mention in this management's CL, but is further elaborated in chapter 3.1.3 within barrier management planning.

All the different phases must be functional and operational for the control loop and maintenance management to function effectively, as well as performing the correct maintenance. In Figure 4, each of the major phases with their accompanying function is defined (NPD, 1998).

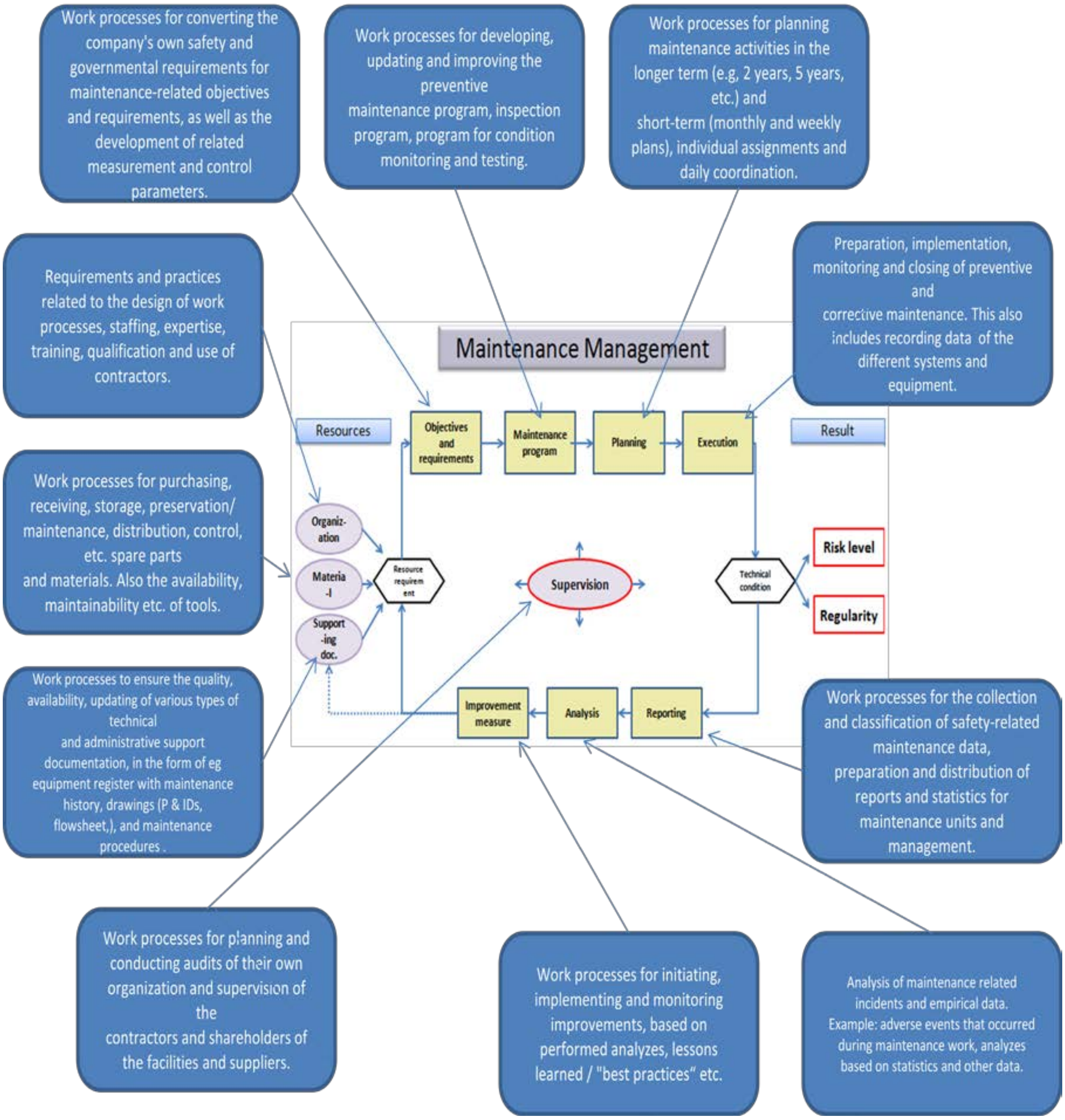


Figure 4 - Control loop with a functional description of each control element (NPD, 1998). (Enlarged in appendix IV1).

2.2.2 Reflection

Based on the system or which device/component the control loop must administer, it may be appropriate to emphasis certain phases more than others. This is often evaluated on the basis of the process complexity, objectives, previous data, efficiency etc. It is through the past decades been a major development in maintenance and MM, from primitive reactive systems, to broad and proactive maintenance concepts (SKF Reliability Systems, 2008), which will be explained in detail in the next chapter. During the last 10-12 years, the integration and importance of maintenance management in areas such as barrier management has been in focus, especially since several of the companies often develops their own separate adaptation or interpretation of the theories. This is also one of PSAN's main priorities of improvement (PSAN, 2014c).

2.3 Maintenance Concepts and tools

***Maintenance management** and maintenance procedures have evolved from being rather simple and primitive, to a much more complex and interdisciplinary system. One of the modern industry's most common concepts and areas of usage will be presented in this chapter, since it is related to the thesis basis and objectives.*

Maintenance concepts are basically developed by the ever fast evolving industry and its demand of greater automation and generally higher quality requirements for the implementation of production.

From reactive systems, which mainly relied on repairing errors as they occurred, to holistic and integrated maintenance systems dealing with advanced proactive risk analysis, monitoring, adaptation during design and active participation from all levels of the organisation (Moubray, 1997).

Maintenance and maintenance management has gradually become more integrated into all levels of the organisation, both in terms of productivity, economics, regulations, health, safety and the environment. Moubray (1997) divides the maintenance development into three phases between 1940 and 2000. This is illustrated and explained in Figure 5, which also indicates the generations in relation to the development of maintenance techniques (SKF Reliability Systems, 2008).

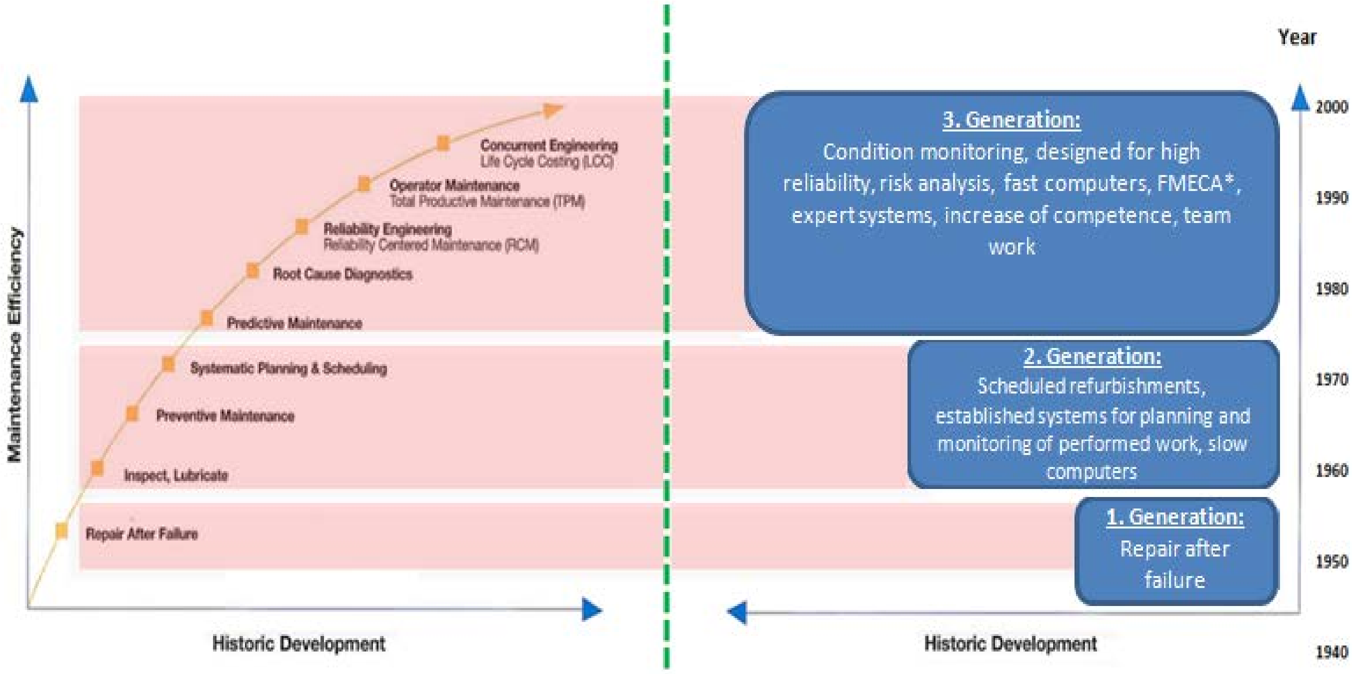


Figure 5 - This is an adaptation that roughly shows the relation between the various maintenance techniques from SKF (SKF Reliability Systems, 2008) and the generation section (Moubray, 1997), and is intended as an illustration. (*FMECA = Failure Modes and Effects Criticality Analyses).

2.3.1 Total Productive Maintenance (TPM)

Total Productive Maintenance was developed in the 1970s in Japan (Nakajima, 1989), and is designed as a tool to improve maintenance in a production by integrating the processes at a increasingly higher rate, which the development analysis in Figure 5 also indicate (CTPM, 2007). TPM aims to maintain a reliable and stable production, with a zero tolerance for faults, defects and accidents (Venkat, 2007).

2.3.2 World Class Maintenance (WCM)

Factors such as technology, processes and organisational culture will be essential in the future development of maintenance concepts (SKF, 2004), which also is described in World Class Maintenance. WCM is a concept developed by Terry Wireman (1990) in the 90s, and can be summarized to reflect a business/organisation with a world-class maintenance and maintenance management program.

<u>A typical WCM business will follow the trends indicated below:</u>

• The organisation's culture evolves by having a learning maintenance organisation. By analyzing and understanding the relationship between employees and the maintenance function, it should be capable of facilitate a learning maintenance organisation.

• Wider and more use of advanced technology related to IT and condition monitoring.

• Continuous proactive, referring to the newly developed business processes.

Meland (2007) has produced WCM with 16 different stages, describing how wide and coordinated a business must be organised to approach the WCM level.

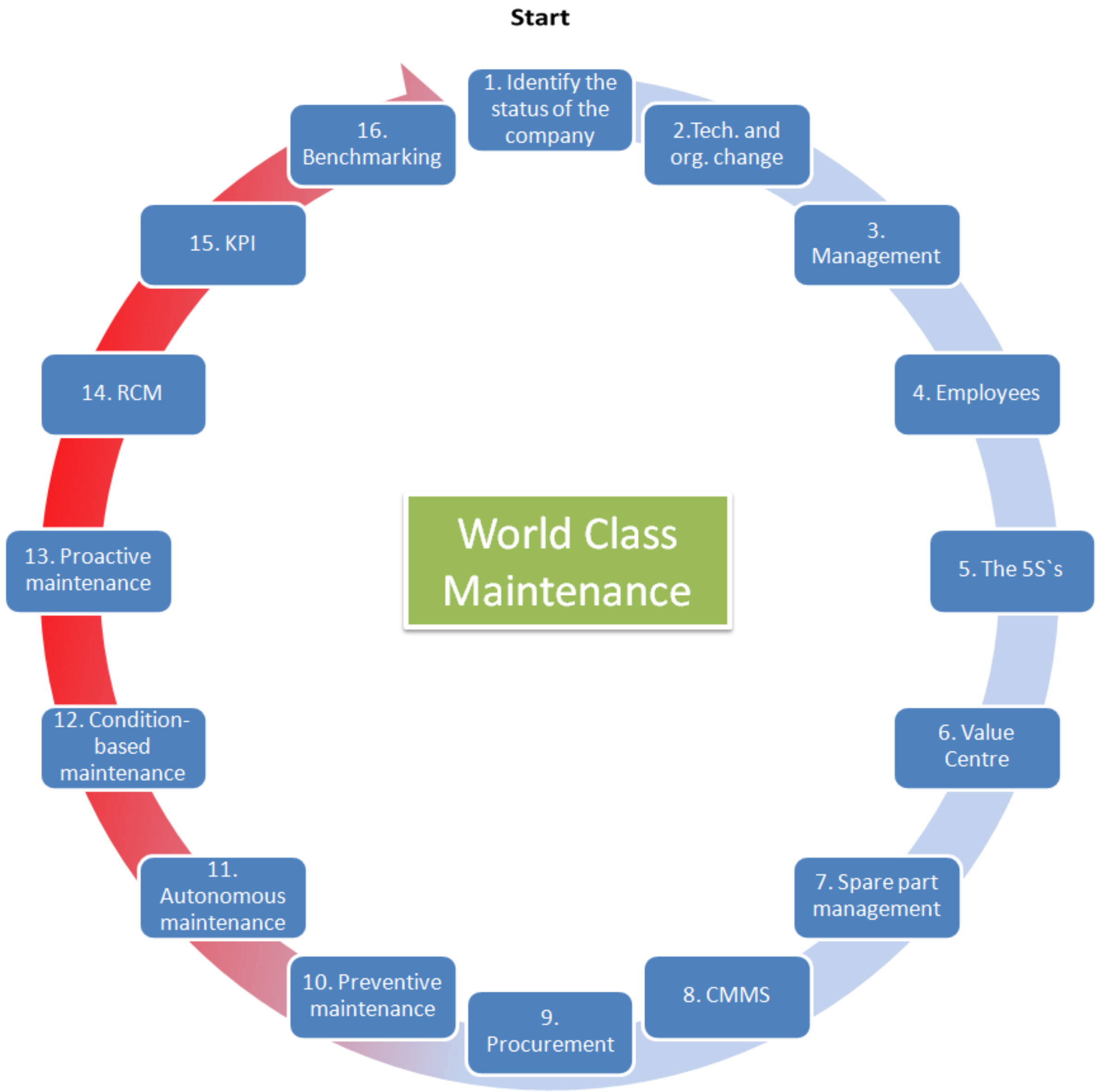


Figure 6 - 16 phases to achieve WCM, adapted from Meland (Meland O. J., 2007).

On the basis of the thesis formulation and objectives, I have chosen not to elaborate on all the joints in WCM, but mainly on the ones which may and will be connected to barriers and maintenance. Extended explanations of the additional phases can be found in Meland (2007).

RCM is not defined as a maintenance concept in itself, but as an integrated tool within other concepts, as e.g. WCM.

2.3.3 Reliability Centered Maintenance (RCM)

Reliability Centered Maintenance is a tool developed primarily within the aviation industry to optimize maintenance planning. RCM is a systematic analysis of all system functions, and for each system function, the reason behind its occurrence is analyzed. By evaluating the entire system on this basis, the RCM method is defined as a preventative maintenance program (Vatn, 2007). It also defines the RCM methodology as traceable, since each maintenance function after analysis and causal evaluation, has a reason.

RCM balances accessibility, security and cost, and is often used on already existing maintenance programs. RCM should be considered implemented and integrated when the consequences of any system failure may result in significant damage to either personnel, environment, production, maintenance costs, the system is over medium advanced and that previous data from the system is available (Vatn, 2007). The results from the RCM analysis will be used to eliminate inefficient maintenance activities, in addition to further development.

Rausand and Høyland (2004) have described a simplified method comprising seven questions to be answered through RCM, together with a description of each step:

RCM- Analysis

• 1. What features and expected performance standards does the equipment hold in its current operating environment?

Here, the user shall explain and define what and how the equipment shall perform. It is divided into two types of functions:

Primary: Rotation rate, storage capacity, quality, customer service etc.

Secondary: safety, emission, structural integrity etc.

It must also be clarified how the equipment is capable of performing its defined functions by the users involvement.

• 2. How can the system fail to fulfil its corresponding functions?

To be evaluated after the first part of the RCM analysis is answered, since the errors (malfunctions) only can be identified once you have identified what is required and expected of the equipment/system.

• 3. What is the cause of each individual error?

When an error is detected, the cause of the error must be identified. The causes must be classified as genuine failure causes. The last step in this process is to execute a Root Cause Analysis (RCA) to uncover the root causes, leading to the error.

• 4. What happens when each failure occurs?

Collection of information to place them in specific groups of consequences (in point 5 in the RCM- analysis). Questions that must be answered (Moubray, 1997):

- What evidence exists that the error has occurred?
- How is the error a threat to safety and the environment?
- In what way does the error affect the production and different operations?
- What physical damage is caused by the failure?
- What must be done to rectify the error?

• 5. In what way does the error have an influence or affection in accordance with importance?

Based on the information in section 4, the potential of the failures consequences in accordance with HSE, quality, maintenance, etc. should be classified. Huge potential impacts indicates that it has to be implemented many new, or improved preventive maintenance activities, and vice versa. After Moubray (1997), the consequences can be divided into four different groups:

1. <u>The impact of hidden errors:</u> No direct impact, but increases the likelihood that an error may occur with serious consequences.

2. <u>Safety implications:</u> Errors that can harm the health, environment or/and safety.

3. <u>Operational consequences:</u> Errors affecting production in terms of quality, quantity, etc.

4. <u>Non-operational impact:</u> No impact on the production and safety, but leads to repair costs.

• 6. What can be done to prevent each failure?

After a certain period of time, it shall be performed preventive maintenance through routine maintenance activities (Moubray, 1997). This is to ensure the next period reliability. Use of electronic equipment has changed the perception of errors developments.

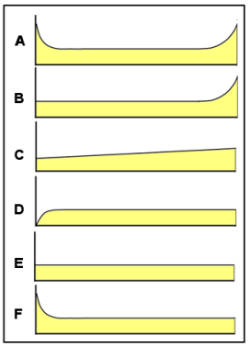


Figure 7 - 6 different errors developments (Moubray, 1997).

A: Bath Basket
B: Constant at first, abrupt increase at the end.
C: Constant increasing.
D: Low failure rate of new component, but a quick abrupt increase and then stabilize.
E: Constant.
F: High failure rate at the beginning, which drops to a constant level.

• 7. What to do if no appropriate preventive activities are there?

1. <u>Troubleshooting:</u> An interval-based approach that only identifies the error if the error occurred before the examination.

2. <u>Re-design:</u> Changes in process, the physical structure, skills / procedures etc.

3. <u>Zero Maintenance:</u> Nothing to be done before the error occurs.

2.3.4 Reflection

WCM could be summarized as the most endeavoured practised maintenance management concept, since it in several ways includes the most efficient and modern solutions. This is both in form of technological solutions, as well as aspects from the safety and working culture. To establish and maintain a top WCM standard in every phase at every situation in an organisation will probably be too costly. Establishing an adapted concept in accordance to interests and objectives should be expedient. TPM could for example be prioritised in phases where zero tolerance for any failure is crucial. This is also discussed in chapter 2.4, about safety and costs. Condition-based maintenance has been proven useful in section 6. above, where preventive maintenance is formulated. Preventive and proactive maintenance is the most important form of maintenance, indicating RCM as a sensible method. However, RCM may be too complex for simple and easy systems.

2.4 Safety

***Safety should** be the number one priority of every organisation and company around the globe, especially in industries where accidents may lead to potentially major consequences. The concept of safety will in this chapter be explained, and several different aspects which influence safety will be illustrated.*

2.4.1 Safety

Safety is primarily about preventing economical, health, property- loss and damage. In a broader perspective, safety is also about the fundamental feeling of being secure, provided by an internal safety, experience of self-mastery and control, as well as having confidence in those responsible for safety (Hovden, 1998).

Safety can be defined as a systems level of resistance, and how capable it is from preventing any potential losses, in addition to the rewarding feeling of comfort involving the users of the system. A well functioning system will keep the risk of adverse events at an acceptable level, while the level is as low as possible, also known through the ALARP principle: as low as reasonably possible (Hovden, 2013a). The ALARP principle is often used in the context that safety risks are identified, evaluated and assigned to different barriers for the scope and significance, but the method can also be used to evaluate an already established system.

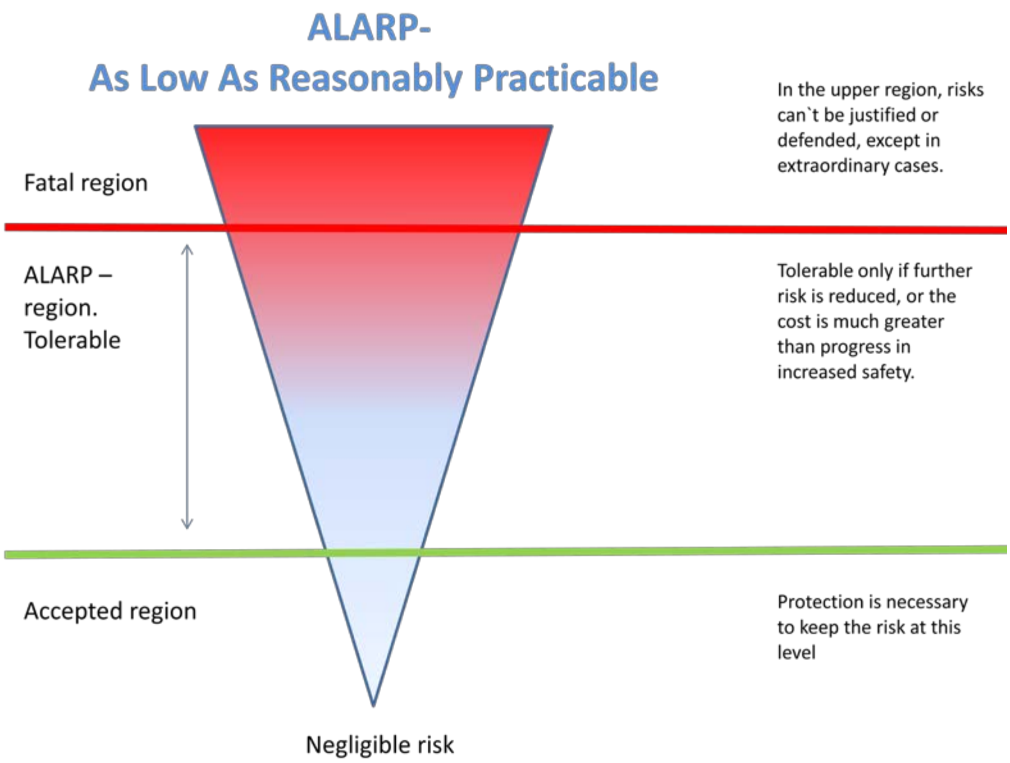


Figure 8 - The relation between risk and acceptable safety (HOVDEN, 2013a).

The risk that undesirable random events will occur in a system may in some cases be calculated statistically, where the calculations assumes that the events occur relatively frequently (Hovden, 1998). In other words, one can from an analytical and mathematical view, classify the safety level of a system, for example by presenting the number of accidents that occur for a given work process over a given time or frequency.

Developments in the understanding of safety and safety research in recent decades has evolved through three generations (Hovden, 2013b):

- **First generation:** Viewed as just a technical challenge and other factors were not included in the overall assessment.

- **Second generation:** The focus was directed over from the technical to the interpersonal challenges. It would endeavour to eliminate human error.

- **Third generation**: Safety is a complex challenge that is created in the relationship between technology, people and organisation, both through informal and formal aspects.

- **Next Generation**? Self-regulating and resilient organisations.

As illustrated in Figure 9, the interaction between technology, organisation and humans will constitute the level of risks and safety. Conclusively, the level of integrated maintenance will also influence the degree of safety, since the relation between maintenance and safety is crucial to any function or system. This relation is further described in detail in chapter 4.1

Figure 9 - The relationship between technology, people, organisations and safety (HOVDEN J. &., 2013b).

Overall, information from both people and technology can help indicate where the greatest and most relevant safety challenges are located in a system, or an organisation (Hovden, 2013b). If an unforeseen event should occur in a system, one can by using this information, identify what went wrong, how it went wrong and through further and deeper investigation, also explain the underlying causes of the incident. In relation to inter alia the ALARP principle, there must be executed a risk assessment compared to the current safety level, where any new or revised safety measures may be required.

Several different safety measures are listed in the Table 1 below (Hovden, 2013b). These will form much of the general principled basis in the further development of DNV GL's barrier management concept later in the thesis.

Table 1 - Different safety measures

Physical measures	Organisational measures	Person-oriented measures
• Amount of energy and type	• Allocation of duties	• Training
• Machines and equipment	• Staffing and shifts	• Information, motivation and attitude
• Work processes	• Safety inspections	• Prosecution warning and sanctions
• Shape and layout	• Management Functions and responsibilities	• Location and relocation
• Protection devices, barriers and protective equipment	• Preparedness and claims handling	
• Order and cleanliness		
• Maintenance		
• Ergonomics, physical/chemical work		

2.4.2 Safety Culture

Safety culture is an essential part of how the total degree of safety establishes in an operation, and how it degenerates or improves the overall safety over time. Safety culture is therefore explained in further detail in this sub chapter, since the concept is useful to emphasis in certain later analyses.

Safety culture is a term that emerged after several serious accident investigations in the 80s, including Chernobyl (IAEA, 1991) and Piper Alpha (Cullen, 1990). Several common factors from the investigation pointed in the direction of weaknesses and deviations in the organisational culture. As a result of this, it was taken a greater interest in the phenomenon of safety culture than before. Safety culture has many definitions, but a general approach may be as follows: those aspects of culture that affects the safety in accordance with the common and shared (Bolman, 2004):

- Perspicuous
- Values
- Attitudes
- Opinions
- Motivation
- Ideas
- Expectations
- linguistic expression
- Specific actions
- Rituals
- Ceremonies
- Symbols
- General behaviour and associated standards

In addition, safety culture is referred to as how the product of different values, both individual and in groups, as well as knowledge and behaviours, will be reflected in the work and performance of safety (HSC , 1993). Safety culture can be regarded as the relationship between the organisational culture and safety, where the relation between the organisation's safety structure, attitudes and performance in practice, contributes and shapes the safety culture:

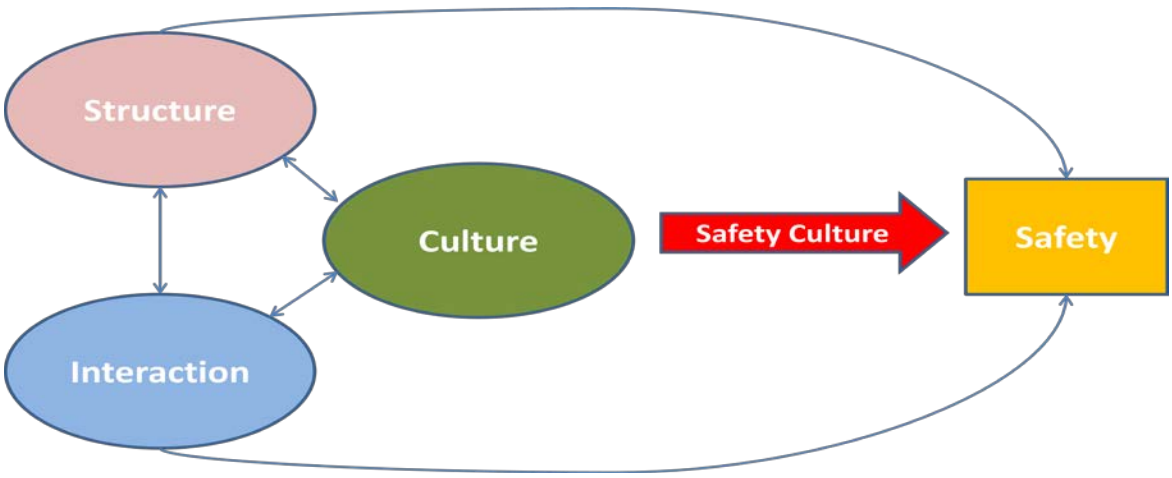


Figure 10 - Illustration of how structure, interaction and culture are related to safety culture and safety.

A well established safety culture is by Reason (1998):

- Informed and fair
- Based on solving problems, not condemnation and punishment
- Emphasises the importance of reporting

From another point of view, one can experience a gap between the determined policy and actual practice, which is based on the different organisational cultures (Antonsen, 2013). The regulations and framework can be interpreted as only paperwork; external management and standardised, but not necessary. Attitudes based on independence, knowledge and crafts can cause informal protocols as "this is the way we do things around here". Problems arise when the gap between procedures and practices becomes too large, resulting in reduced strength of safety in several areas, such as:

- Inspection
- Risk assessment
- Learning

By analyzing and determine the organisations safety objectives, it is important to try to understand the safety culture, instead of trying to directly modify it by any allegations of error. A culture can rarely be controlled or produced, it is something that naturally occurs based on the given conditions. It would therefore be appropriate to try to facilitate communication and understanding across cultural interfaces in an organisation (Antonsen, 2013). Much of the safety culture consists of the ability to:

- Recognize risk
- Capturing changes in the risk profile
- Challenge their own understanding of risks
- Be able to prioritise and implement improvement

Shell's minds and hearts program

An organisation's safety culture can also be positioned and defined after Shell's minds and hearts program, where it illustrates the organisation's policies and practices in relation to each other (Westrum, 1988), as shown in Figure 11

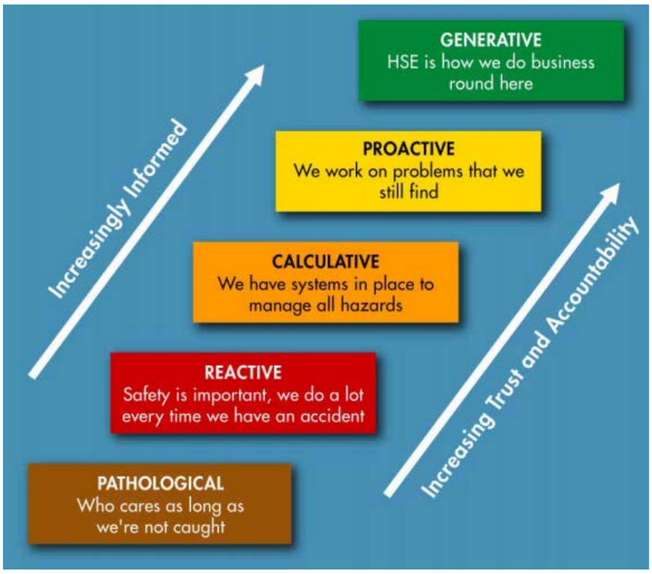


Figure 11 - Shell's minds and hearts program.

The different approaches have typically different characteristics, which show how reactive or proactive the organisation's safety culture is. From the pathological standpoint, which is the culture with the lowest interaction skills, as well as available information for a sustainable safety culture, to generative, which is the opposite.

Table 2 - Characteristics of the various approximations.

Pathological	Reactive	Calculative	Proactiv	Generativ
Dismiss the man who had the accident / incident	Safety is high on the agenda after an accident	Have a somewhat random "we solved it!" attitude	Resources are allocated for maintenance before an accident occurs	Chronic anxiety
Accidents are seen as part of the industry	Much discussion around an accident to re-classify it	Much is being led oversees	Management is open for suggestions, but still very focused on statistics	Security is seen as a profit center
The lawyers and the administrators said it was okay	Weak follow-up by management even if things are not done by the book	HSE advisors searching for statistics	The procedures are "owned" by the workforce	New ideas are welcome

Safety culture can therefore be noted to have a vital role in how a safety system actually works in practice. This is seen from multiple perspectives, of which the two most important is how the management affects and follows up the safety and puts it all into a functioning framework. It is also essential how it is exerted and functionalised (IAEA, 1991). Safety culture is essential in how to proactively work towards a more robust organisation, for the earliest possible detection and understanding of different warning signs, and how to further restore balance in the system (IAEA, 1991).

This is obviously to prevent accidents from occurring. To achieve a proactive and robust organisation, HRO - High reliability organisation (see chapter 3.1.5), concepts as robustness, implementation of redundancy and the ability to adjust in response to changes is necessary (Roberts, 2010). In order to maintain a sustainable, efficient and proactive safety culture, it is important to have a good balance between multiple relations. Today's trend is mainly aimed at detecting warning signs before an accident occurs, and typical proactive measures that affect the safety culture are (Roberts, 2010):

- Reward and Recognition: Contributions and proposals are rewarded, not punished.
- Process Monitoring: Discover the expected and unexpected.
- Leave decision-making to the most appropriate person.
- Good structure in the formal rules and procedures.
- Risk perception: Knowledge about the existence of risks, as well as its scope and extent.
- Training: High technical competence.
- Organisational capacity.
- Managers and persons in charge who sees the whole perspective of a situation.
- Quality Assurance System.

From preparation, attentiveness and action, it has been set up different organisational prerequisites in the Figure 12, which is the fundamental basis for a well functioning proactive and reactive system (Schiefloe, 2013). This illustrates the relationship between the various conditions in safety culture, and how it affects the operation.

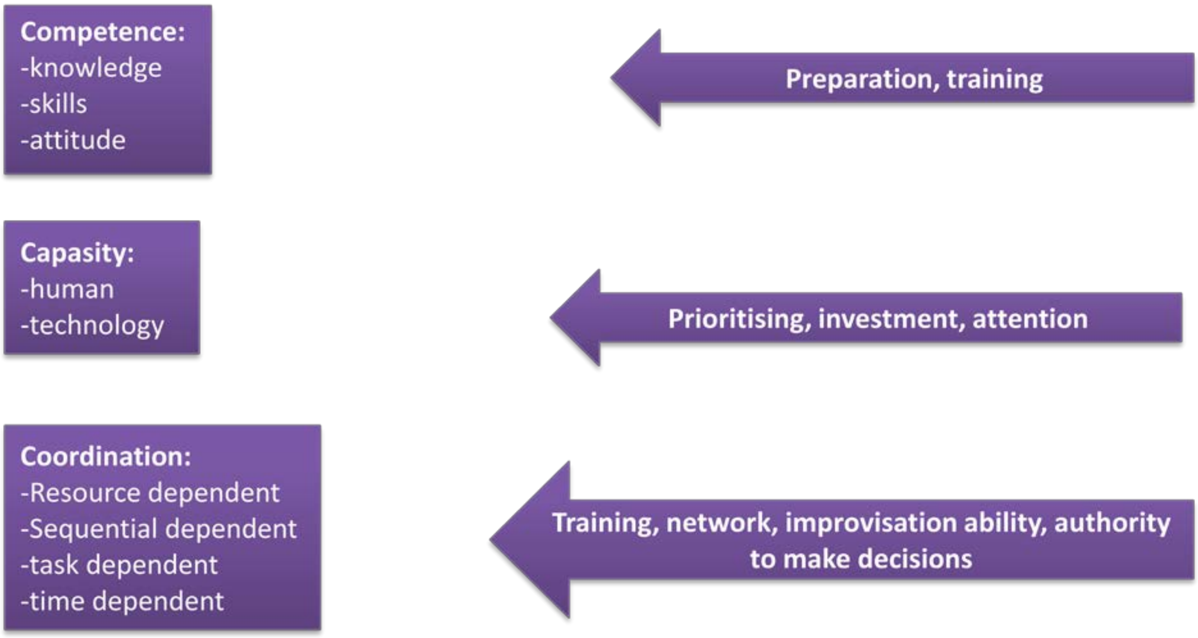


Figure 12 - How different safety culture conditions will affect a safe operation.

Hovden and Albrectsen points out several overarching principles of safety work (2013b). These are highly significant in the management of safety, and how and where to include maintenance. This can be useful to integrate in the concept development later in the thesis. The principles are described as :

- ✓ Closed control loops and systematic exception handling.
- ✓ Safety culture and learning.
- ✓ Management Responsibility.
- ✓ Technical, administrative and individual-oriented measures for increased safety.
- ✓ **Barriers and redundancy with defence in depth.**

3. Barriers and barrier management

This chapter *will focus on barriers which are the most essential obstacles or functions in keeping both personnel and equipment from dealing more (or any) damage or abrasion than necessary. Barriers and barrier management are as written in the problem formulation, becoming more and more important.*

3.1 Barriers

3.1.1 Barriers

The word barrier has its origin from France, where its general function and meaning is defined as an obstacle, hindrance or sharp distinction (PSAN, 2013b). Different barriers and their wide area of usage have been present in several industries for many decades, and some will even say millenniums. From the early usage of shoes to protect our feet, to hearing and sight protection at a modern industrial plant. Everywhere one goes, one meets different solutions and usage of barriers, and they are all there to protect people and equipment from different forms of damage and injuries. Barriers' main objective and purpose are to minimise any potential danger and consequences, where someone or something are exposed to any form of risk. In recent years, the focus at barriers and barrier management has been increasingly prioritised, since the basis of barriers in safety management has proven to be significant and crucial.

The usage of the term *barrier* was first implemented in the Norwegian petroleum regulations in 2001/2002 (PSAN, 2013a). From the PSAN's barrier report, which elaborates about different principles regarding barrier management, they translate a barrier as follows (PSAN, 2013b):

"Technical, operational and organisational elements that individually or together shall reduce the possibility that any specific error, hazard and accident occurs, or restrict or prevent damage/inconvenience".

In accordance to this definition and a more general barrier insight, several expressions and terms are determined to better explain the concept of barriers (PSAN, 2013b):

Barrier function

- **Why is the barrier there?** The fundamental and specific task which each barrier has been delegated.

- **Examples of this can be:** Prevent gas leakage, prevent ignition, reduce fire impact, justifiable evacuation and hearing protection.

Barrier elements

- The summation and interaction of technical, operational or organisational measures or solutions which "builds" and realises the barrier function:
  - Physical barrier elements:
    - Technical
  - Non- physical barrier elements:
    - Organisational: Related to the employees and their position in determined functions.
    - Operational: Specific tasks and acts the employees are obliged to perform.

Figure 13 - Reason's illustration of barriers related to different elements and factors (Reason, 1997).

As illustrated in Figure 13, several factors are crucial to prevent any form of accident. From organisational and local workplace factors to unsafe acts, maintenance has an important role of proactively prevent and maintain every barrier's function. This is further described in chapter 4-6.

Performance requirements

Verifiable requirements to ensure that the barriers are effective:

- Physical barrier elements:
  - Glasses, fire wall etc.

- Non- physical barrier elements:
  - Competence, experience, delegated resources in personnel etc.

Both technical, operational and organisational measures may have the same grading scale to evaluate and determine the quality of the barrier element. This may be analysis of the elements capacity, functionality, efficiency, integrity, reliability, robustness and availability.

Barrier management: Further described in chapter 3.1.2.

3.1.2 Barrier management

***Barrier management** administers the concept and development of barriers. In that way, BM is a vital phase of ensuring the barriers continuous improvement and functionality. This chapter will summarise the area of barrier management, with emphasis at the planning phase.*

As in the definition from NS-EN13306 (13306, 2010), barrier management in general can be obtained on the basis of maintenance management and adapted as:

"*.. all management activities that determine the barriers objectives , strategies, responsibilities, risk analysis, and implement them through initiatives such as barrier planning, control and supervision. This is done with a continuous improvement of the organisational methods and strategies, including health, safety, environmental and financial aspects*".

Barrier management has its main purpose to establish, maintain and monitor that every barrier is effective, thus that every barrier element is necessary, as well as continuously ensure that the required barrier function is fulfilled (PSAN, 2013b). This applies to both technical, operational and organisational elements, and how those are integrated and coordinated to maximise the compliance for an optimised and total barrier effect.

It is also essential to point out that barrier management cannot be integrated as a distinctive or separate form of management in an organisation.

Figure 14 - Barrier management as a part of an integrated and overall organisational management (PSAN, 2013b).

To ensure that every aspect in the overall management will optimise their desired affect and influence on their respective area of interest, every subsystem should be considered in correlation to each other, and integrated as one complete and overall system.

As mentioned under Barriers in 3.1.1, the term *barrier* was first implemented in the Norwegian PSAN's regulation in 2001/2002. In retrospect, PSAN has experienced many deviations in different interpretations when comparing different actors and companies. The most important weaknesses regarding barrier management in the Norwegian petroleum industry are listed up beneath (PSAN, 2013a):

- The actors have in varying extent implemented regulatory requirements on barriers as intended.
- Failure or degradation of performance of one or more barrier elements is a general causation of incidents and accidents.
- Strategies and processes for improving the robustness of barriers in the various phases of a facility's life cycle have evolved in different directions and have different maturity.
- There is a need to highlight the commonalities and complementary features between a barrier element's condition, as well as its performance and operating maintenance and risk management.

PSAN has developed a fundamental model for how to plan and perform barrier management in the petroleum industry. The model is vital and useful in this thesis, and will therefore be relatively thoroughly explained (PSAN, 2013b). Maintenance as mentioned in chapter 2, is also vital to include in PSAN's BM. PSAN also argues that in today's situation, maintenance within barrier management also has areas of expansion, integration and improvement.

An overall and general approximation of each planning process contains five mainly evaluations and steps:

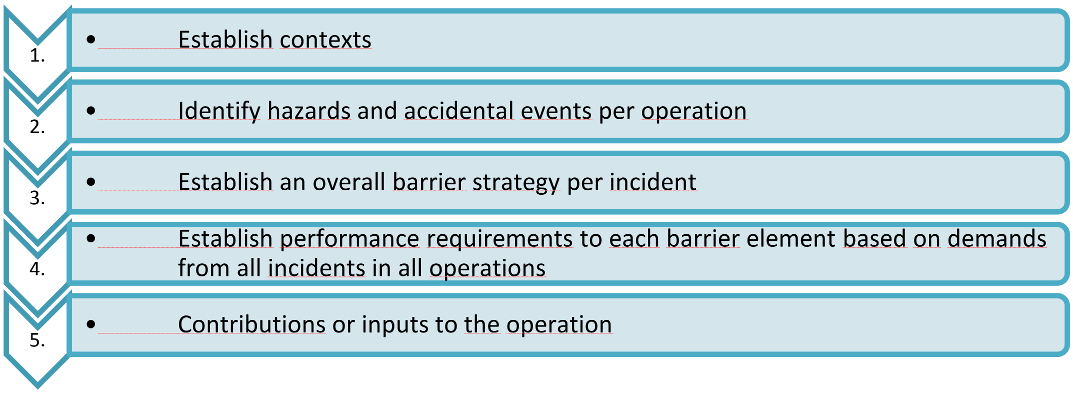


Figure 15 - 5 overall evaluation steps.

Figure 16 illustrates how the different aspects of barrier management planning and evaluation correspond to each other. Each step in the process will also be explained:

3.1.3 Barrier management planning process

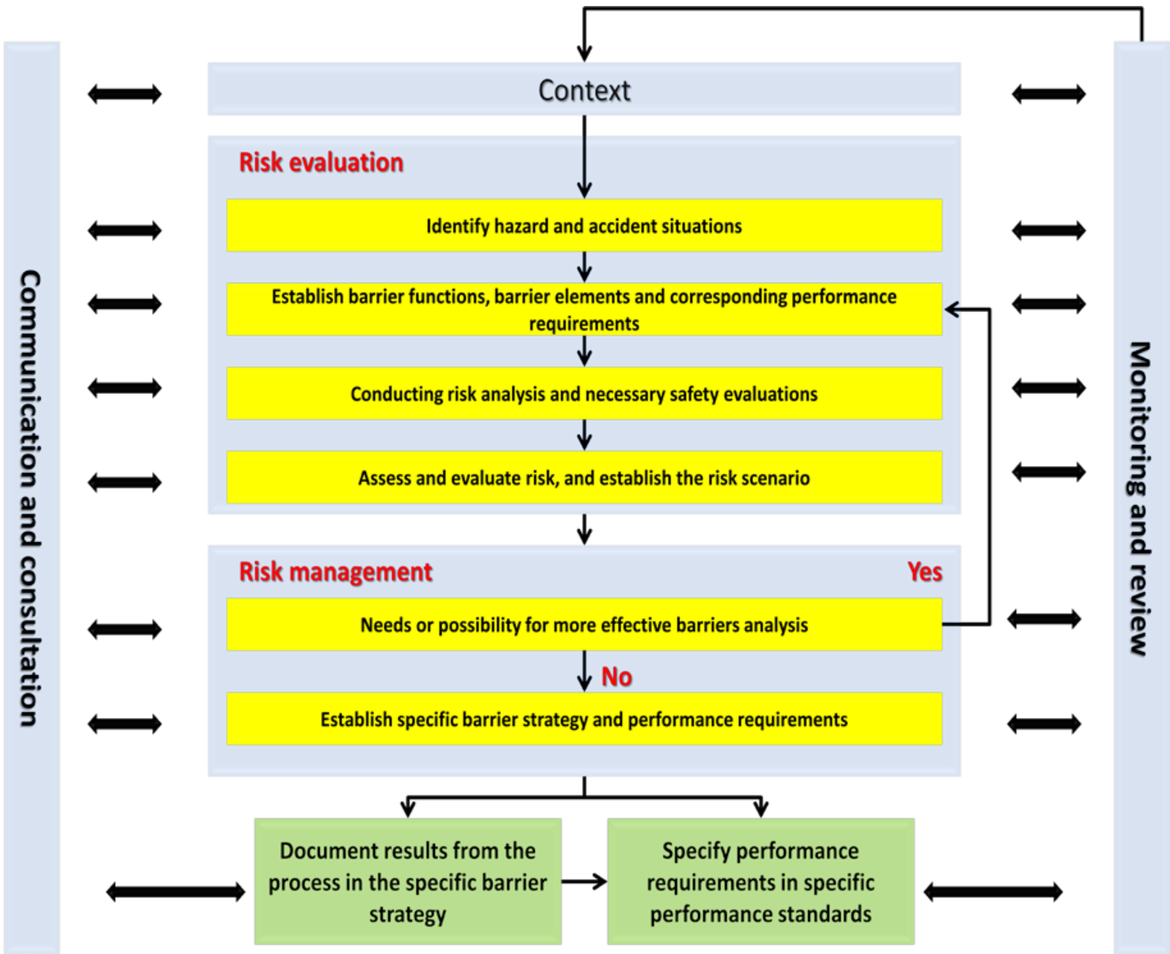
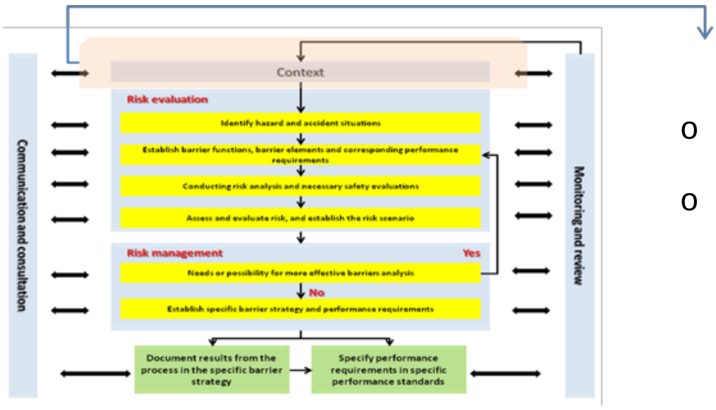


Figure 16 - Barrier management planning process (PSAN, 2013b).

Barrier management planning process - Step 1

Context is the process where all external regulations, as well as any additional internal conditions, are evaluated and considered before proceeding. All information and data which may have an impact or influence at the overall and further process, must be gathered and evaluated before finalising this process step.



- Establish contexts.
- Evaluate requirements and principles in legislation, standards and the organisations own policy.

Figure 17 - Barrier management planning process - Contexts (PSAN, 2013b).

- Specific solutions, objectives, policies, strategies, and principles for barriers and barrier management, in accordance with the specific company or organisation.
- Risk reduction and post operation requirements.
- Ambitious objectives and requirements will often indicate the solutions resilience later in the process.

Barrier management planning process - Step 2

Risk evaluation shall contribute to identify, establish and describe different barrier functions. It is also essential to specify every barrier element and its properties.

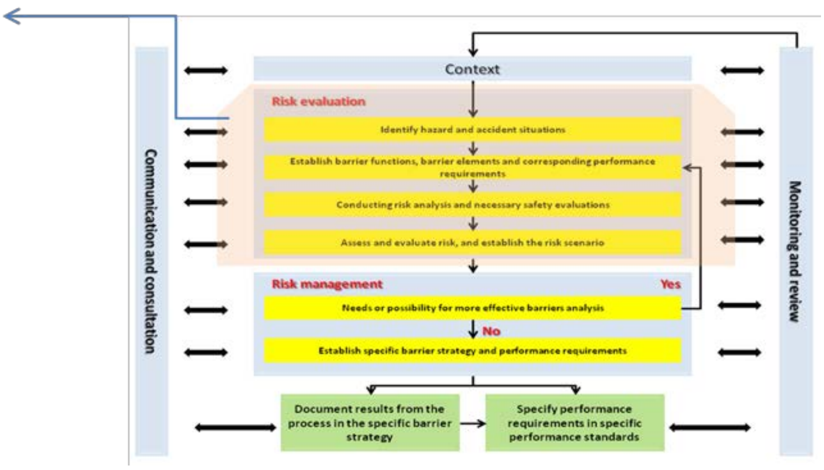


Figure 18 - Barrier management planning process - Risk evaluation (PSAN, 2013b).

- **Identify hazard and accident situations regarding root causes and potential consequences they may add:**

  In this section, every possible situation that may be hazardous and lead to a potential accident, must be identified and classified. This adds the fundamental basis for the development of barriers and its corresponding elements, where each element has its particular function and "responsible" area of protection.

  At first, e.g. in an organisation or at an industrial plant, different areas are separated and individually evaluated. Every risk or hazard that gets identified gets its specific barrier element to maximum decrease any potential consequences if an unwanted situation should occur. The second step is to analyse the barrier elements in accordance with any potential hazards or threats from other areas and exposures, to ensure their resilience and function efficiency.
- **Establish barrier functions, barrier elements and corresponding performance requirements:**
  When every potential hazardous and accidental situation is predicted, identified and analysed, the next step is to determine the barrier's function, the barrier elements and its performance requirements.

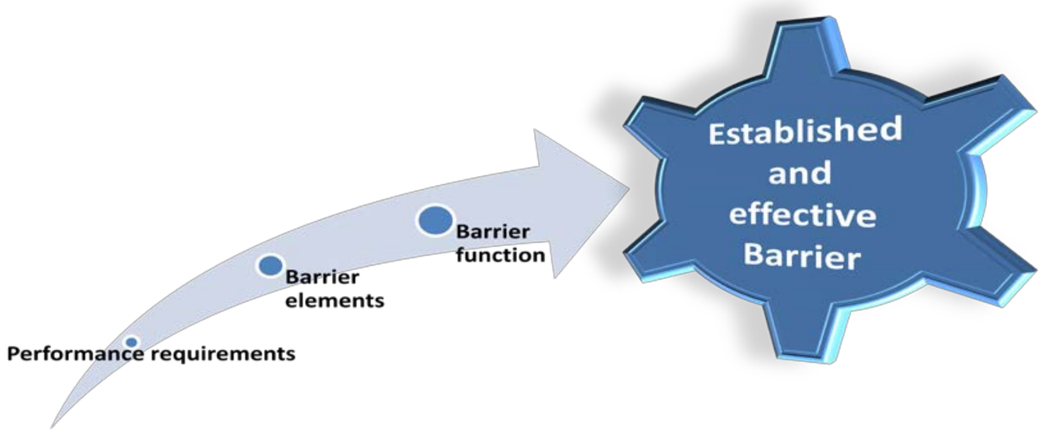


Figure 19 - Logical development progress of barrier functions.

In an early phase of the planning and development of the design, it is common to base the requirements from regulations and standards. Then several risk analysis, mapping of areas with uncertainty and additional details regarding the project, are considered to optimise the performance requirements.

Maintenance is an essential function to include in the development of these phases, since maintenance is the basic process of ensuring the barrier's continuously capability and function over time.

- **Conduct necessary risk and safety analysis, as well as evaluating their relation and corresponding purpose:**

  This is added as an independent section, since several barrier functions and their corresponding performance requirements often are developed after performing a qualitative analysis. By making this as a separate step, providing that quantitative analysis are added, will increase the level of details regarding the development of the final performance requirements. The present situation indicates that the industry should be better at making different prerequisites available during the planning and development of barriers.

- **Assessments of the different risks, including any sensitive and unsafe factors. Establishing the overall risk scenario:**

  The results from the different risk analysis shall be compared and assessed towards the established criteria. The criteria, which the results from the analysis are to be compared with, will often be both internal and external organisational objectives, as well as different standards.

  In accordance with barrier management, the overall risk scenario is the basis for developing the barrier strategy and ensuring that the barriers hold the necessary properties which are required.

Barrier management planning process - Step 3

Risk Management is the last process where risks and potential needs are evaluated before starting the final development of the barrier strategy.

Figure 20 Barrier management planning process - Risk management (PSAN, 2013b).

PSAN specifically points out that working with risk analysis and reduction in an early stage in the development increases the possibility of creating high quality and efficient solutions, without causing too much expenses. If any unidentified needs or more efficient solutions are discovered, the planning returns back to Risk Evaluation step 2 - establishment of barrier functions. If not, the final barrier strategy establishment continues with the development of the two final products, which are described in Step 4.

- Specific, detailed and an overall barrier strategy.
- Specified and detailed performance requirements in specific performance standards.

Barrier management planning process - Step 4

Barrier Strategy shall provide a common understanding for all actors and involved personnel, including areas as:

Figure 21 - Barrier management planning process - Barrier strategy (PSAN, 2013b).

- Which phases, operations and activities that the strategy is established towards.
- Which hazards and accidental situations that may occur during both the operations and activities.
- Which barrier whose necessity is to ensure the safety and loss-reduction in case of the occurrence of an unwanted situation.
- Where to find more detailed information regarding the performance requirements to each specific barrier.

- o Be divided into reasonable areas (early phase basis for consideration and evaluations) at every facility, regarding systems, areas, operations and activities the strategy is designed for.
- o Continuously updated.

- o Demonstrate the specific task and purpose for each barrier function, whether it is to prevent any unwanted hazardous situation from occurring, or decrease any potential consequences in case of an accident/incident.
- o Demonstrate important assumptions which are essential to each barrier function and every individual barrier element.

- o Demonstrate the transition from strategy and performance requirements, which are established in every barrier. The strategy shall give information about where the different performance requirements are described towards each barrier function and element.

Barrier management planning process - Step 5

The performance requirements shall be determined and documented to each of every technical, organisational and operational barrier elements. These requirements are a formal definition which enables them to describe specifically what a barrier element's purpose is, and how the element shall sustain the barrier function effectively.

Figure 22 - Barrier management planning process - The performance requirements (PSAN, 2013b).

- This can be analysis of the elements capacity, functionality, efficiency, integrity, reliability, robustness and availability.

In relation to technical barrier elements, the different categories are separated in several groups or networks to better explain the purpose and effect of each regulation. This is illustrated in figure 23, and is primarily based on the Norwegian Regulation of Petroleum Management sf. § 5. (PSAN, 2013c).

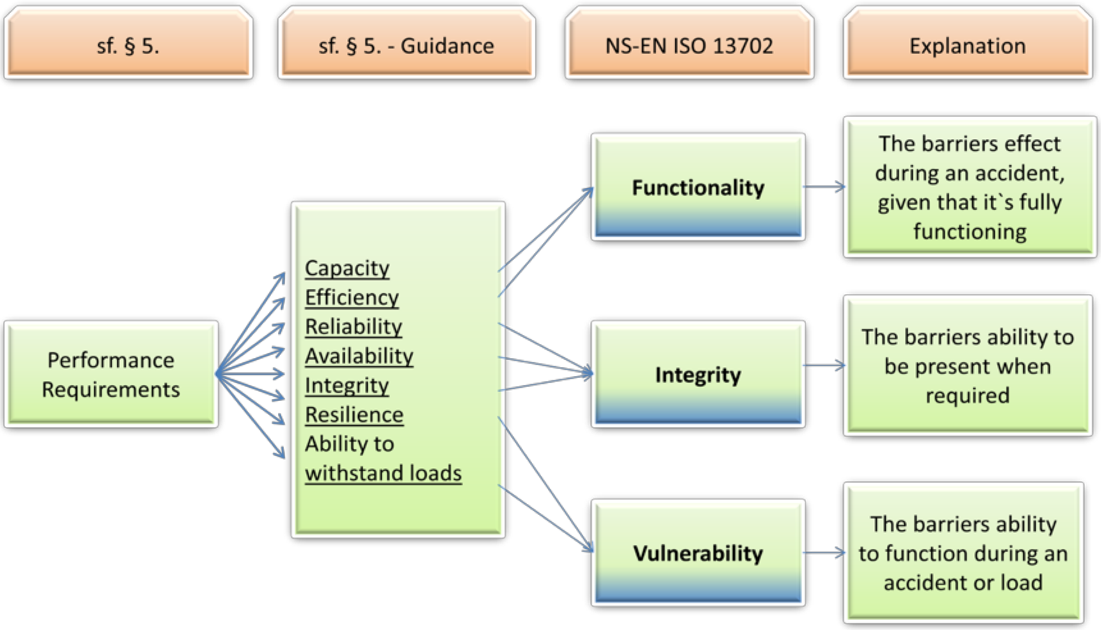


Figure 23 - PSAN`s regulation criteria (PSAN, 2013c), guidance (PSAN, 2013d) and standard (NS-EN ISO 13702, 2014).

Communication and consultation

Communication and consultation should not be regarded as an independent activity. Rather, it should be regarded as an overall and integrated process through the entire barrier management. This section will ensure that communication and consultation with both internal and external actors are adhered. The purpose and objectives are to ensure the following points:

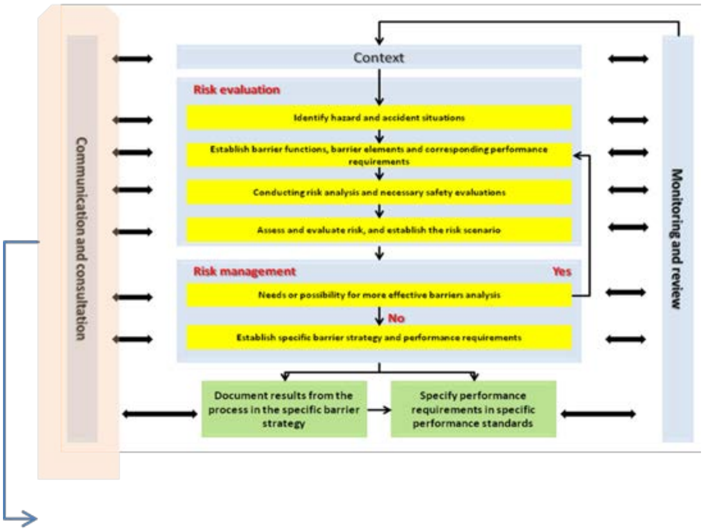


Figure 24 - Barrier management - Communication and consultation (PSAN, 2013b).

- Endeavour good quality by using relevant expertise and experience in the entire process, and to supervise and monitor it at all times.
- Participation by stakeholders that will be affected by decisions in all phases.
- Understanding of the basis for decisions.
- Risk analysis should be conveyed in a comprehensive way to all audience.
- That the documentation of the barrier strategy is used actively to provide involvement and to contribute to a common understanding of the basis for the requirements of the various barriers.

Monitoring and review

Monitoring and review shall be conducted during the entire process, from determination of context, to continuous improvement and optimisation of the barriers. This will be further explained in the next sub-chapter.

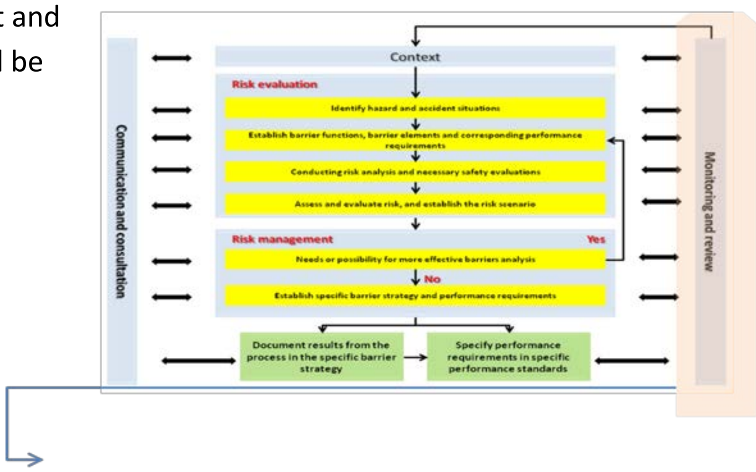


Figure 25 - Barrier management - Monitoring and review (PSAN, 2013b).

3.1.4 Routines during the operational phase

The operational phase *is also important in barrier management since errors or weaknesses in the established and integrated system/solution may occur. Throughout this chapter, the relation between the phases will be illustrated.*

Figure 26 illustrates how an ideal operation and its corresponding phases could be performed, and which elements that could be monitored and analysed in accordance with safeguarding the barriers function. This is no complete list, since every operation has its own requirements and individual conditions that must be considered.

Monitoring and review is one of the most important parts in barrier management, when it comes to ensuring the barriers efficient function and purpose. In the barrier management planning, risk management and analysis is an essential part of identifying risks, as well as developing and determine its corresponding barriers and barrier elements (PSAN, 2013b). It is, however, difficult to predict a complete aspect of every barrier and its elements, and how the barrier's actual efficiency will develop from its initial phase and beyond.

By continuously monitoring, reviewing, evaluating and developing new and improved solutions, the probability of any inefficient, unnecessary or misinterpreted barrier or barrier element, will highly diminish.

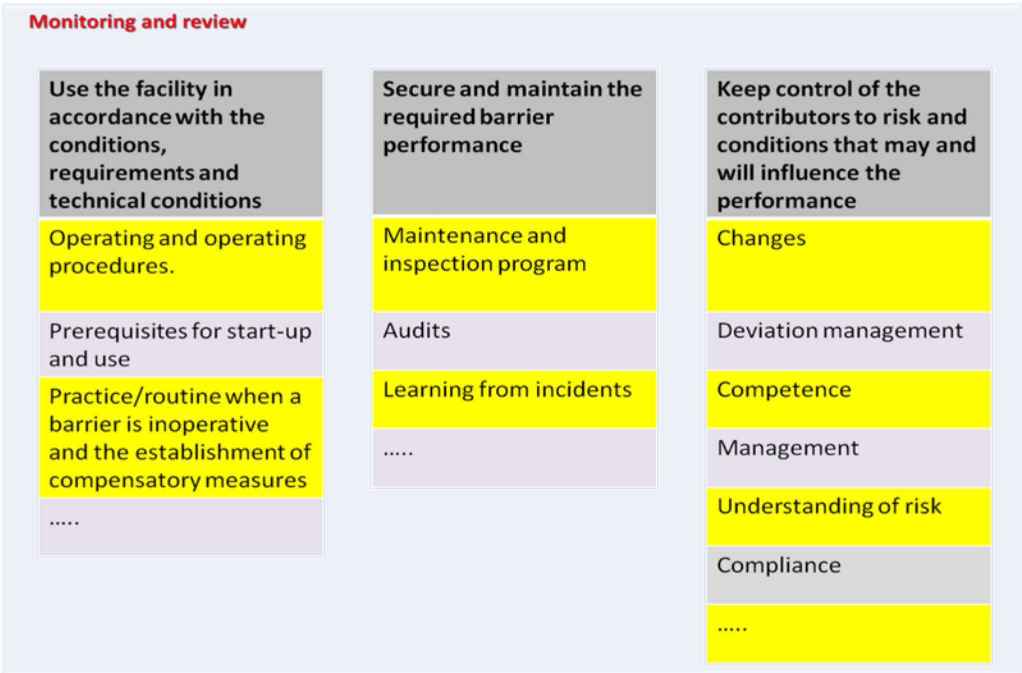


Figure 26 - Monitoring and review (PSAN, 2013b).

For any monitoring, testing and verification to have any significant contribution, it is required to establish systems to evaluate the result and objectives regarding the purpose of the barriers. This is also in accordance with the regulations (NS-EN ISO 13702, 2014). The principles behind the barrier functions performance requirements, as well as different indicators to evaluate performance, are illustrated in Table 3.

Table 3 - Adapted from PSAN's table regarding performance requirements (PSAN, 2013b).

Barrier function nr. x:							
Barrier element		**Performance requirements**					
Type:	Element:	Functionality:	Reliability:	Vulnerability:	Capacity:	Competence	.....
Technical	TE. 1	x	x	x			
	TE. 2	x		x			
	TE. 3	x	x				
Operational	OP. 1	x			x		
	OP. 2		x	x			x
	OP. 3	x				x	
Organisational	OR. 1		x				
	OR. 2	x	x	x			
	OR. 3		x				

Table 3 above presents an example of how the different barrier functions and its related barrier elements, both technical, operational and organisational, are evaluated in term of functionality, reliability etc., and further analysed in accordance with their actual results. The data, and their respective results, are examined within several areas, including maintenance history, event history, system for different measurements etc. This is illustrated in Figure 27.

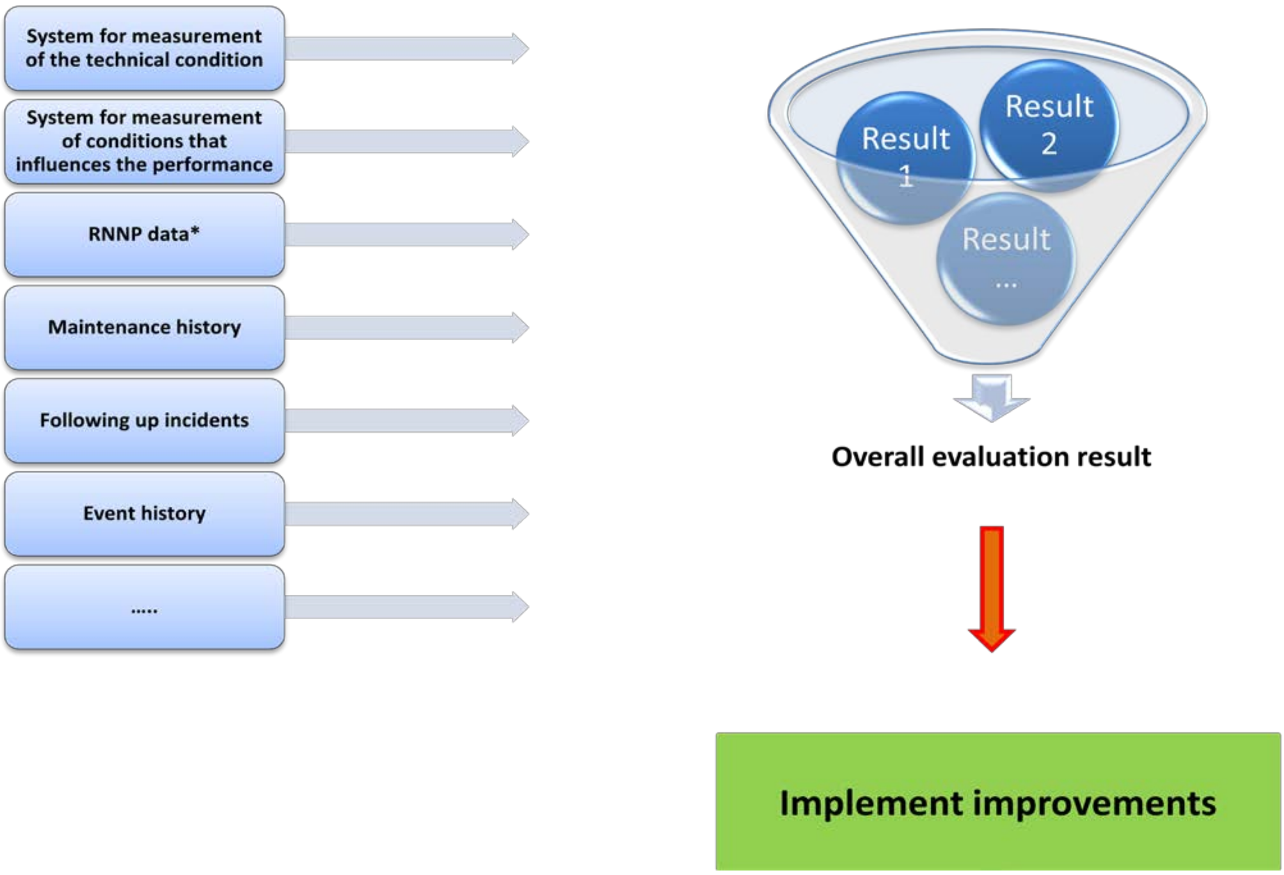


Figure 27 - Evaluating the results and data for better solutions.

To summarise the most major phases of an efficient barrier management in four phases:

- 1. Establishment of context, risk and barriers.
- 2. Develop and establish the entire barrier strategy.
- 3. Monitor and evaluate actual results.
- 4. Improve and implement.

From the initial process of planning, to barrier operation, monitoring, analysis and implementation of improved solutions, an overall illustration scheme is developed to simply reveal the entire process of barrier management in Figure 28. For further details regarding each individual figure in Figure 28, see the previously figures in this chapter, starting at Figure 16.

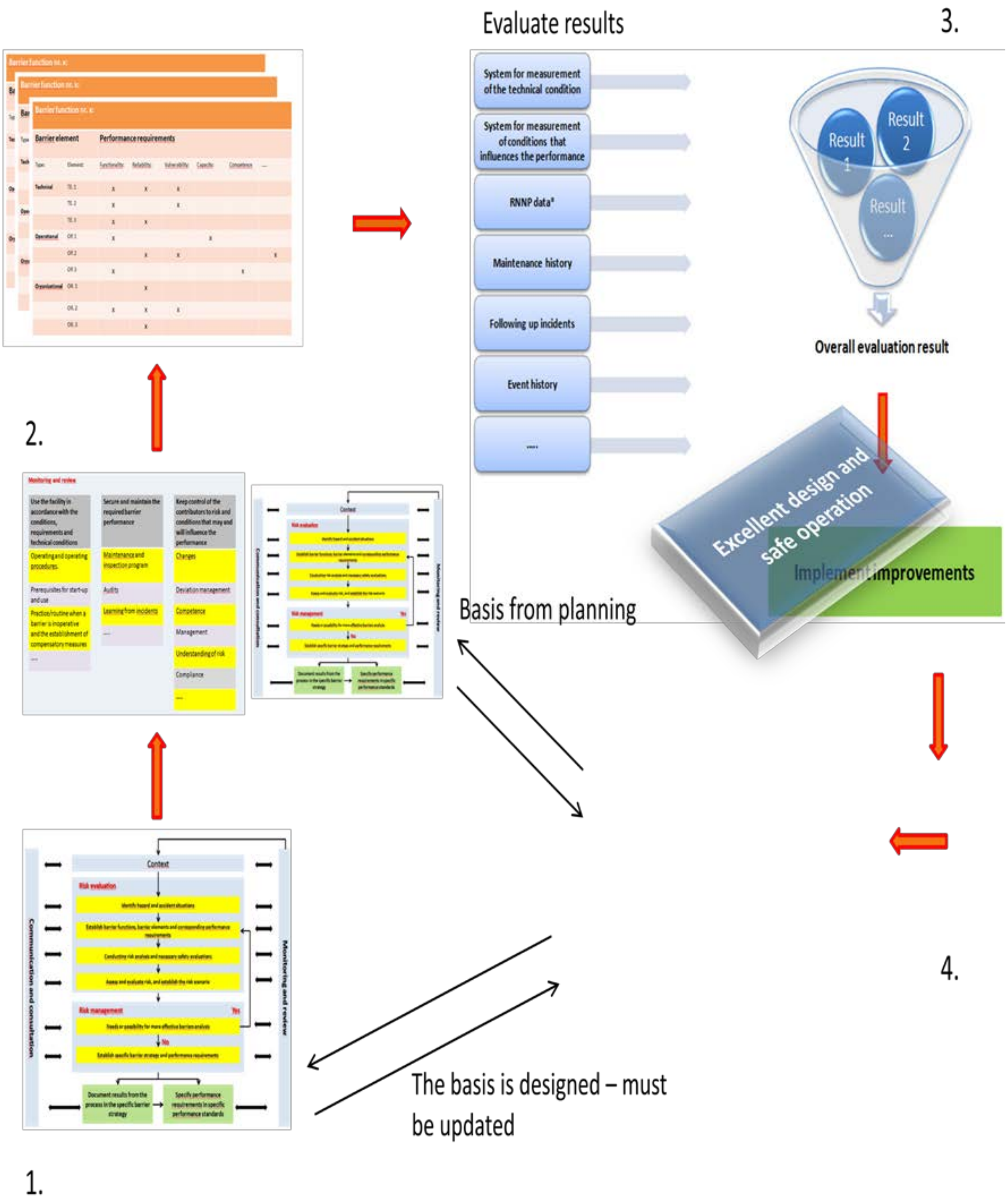


Figure 28 - Four major phases of barrier management.

3.1.5 Safety barriers and accidents

***In relation to safety** work, technology and organisational accidents, multiple perspectives and theories has been developed to better understand the contexts of how an accident can occur. This can be useful as a reference in some of the later analysis. Accordingly, this chapter will present some of the most commonly known and used theories.*

Most theories attempts to describe why and how an accident occurs, and how to prevent it from repeating itself (Hovden, 2013c). It has also been developed several models that evaluate this from a selection of views, of which the main elements included often are:

- **Sequence**
- **Process**
- **Energy**
- **Logical trees**
- **Human information interpretation**
- **Safety Management**

Three different perspectives or models are further elaborated, of which the Energy & Barrier perspective is most emphasised, as it is referred to as the most suitable for offshore oil platforms (Rasmussen, 1994).

1. Energy & Barrier perspective

The Energy & Barrier perspective illustrates that accidents can occur when hazardous energy accumulates and permeates the constructed and insufficient barriers, which are integrated to prevent accidents from occurring. The energy can be interpreted and modified to various situations, such as protection against computer viruses and for protection against a hurricane. Consequently, this makes the model flexible and user friendly with a relatively wide user basis. The model was first made visible by William Haddon (1970), when he demonstrated how the model could be used to prevent accidents. Haddon also described ten different strategies to reduce losses, as presented in Table 4:

Table 4 - 10 strategies in the Energy & Barrier perspective.

Hazard and risk	Barrier	Victim protection
1. Prevent accumulation of energy (thermal, kinetic, electrical)	5. Separation of time and/or space, removing energy away from the victim (pavement)	8. Make the victim more resistant to take damage from energy (safety helmet)
2. Reducing the amount of energy (reducing the speed of a car)	6. Separating the victim and energy with a physical barrier (Vehicle and body)	9. Limit the development of injury (first aid)
3. Prevent uncontrolled release of energy (salting of roads)		10. Rehabilitate victims
4. Modifying the rate of released energy (safety belt)		
7. Modify the quality of energy (soften hard objects)		

A commonly used representation of the principle behind the Energy & Barrier perspective is Reason's *Swiss cheese model* (1998). This model shows how various energies penetrate several barriers, which ultimately ends in an accident, referred to as "*defence in depth*". The small gaps due to latent conditions, while the large ones are active and direct faults. A barrier has several definitions in the literature, of which a specific definition is that the barrier is a physical countermeasure to eliminate, or reduce an injury-filled result (Kjellén, 2000).

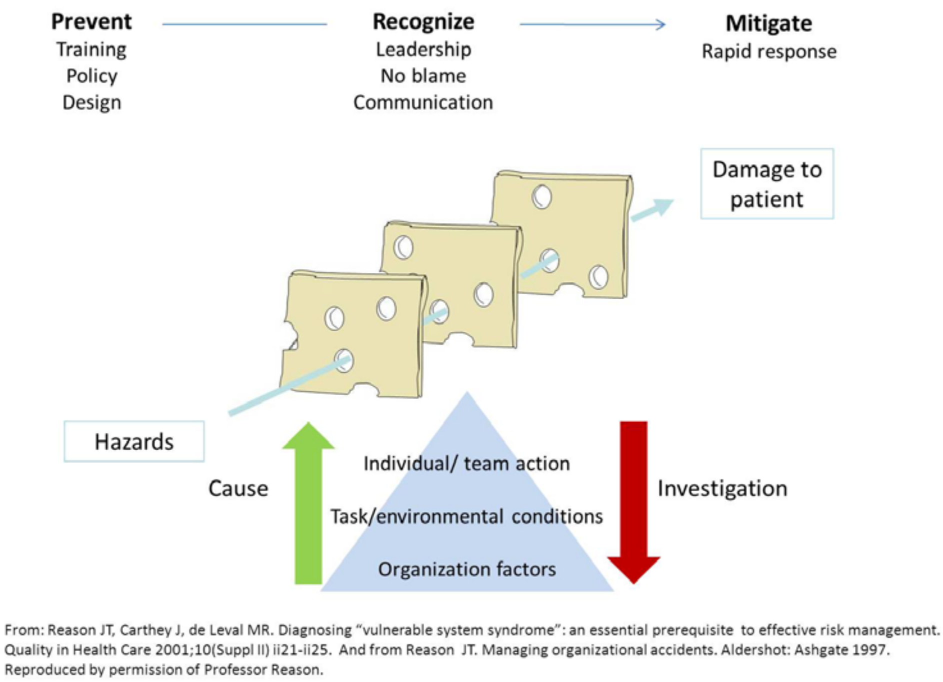


Figure 29 - Reasons "Swizz cheese model" .

<u>Key questions used to identify if the Energy & Barrier perspective is appropriate for a given situation</u> (Rosness, 2010):

- Can the protection problem be described by the principles of energy transfer?
- Is it possible to use the three classes of protection?
- Is it possible to analytically identify hazardous sequences of events?
- Is it possible to introduce technical or procedural barriers to these sequences?
- Can the barriers introduce new risks and dangers?

2. Normal Accident Theory (NAT)

After a major accident has occurred, the responsible managers often stand as outsiders to the event (Turner, 1978) & (Woods, 1990). Charles Perrow (1984) believed that many systems have a composition and structure that makes certain accidents unavoidable. Perrow defined minor events as component failure accidents due to errors in one or two components in the system, and can in most cases be predicted and detected through standardised risk analysis.

In contrast to the minor component fault accidents, he defined system accidents. These systems consisted of complex and multiple components, which through active faults, led to accidents that are very difficult to predict. System accidents often had organisational involvements, and were related to the system's complexity and connections. A graphical illustration is showing how the various connections increase the complexity of a system, and how technology and human interaction potentially makes the system more vulnerable (Hovden, 2011):

Permanent connections: No buffer between two events or objects. If something happens to one element, it will directly affect the other.

Loose connections: Slightly resistant to impacts, and will not be less stable under shock, failure or pressure. High dense systems can respond more quickly to these types of stresses, and the consequences can be disastrous.

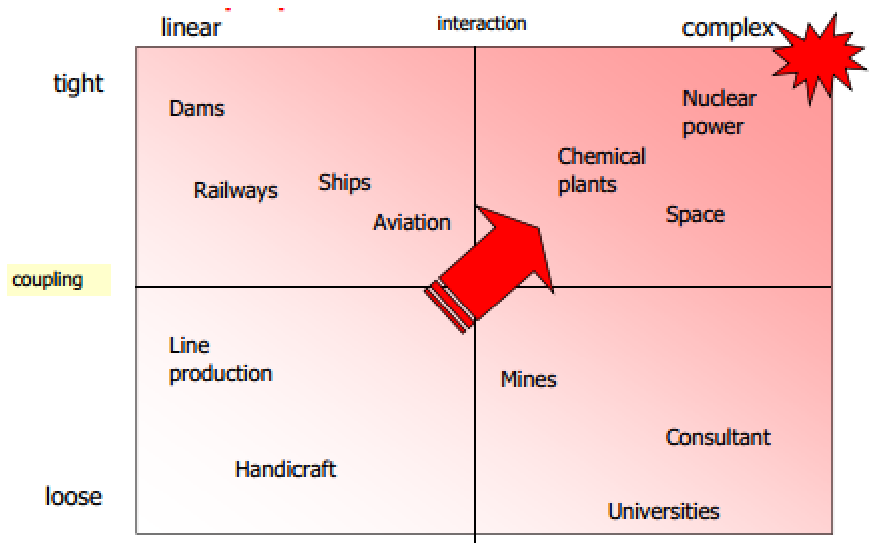


Figure 30 - Vulnerability to sociological-technological systems (Hovden, 2011).

3. Highly reliable organisations (HRO)

"*Working in practice but not in theory*."

Unlike the previous perspectives that attempt to explain why serious accident occurs, the highly reliable organisations - perspective tries to explain why it does not occur more serious accidents, especially in complex systems. Weick (1987) argues that the culture of an organisation can impose a higher degree of order and predictability, and thus work better than formal technical means to form an optimal decision making foundation.

In order to facilitate the people who make mistakes and errors, an organisation must have the resources and the structural and cultural dimensions to be able to show, guide and learn what is considered appropriate behaviour and procedure execution (Rosness, 2010).

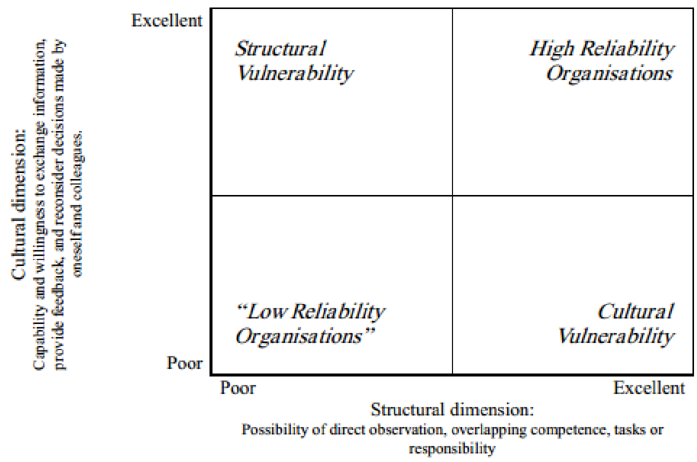


Figure 15 - The relationship between the culture and structure in an organisation (Weick, 1987).

3.2 Scorecard and Indicators

This chapter *will present the content of scorecard and Indicators. Scorecard is a form of administration and management relating to how an organisation will be working towards their overall objectives, often with the usage of indicators as a necessary tool or equipment.*

3.2.1 Scorecard

Scorecard has its theoretical origins from Drucker (1955), in which scorecard theories were defined and demonstrated. With the usage and focus on the results and performance management, the organisation will be working in accordance with predefined and established objectives (Johnsen, 2007). Using the results, one can constantly develop and improve the system. More importantly, use of scorecard will have an impact on behaviour and priorities.

Drucker sums up scorecard to be a guiding principle, where each individual in an organisation has its delegated responsibility and authority, with a common vision to harmonise individual goals with the overall objectives. Collected from Drucker (1955) and Johnsen's (2007) further work, there were developed three main branches that are necessary for a functional scorecard:

- **Clear and well-defined written objectives**
- **Participation and involvement of employees in the formulation of the objectives**
- **Result evaluations**

The first phase is to collect all the necessary information and data. This information constitutes the basis for the indicators and the further evaluation, and will be compared to the predetermined objectives.

A scorecard may be visualised as a corresponding and continuous relation between the following aspects (Wireman, 2005):

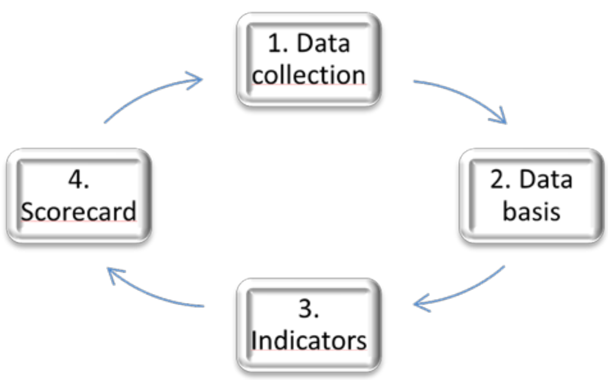


Figure 31 - Relation between the data collection, basis, indicators and the scorecard.

From the data collection, data basis and scorecard development and determination, the system is continuously monitored with the help of the different indicators. If one or more of the indicators points out a non-acceptable value (beneath or above the pre-determined value) as illustrated in the red box in Figure 32, there must be initiated an improvement process where causes and measures are evaluated. The process (Schjølberg, 1999) and a general and overall strategy overview (Maintech, 2014) are illustrated in figure 32.

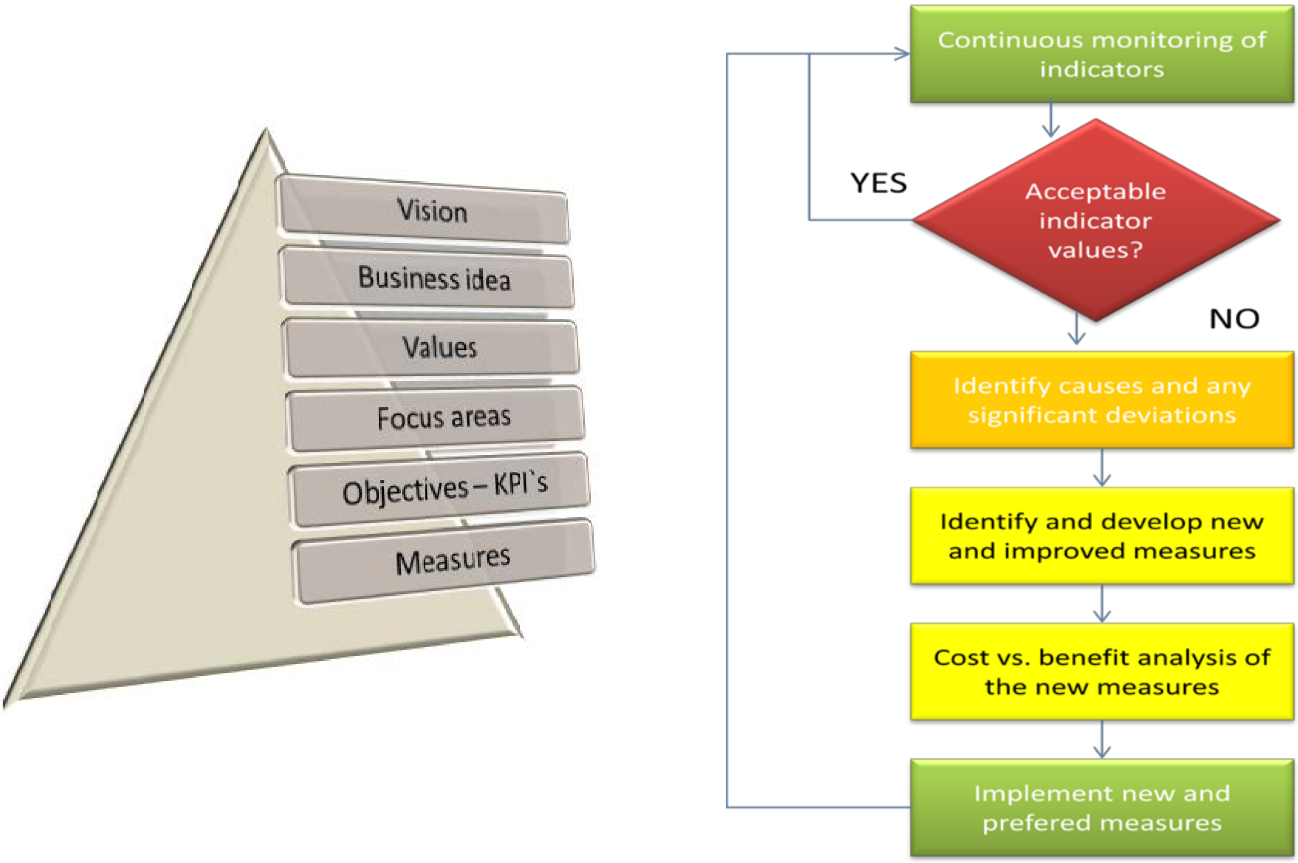


Figure 32 - Overall pyramid strategy to the left - adapted from Maintech (Maintech, 2014). Process diagram (Schjølberg, 1999) to the right.

3.2.2 Indicators

An indicator is the specific measure in a performance measurement. The indicator will display the actual ratio or level of performance, often related to an activity, resources, processes or incidents, where each has their designated formula or approach (Meland, 2008).

When developing a scorecard concept from collected data and information, various indicators must be defined associated to each individual organisational area or discipline. Several indicators from different areas will help identify areas of improvement, and locate potential weak elements (Andersen, 2001). It requires a good understanding of the organisation/system operations to be able to identify which indicators who will reveal the most relevant data for the area of interest.

Generally, the indicators help to assess and measure a process or phenomenon, distinguishing between various measurements (Andersen, 2001):

• ***Hard* versus *soft***

Quantitative measurements are pure hard facts that can be measured directly. Qualitative soft measurements are intangible, e.g. "mood".

• ***Financial* versus *non -financial***

Financial measurements include both direct and indirect measurements of a financial character that are illustrated and measured in a currency value. Non-financial measures do not have a currency unit and cannot be measured in monetary value, and may be both hard and soft.

• ***Results* versus *process***

Result shows measurements of direct result and performance, while process refers to the measurement of various process characteristics that led to a direct result or turn.

• **Measurements defined by their purpose (result, diagnosis and competence)**

<u>Results:</u> Measurements showing what an organisation has achieved and completed (profit, market share).

<u>Diagnostics:</u> Measurements predictive of future results, and are critical success factors (flexibility, product quality, lead time, customer satisfaction).

<u>Competence:</u> Measurements showing how robust an organisation is to meet future demands and challenges (complexity, competition, innovation, expertise, and training). In a proactive safety work, this will be the key to both learn about, and prevent new accidents.

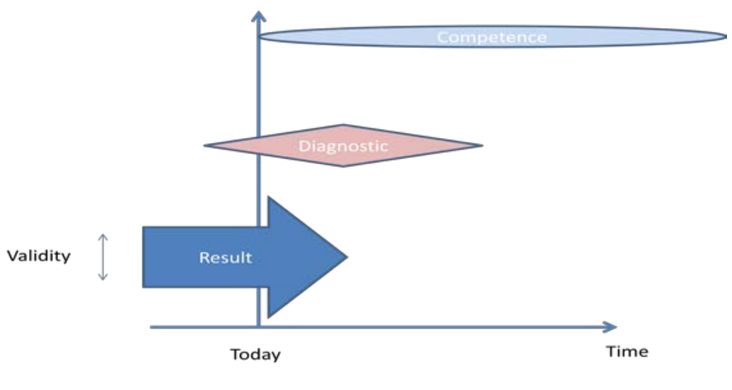


Figure 33 - Validity horizon of the different measurements (Andersen, 2001).

- **Efficiency, effectiveness, and flexibility / variability**

- **The four classical measurements: cost, time, quality and flexibility**

3.2.3 Key performance indicators

An indicator that points out a significant aspect or process of an organisation is often called a key indicator, or key performance indicator - KPI. These will indicate an organisation's achievement level of their main objectives and by integrating KPI's in every department, the common will and interaction to continuously increase the level of achievement will increase (Meland, 2008).

KPI's are often developed in relation to "deeper" organisational aspects, and should be developed under the influence and common understanding of every involved actor and personnel. Meland (2008) divides KPI's in three different levels:

- **Level 1: Includes the entire organisation/company**
- **Level 2: Includes individual departments or production lines**
- **Level 3: Each component**

Adapted from NS-EN 15341 (2007), various examples of different Key performance indicators in accordance with economical, operational and organisational aspects:

Examples of KPI`s	
Economic KPI`s	$\frac{\text{Maintenance costs related the production line}}{\text{The value of the production line}}$
	$\frac{\text{Maintenance costs regarding the production line}}{\text{Value of the produced}}$
	$\frac{\text{Preventive maintenance costs}}{\text{Total maintenance costs}}$
Technical KPI`s	$\frac{\text{Operating time}}{\text{Operating time + Repair time}}$
	$\frac{\text{Downtime due to preventive maintenance}}{\text{Downtime due to maintenance}}$
	$\frac{\text{Uptime}}{\text{Required uptime}}$
Organisational KPI`s	$\frac{\text{Number of maintenance employees}}{\text{Number of employees}}$
	$\frac{\text{Ratio of maintenance work connected to improvement}}{\text{Maintenance work}}$
	$\frac{\text{Number of work orders performed as planned}}{\text{Total number of work orders}}$

Table 5 - Examples of KPI`s.

Examples of typical ***key performance indicators*** for maintenance are listed as (Andersen, 2001):

- ✓ Machine Availability
- ✓ Machine Reliability
- ✓ Total system downtime
- ✓ Preventive to reactive maintenance conditions
- ✓ The service level of spare parts in stock
- ✓ Total maintenance cost
- ✓ Percentage of employees with basic maintenance skills.

When doing research about an organisation with that purpose to develop indicators for a safety system, there are several main aspects that are essential to include. Holmberg (1994) exhibits the following barriers and relations based on IAEA (1988) regulations, all in their own "level" and in relation to each other, represents the overall barrier safety against accidents and errors.

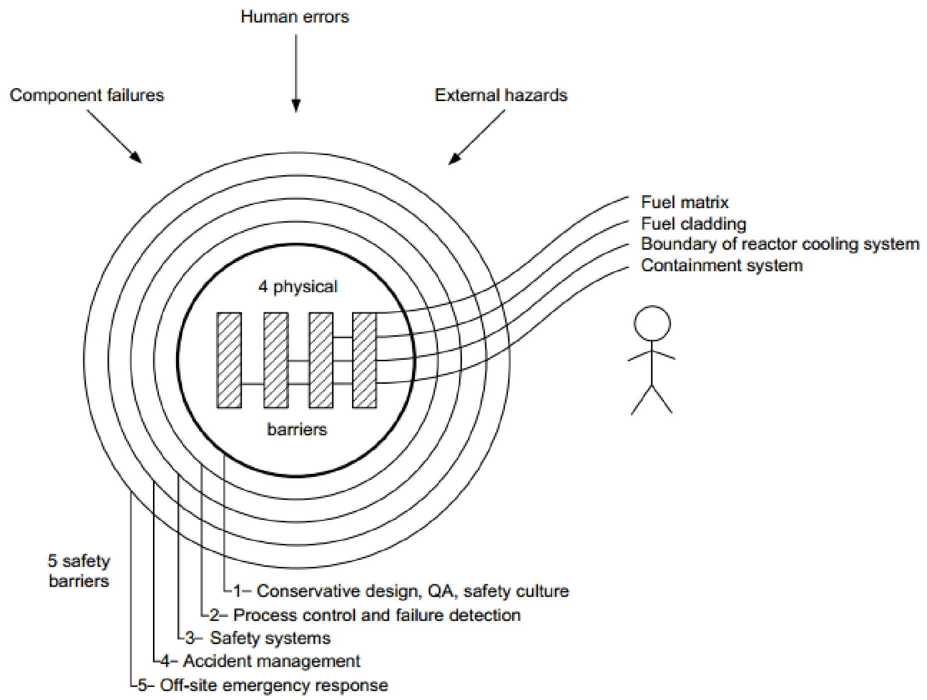


Figure 34 - Based on the International Atomic Energy Agency - (IAEA , 1988).

In accordance with the initial start-up of oil production at the Goliat field in the Barents Sea, several different indicators of vital areas are prepared to maintain a high safety offshore (Øien, 2010). There are focused on areas such as:

- Process
- Focus on potential major accidents
- Focus on personal and environmental risks
- Focus on individual installation levels
- Proactive / leading indicators
- Maintaining system knowledge locally
- Be able to interpret and evaluate when assistance is needed

There are also classified several different types of indicators regarding what to measure, and to which area (Øien, 2010):

Table 6 - Different types of indicators. * calculates the quality of various programs and functions in relation to safety (Øien, 2010).

Safety Indicators :	Risk indicators :	Event -based indicators	Elastic indicators (Resilience - based) :
- Event indicators	- Technical Indicators		
- Barrier indicators	- Organisational indicators		
- Activity indicators			
- Programmatic indicators *			

In Figure 35 is a sample list of barriers and indicators developed in conjunction with *early warnings* of potential hydraulic leaks, i.e. indicators that as early as possible may indicate potential warnings. This was developed in relation with the investigation of the leak at the Eirik Raude - drill in 2005 (Øien, 2008):

Barriers and information providing early warning indications of potential hydraulic leaks.

Barrier	Checkpoint
1. Close off/lock off valves for system isolation	Check depressurization of isolated systems
2. Use of standing instructions for system de-isolation	Check use of WP[a]/SJA[b] when de-isolating
3. Visual inspection of system prior to use	Check that visual inspection is carried out
4. Monitoring of valve operation	Spot check presence of watchman
5. Use of system under controlled weather condition	Check/verify that restrictions are followed
6. Inspection of hoses according to PM[c] program	Check/follow-up PM-program
7. Review of critical overdue maintenance log	Check the critical overdue maintenance log

[a] WP – work permit.
[b] SJA – safe job analysis.
[c] PM – preventive maintenance.

Early warning indicators.

Early warning indicators	Data collection frequency
1. Rate of inadequate depressurization of isolated systems	Daily
2. Rate of inadequate use of WP and SJA	Daily/weekly
3. Rate of inadequate visual inspection of system prior to use	Daily/weekly
4. Rate of inadequate use of a watchman	Daily
5. Rate of failure to comply with weather restrictions[a]	Daily/weekly
6. Number of PM work orders for hydraulic hoses in backlog	Weekly/monthly/ quarterly
7. Number of critical CM[b] work orders in backlog[c]	Weekly/monthly/ quarterly

[a] Given bad weather, i.e., not counting use of hydraulic systems in good weather.
[b] Not necessarily restricted to hydraulic hoses.
[c] CM – corrective maintenance.

Figure 35 - Indicators developed by Øien (Øien, 2008).

3.3 Petroleum Safety Authority Norway

***Every major industrial** department in Norway has its own delegated authority of supervision and regulation. PSAN is the superior authority in the Norwegian petroleum industry, hence its direct relation to the development and regulation of barrier management and maintenance, and will therefore be presented in this section.*

3.3.1 PSAN

The Petroleum Safety Authority Norway is a governmental managed organisation or agency, which was established January 1, 2004, in order to regulate and control a sustainable petroleum industry with emphasis on safety (PSAN, 2014a). PSAN has today around 170 employees with a headquarter in Stavanger - Norway, and was earlier a part of NPD, the Norwegian petroleum directorate, which has regulated the industry since 1972. NPD's superior objective is to contribute and produce a social, economical and safe petroleum resource management to the community at large (NPD, 2014).

To sustain and develop a high level of safety, as well as preventing undesired accidents and incidents, PSAN was separated as an individual agency with the responsibility and focus on safety and maintenance. PSAN's main responsibility and objective is to regulate a high technical and functional safety during the development and operation of petroleum related projects, as well as monitoring the several different industrial plants within the Norwegian Continental Shelf (PSAN, 2014a). Ensuring the safety and contingency for every actor involve, as well as the environment, is also a major part of PSAN's responsibility.

Figure 36 - Overview of the different plants and areas of responsibility.

In case of any accidents, PSAN is the delegated agency to investigate and identify the causes and any potential weaknesses within the protocols, technical equipment or safety culture, with the main objective to prevent further recurrence. PSAN has also the obligation and authority, if necessary, to provide any form of consents, orders, coercive fines, suspensions, prohibitions, exemptions etc.

The government of Norway has delegated PSAN as the responsible agency for these following tasks:

- *PSAN shall supervise and cooperate with other authorities regarding HSE, to ensure that the industry comply by the determined governmental regulations.*

- *PSA will further carry out information and advisory activities with the actors in the industry, establish appropriate cooperative relations with other safety authorities nationally and internationally, and contribute to transfer in experience regarding health, environment and safety in general.*

- *PSAN shall inform the parent ministry about different cases that are processed by the department, with the corresponding support if requested.*

PSAN's main disciplines are further divided into six different areas of expertise (PSAN, 2014b). Enlarged version in appendix IV3.

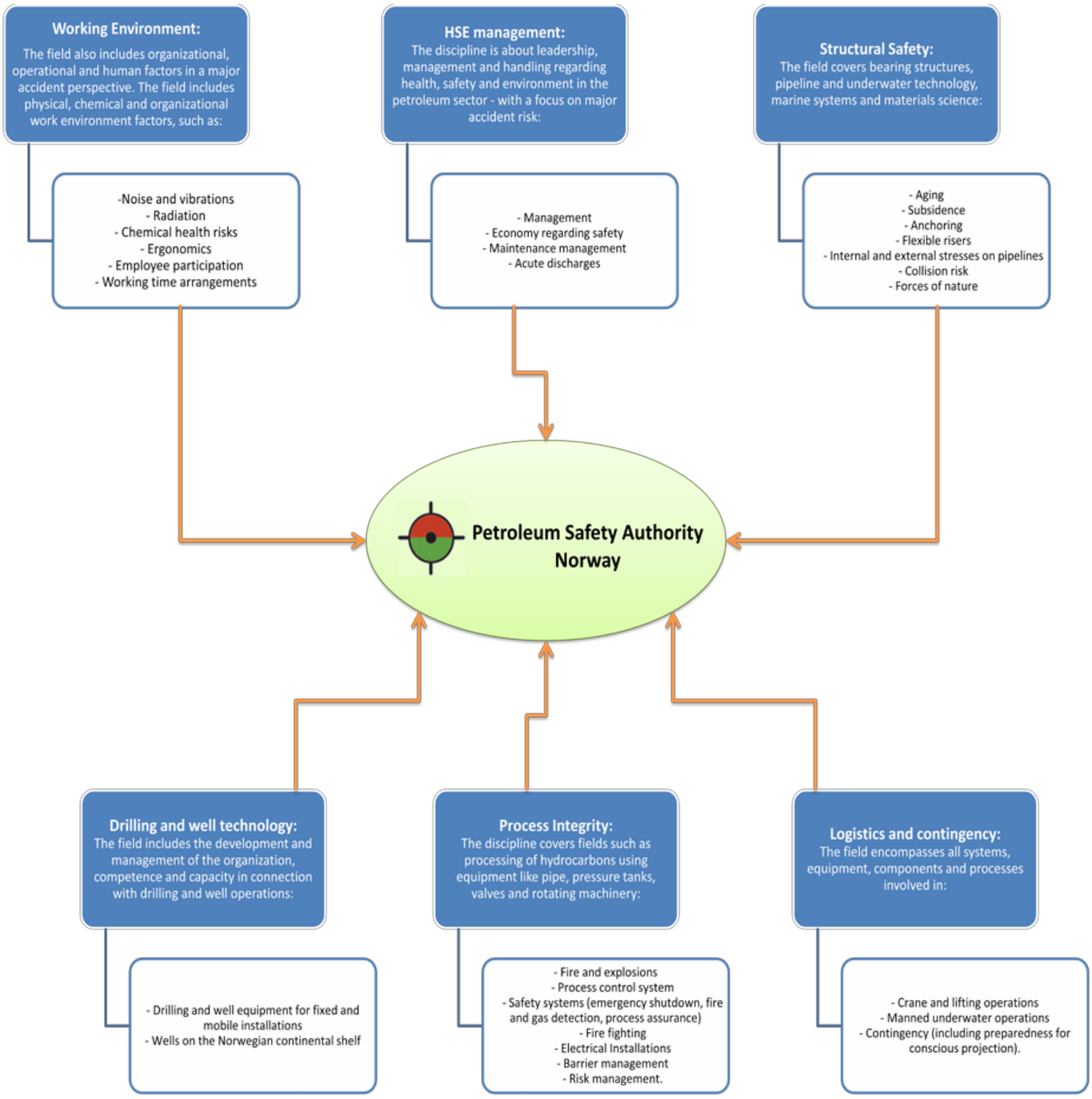


Figure 37 - PSAN`s main disciplines is further divided into six different areas of expertise (PSAN, 2014b). (Appendix IV3)

3.3.2 PSAN focus, ambitions and priorities

***A high priority** at PSAN is to continuously improve and develop their regulations in accordance with the newest technology, requirements, newly identified weaknesses etc., in order to maintain a high quality and professional agency. PSAN's current priorities and areas of focus will be presented through this subsection, and further applied in several analysis, as well as in the development of the barrier management concept in the final chapter.*

The utilization of acquired knowledge and experience is essential to proactively prevent accidents from occurring, as well as locating new and unidentified hazards.

From PSAN published journal, Safety, Status & Signals (PSAN, 2013a), they elaborates about safety and its corresponding weaknesses and challenges related to the current and future situation in the industry, especially with the focus at barriers and barrier management. Based on this and the Deepwater Horizon-report (PSAN, 2011), the four main determined objectives and priorities for remediation during 2014 are as follows:

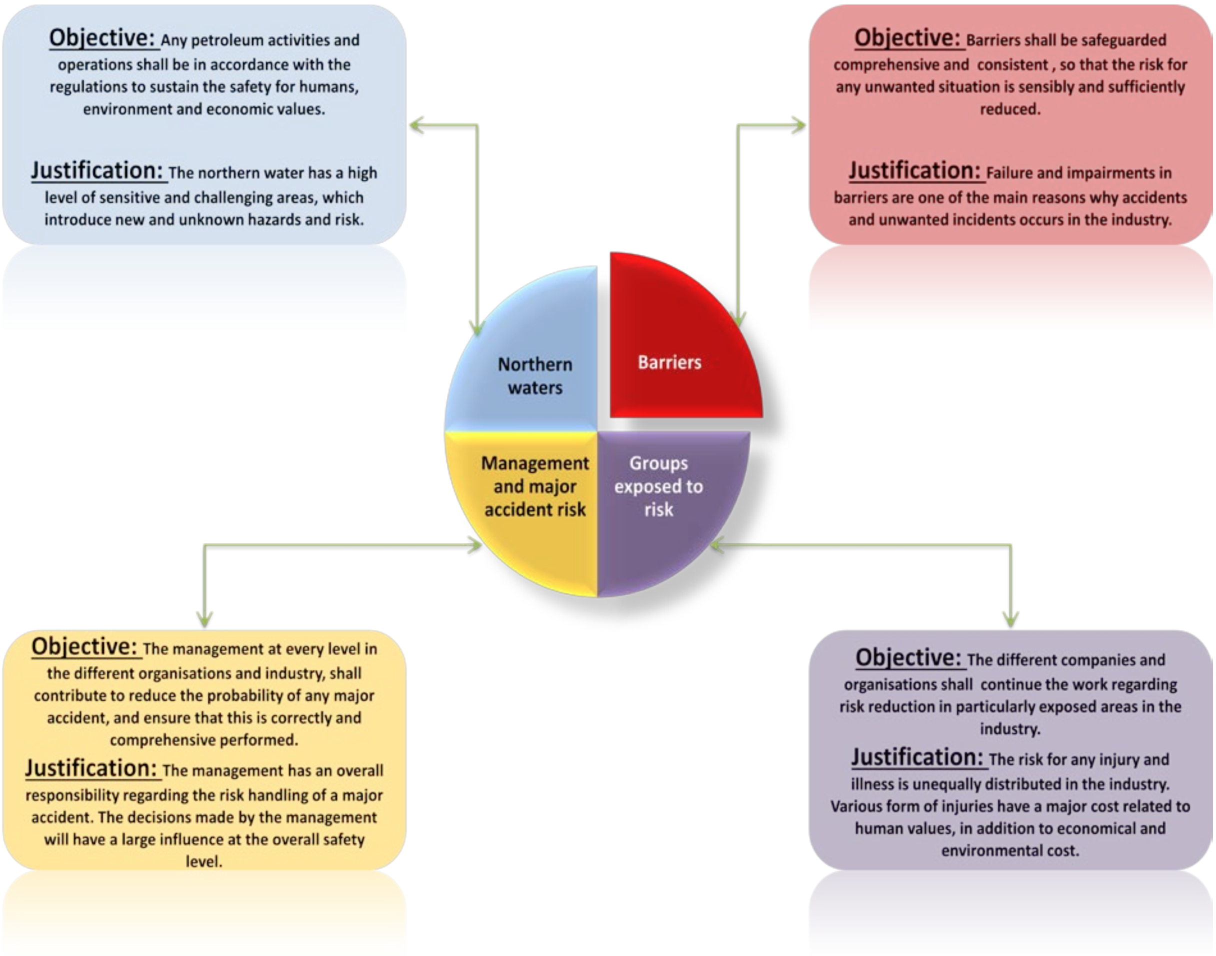


Figure 38 - The four main determined objectives and priorities for remediation in the Norwegian petroleum industry (PSAN, 2011). Appendix IV2.

In accordance with PSAN's objectives and different justifications, a list of several aims and contributions are listed below (PSAN, 2014c):

- **Barriers:**

  From the industry's point of view:

  - The industry and its actors must comply after the requirements in the Management of Regulations in such a way, that the evaluation and connection between risk and barrier management is distinct.

  - The barrier management shall have a fully integrated function in every organisation.

  - Operational, organisational and technical barrier elements shall be highlighted as a part of the risk evaluations.

  From the Petroleum Safety Authority Norway's point of view:

  - PSAN shall contribute the industry so that the knowledge about operational, organisational and technical barrier elements becomes well-known, especially in accordance with how they affect each other and the safety in general.

  - Contribute and optimise the relationship between the different actors, making them share both experience and knowledge.

  - PSAN's priorities are in this case efforts in well integrity and control, hydrocarbon leaks, constructions, marine systems, early phase projects and uncertainty and the level of knowledge in risk evaluations.

- **Groups exposed to risk:**

  Not described as it is not in relation to this thesis objectives.

- **Northern waters:**

Not described as it is not in relation to this thesis objectives.

- **Management and major accident risk:**

From the industry's point of view:

- Management at every level in the organisation shall prioritise the work and the contribution to reduce the risk of major accidents.

- Systemise the data and information about major accidents, and how they are integrated in different strategically solutions and decisions.

From the Petroleum Safety Authority Norway's point of view:

-PSAN will supervise and monitor how the management in the industry are controlled.

- Evaluate how the management works to sustain an overview of any incidents or accidents, and how new and improved procedures are implemented.

- Evaluate how different operations are scheduled, planned and completed in order to analyse any deviations from the regulations. Factors here will be allocated resources, knowledge, competence and experience in the different phases.

- PSAN will also especially follow up new and low experienced actors, with new fields of expertise etc.

4. Maintenance and safety

***The** sections in chapter 2 have earlier explained both maintenance and safety, in addition to various aspects of how to manage and administrate them. Throughout this chapter, an analysis, illustration and some examples of how they influences and affects each other will be discussed and presented.*

4.1 The relation between maintenance, maintenance activities and safety.

As discussed in the maintenance theory section 2.1, maintenance is described as a generic term for the various processes dedicated to a system with the primary purpose of maintaining, or restoring a device's function.

- When a function is able to perform its given tasks or processes, it is stable and fully functional. Maintenance can thus be summarised as maintaining a function's stability and consequently its operational capability.

In order for a function to carry out its optimal capability, it must in most contexts be maintained and if necessary, monitored. This can be anything from the cleaning of medical devices on a hospital, to troubleshooting in the electrical system on an airliner. Larger and more complex maintenance processes often requires more resources, than simple and more direct processes. A maintenance performance is planned and scheduled on the basis of the requirements of its function, how and when the maintenance should be implemented, and how it should be followed up afterwards.

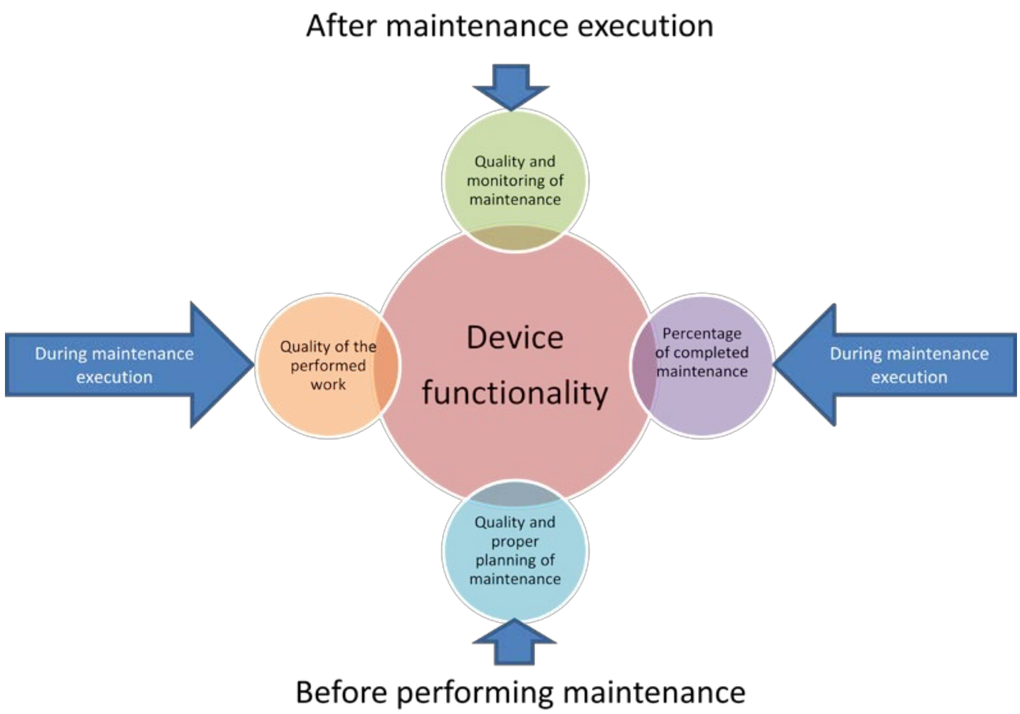


Figure 39 - Illustrates maintenance will affect the device functionality.

Maintenance processes that have been conducted before, during and after the total maintenance activity, is to determine and affect whether the device actually maintains its functionality or not. If the quality of the procedure is unsatisfactory, not correctly performed or contains deficiencies, the device will exert a greater risk of failure and loss of function. Based on the process of evaluation, some processes will be more critical than others, and hence exert a greater risk of serious and fatal errors. The gravity and probability of function failure in case of any absence of correctly performed maintenance will increase relatively to the devices maintenance dependence and requirements.

Safety is in section 2.4 portrayed as the degree or level of prevention against economic, health, and property loss and damage. A high and significant level of safety will decrease the probability to be affected by any of the conditions as mentioned, while a low safety level will increase the likelihood of unwanted events to occur. A given, or several risks must exist and be present in the system to constitute a realistic threat, in order for a safety system to be adequate.

Safety is also about a person's self- esteem, where the person is relying on its own internal confidence and consciousness regarding safety, as well as those responsible for the safety and environment around him/she.

To simplify and summarise safety:

- The degree of preventing unwanted events and accidents which could lead to either direct or indirect health, financial and/or material losses.

Based on this, safety could from a given perspective, be considered as a function. A safety function, or a system composed of several functions, will be stable and operational when neither any economic, health, or property loss or damage occurs.

Figure 40 - Safety contributors.

For a function, or a system composed of several functions, to sustain and ensure its operational capability, it is necessary to frequently perform different forms of maintenance. It is illustrated in figure 41 how the correlation between maintenance and safety depends on each other, and that it could be visualised like two dependent gears in the same coherent system. They reflect and influence each other in an overall integrated system. If one of them fails or breaks down, the other one will lose its functionality instantly, or with a random or specific time delay. Different relations can create different problems, solutions, weaknesses and strengths, depending on which sub-gears that affect the system. Examples of relation that can occur:

- Quality and monitoring of maintenance affected by high levels of expertise
- Completion of performed maintenance influenced by the safety culture

It is important to emphasise that this is just examples of relations, and that most connections and affiliations from both maintenance and safety can infiltrate and influence each other, both positive and negative.

Figure 41- Merge of safety and maintenance.

Another important aspect between maintenance and safety is the correlation based on the ALARP principle from Section 2.4, where different risks, consequences and corrective action are evaluated relatively to each other. How much resources are allocated for maintenance operations, and how is the corresponding effect on the safety. Reason (1997) shows that maintenance can impose new hazards since new errors may be introduced to the system, simultaneously as it is necessary for the existing processes. Based on this, it should not be performed more maintenance related work, than what is appropriate and necessary. If an organisation allocates a lot of resources for maintenance, both proactive and reactive, it may be an indication of poor safety management, and that the overall and lack of safety control is compensated with the overuse of maintenance processes. By the gears Figure 41, one can also consider excessive compensation/design of one wheel to contribute to an inharmonious relation to the other, as well as creating an imbalance in the entire system. The connection between the usage of resource and efficiency of maintenance is also presented in Section 2.1, in the cost-benefit chart.

The relations and conditions that are discussed so far in this chapter are also emphasised in the Norwegian governmental White Paper No. 12 p. 46 (AID, 2006) about HSE in the petroleum industry:

"Lack of maintenance can increase the risk of major accidents, injuries and mishap. The Petroleum Safety Authority Norway has reviewed the 188 audit reports on the shelf, from the period 1 January 2004, to May 2005. Around 50 of these were related to maintenance management and maintenance."

This is also argued by Meland (2008), where maintenance and safety are evaluated against each other. In this report, three different unwanted situations become especially highlighted, which could be linked back to unsatisfactory management of maintenance:

- **Direct injury to those performing maintenance.**
  Damage to personnel performing maintenance, or people in the immediate vicinity.

- **Errors in planning, execution and control of maintenance.**
  Source of maintenance induced errors in a system.

- **Lack of maintenance.**
  Existing errors are not detected, which can cause everything from production reduction or stoppage, to more serious incidents and accidents.

From Meland's (2008) report, there also follows a summary of the PSA supervision (2006-2008) according to seven different offshore companies' maintenance management. The conclusion points out several errors and weaknesses. Numbers in parentheses indicate the number of companies with revealed errors in Figure 42.

There are some variations regarding the deficient documentation. Typical are choice of methods, use of standards etc., and which specific disciplines that are violated (management, prioritising etc.).

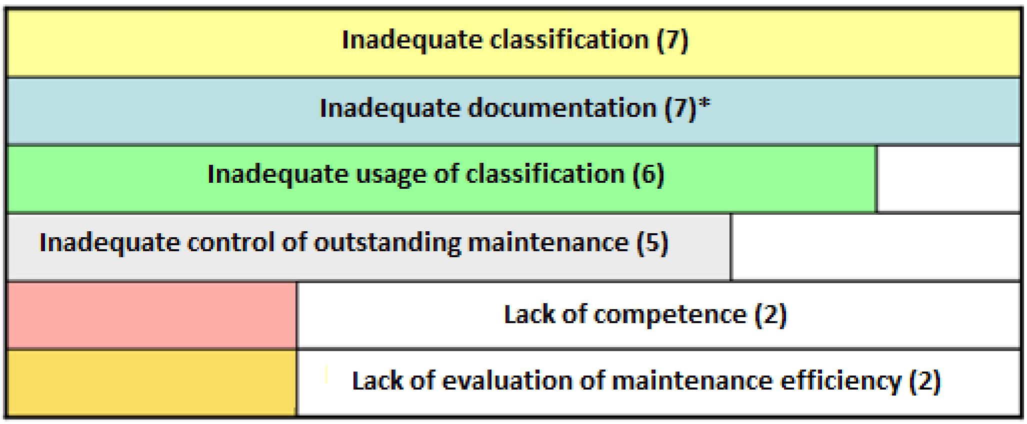


Figure 42 - PSA's supervision (2006-2008) with maintenance management to seven different offshore companies (Meland, 2008).

As indicated in Figure 42, there are clear differences between a theoretically ideal maintenance management and the actual realistic situation in the offshore industry. The numbers also amplify the arguments about the three highlighted situations from Meland's report as presented at page 74, where they can be connected and correlated to one or more of the breaches illustrated in Figure 42.

Violations within several maintenance related areas, especially under maintenance management in the petroleum industry (Okstad, 2007), are increasing the risk of accidents and the possibility that safety-critical events may occur. The overall impression implies that there exist a great potential for improvements related to management and maintenance.

As it has been argued by earlier in the thesis, the majority of the modern and current safety and maintenance focus is to proactively prevent and avoid accidents of occurring. A proactive approach of safety management has been proven as effective compared to the old and traditional reactive *firefighting* systems. Based on Schiefloe approach (2013), there is adapted an illustration to point out the correlation between maintenance and safety in a systematic interaction, and the importance of particularly proactive maintenance.

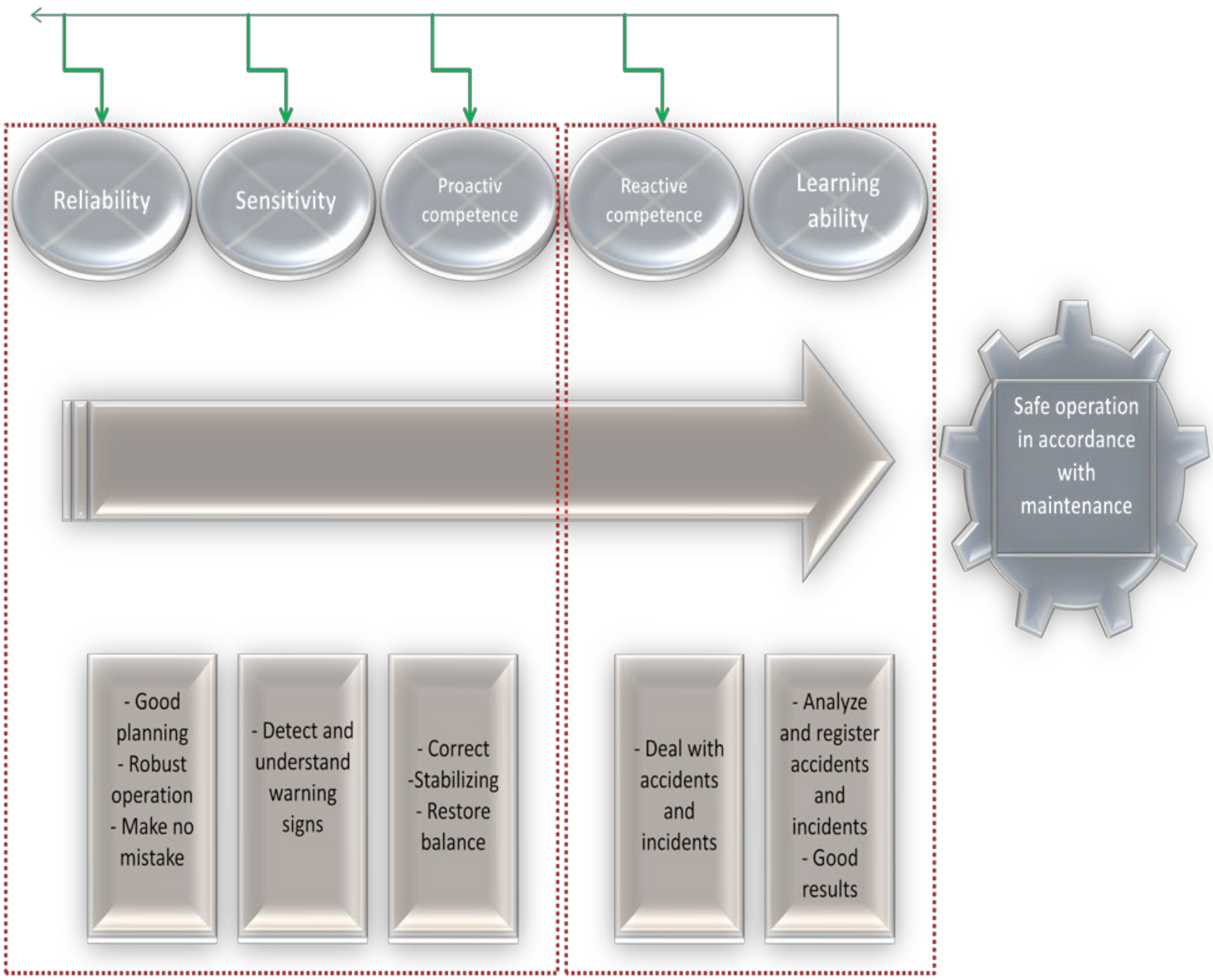


Figure 43 - Maintenance and safety (Schiefloe, 2013).

5. Petroleum Safety Authority Norway, Barrier management and maintenance

Barriers have *at some level always existed in the petroleum industry. However, barrier management in PSAN's overall strategy management is a relatively new area of focus. Especially during the last decade, the focus at BM has been prioritised by the industry and authorities. This subchapter will present the state of the art of PSAN's barrier management, as well as the importance and influence of maintenance regarding BM. This is fundamental to both understand and reveal any areas of potential improvement, which again will create the basis for the concept development in chapter 8.*

5.1 Barrier management in Petroleum Safety Authority Norway.

Barrier management includes the entire process of activities regarding planning, evaluating and monitoring in the barrier strategy development, determination, optimisation and implementation phases.

Barriers and barrier management have an essential role in the entire safety policy of PSAN. The concept or usage of the term barrier was first implemented in their regulation in 2001/2002, as mentioned in subchapter 3.1.1. From that point, BM has gotten increasingly prioritised and integrated in the development of strategies, primarily to optimise the prevention of any incidents or accidents, as well as decrease any potential consequences in case of an emergency.

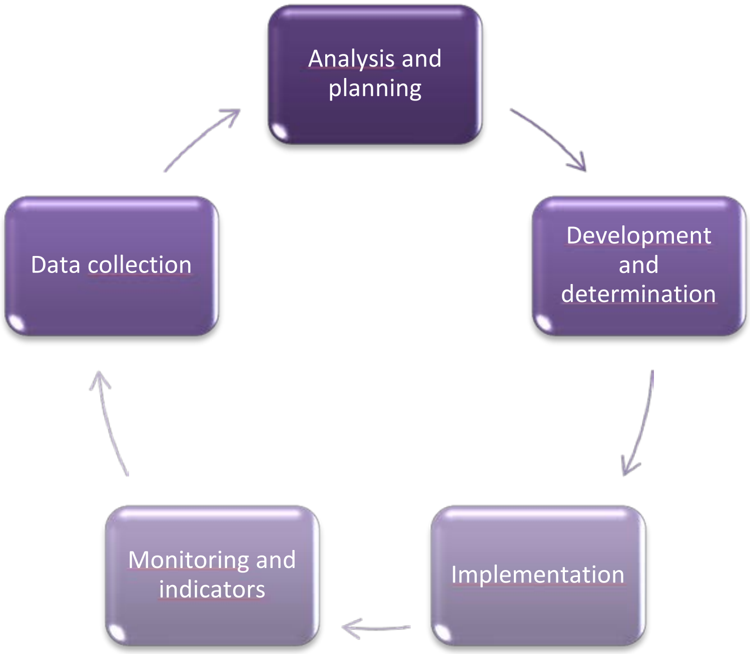


Figure 44 - Cycle in barrier management.

The fact that barriers are much more complex than just physical barriers, which often is the historical way of approaching barriers, have also gotten more in focus.

Each year PSAN develops and determine an annual plan for which areas and corresponding challenges to prioritise. This is done after different analysis of the entire industry including collection of data, and indications of weak points regarding competence, working and safety culture, technical condition of equipment, integration and follow up in the organisations etc. This is evaluated at every level in the organisation in accordance with determined regulations and standards.

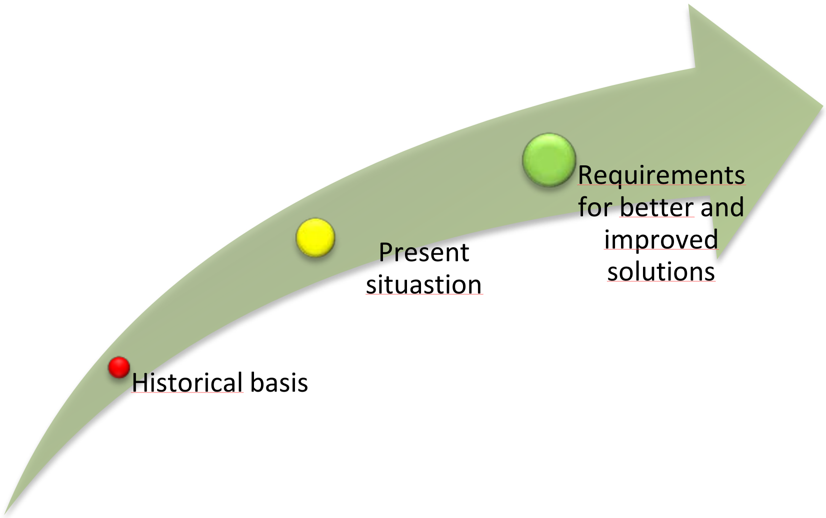


Figure 45 - Development of barrier functions.

In PSAN's four top prioritised areas of ambitions, innovation and objectives for the year 2014, barriers and barrier management are delegated as one of them. As written in chapter 3.1.2, the industry lacks a common understanding of the concept, often regarding the understanding and assessments of the terminology in PSAN's definition and framework of barrier management, in addition to the various degrees of barrier implementation.

Their arguments and suggestions are to accumulate a much more common and regular understanding of every aspect regarding BM, so that different companies both internally and externally, can contribute to make the entire area of barrier more efficient and valued.

This will also in a larger perspective increase the overall safety in the industry, hence barriers main purpose, which is to prevent unwanted and potential hazardous situations of occurring, in addition to prevent any unfortunate material losses.

PSAN has also designed several documents and reports regarding barrier management, from how to plan and develop the barrier strategy, to how to operate and improve the entire system as it progresses. This is widely explained in chapter 3.1.3.

5.2 Analyse the importance of maintenance in barrier management.

***How is maintenance** in barrier management important, and in which way? The relation and influence between maintenance and barriers, as well as the objectives for maintenance in this context, will further be analysed through this section.*

5.2.1 Maintenance

Maintenance is in the industry known as the way of execute administrative, technical and managerial processes to maintain or restore an item's function, so that it is able to perform its required function, as well as ensuring the safety for the environment and involved personnel. This is just a brief recap of both maintenance and maintenance management, which are closely elaborated in chapter 2. Maintenance is in most cases an important aspect of a function's reliability and efficiency, especially over a given period of time, or continuously. The frequency of how often a maintenance performance is required or desired, is assessed on basis of its complexity, function purpose and its level of integration and influence on a potential larger system.

Barrier management includes the phase of continuously monitor and evaluate the different barrier functions, as well as their corresponding barrier elements. The barrier elements are delegated several performance requirements (PR), hence their given ***function*** and purpose. The performance requirements are determined as a basis of how to be able to proactively evaluate the barriers function and ability to be:

- Relevant
- Efficient
- Resilient

These are important aspects of a function's fundamental resistance of becoming outdated, particularly where the barriers function often may undergo several changes and potential modifications. This can be in term of both changes from internal and external environment factors (both physical and non-physical), and is common in most industries where technology and regulations are an essential part of the entire system. Resiliency is the barrier's capability of being robust and prepared against expected and unexpected challenges.

Performance requirements are made to ensure the barrier functions and barrier elements:

Figure 46 - Performance requirements to ensure the function's relevancy, efficiency and resiliency.

The PR is therefore continuously monitored in relation to several aspects, both from technical, operational and organisational barrier elements (which are further explained in chapter 7).

5.2.2 Barrier management and maintenance

To achieve a proactively barrier function, the integration of ***maintenance*** within barrier management is essential for the BM's systematically and continuously process of monitor, maintain, optimise and implement new and improved solutions and functions**.**

This could, among others, be done by a maintenance test and inspection system. As shown in chapter 3.1.2, barrier management is a minor part of the entire and overall organisation management and strategy. However, this does not mean that it is less important.

From the same point of view, one can visualize maintenance management as a part of the barrier management, were both are integrated sub-systems of e.g. WCM - World Class Maintenance. Within WCM, Reliability Centered Maintenance - RCM is a method of managing, planning, monitoring and usage of maintenance as a preventive and proactive approach, which often are featured as one of the most efficient maintenance systems in the petroleum industry.

RCM, as a part of World Class Maintenance, should be implemented and integrated in the organisation's strategy, if a failure or error in the considered system may lead to potential large damage, severe consequences, and the system contains of a moderate to high functional complexity. RCM also have an efficient process program of ***continuously monitor and improve existing system, making the system good in accordance with maintenance and barrier management, with the objective of highly reliable and efficient barriers.***

WCM and RCM as an integrated method and tool are both explained in the theory section, chapter 2.3.2 and 2.3.3.

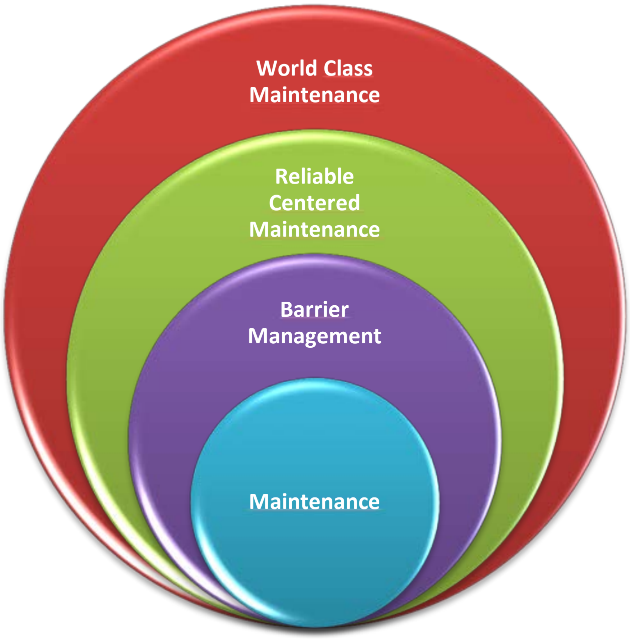


Figure 47 - Organisation management overlapping.

Maintenance is an overall process of ensuring different parts of a function to maintain at a predetermined sufficient and satisfying level. This could either be continuously, or frequent over a period of time. Maintenance is directly linked to maintain a barrier's degree of:

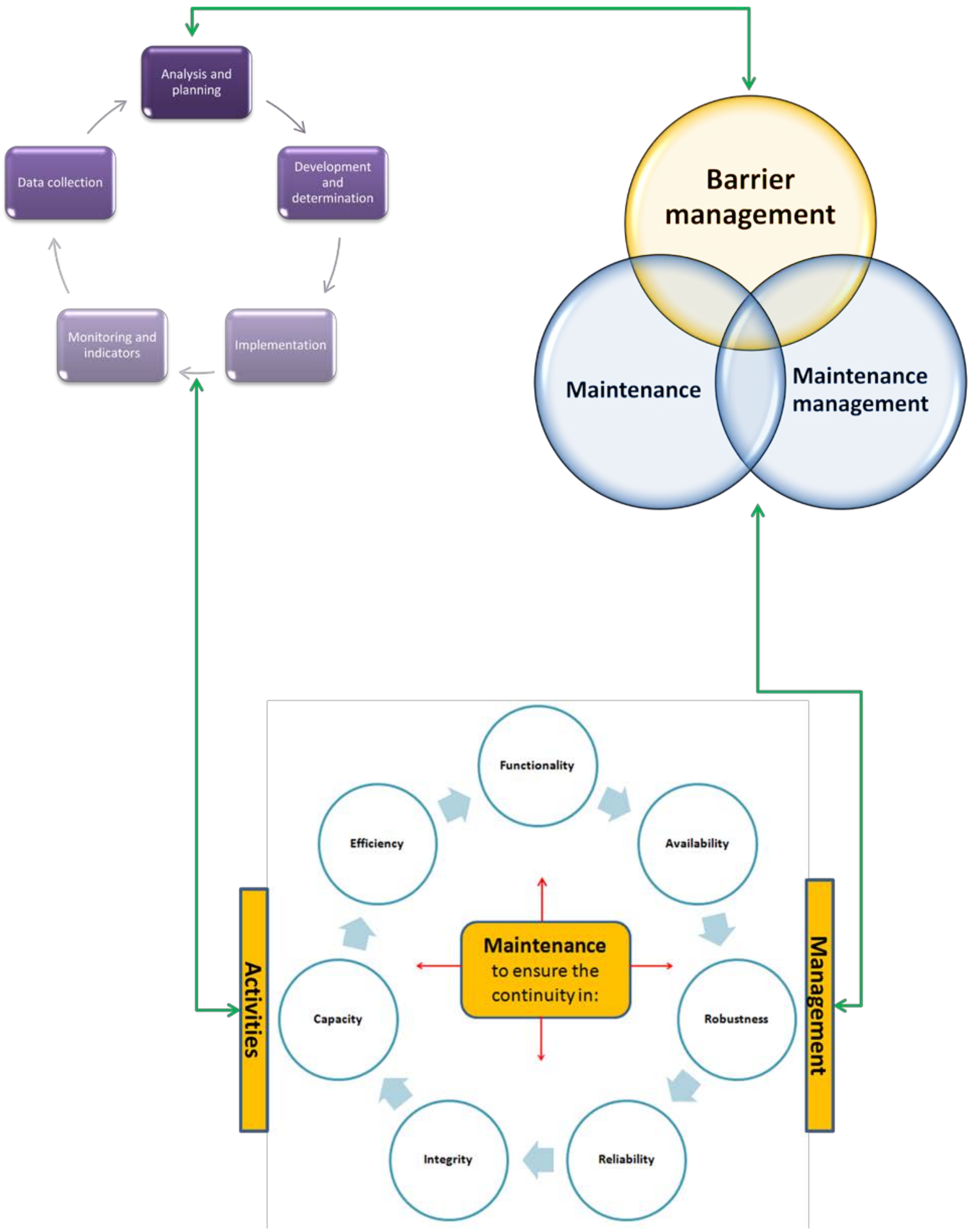


Figure 48 - Illustrated relation of barrier management, maintenance and maintenance management.

To further analyse, illustrate and underpin the link and importance of maintenance in barrier management, the accident of Deepwater Horizon is going to be analysed. There is also going to be analysed whether there are any causations between PSAN's prioritised areas of improvement, compared to causes indentified in the investigation report from the Deepwater horizon accident.

5.2.3 Deepwater horizon, barriers and barrier management

The 20th of April *2010, a major blowout, explosion and fire occurred at the mobile oil rig Deepwater Horizon (DwH) at the Macondo field in the Gulf of Mexico* (PSAN, 2011)*. How can the investigation and information from this accident contribute to prevent any form of resumption?*

The rig sank after two days, several people got seriously injured and 11 people were killed. Approximately 4 million barrels of oil leaked out of the well before it was stopped 87 days later, causing environmental, economic and potential severe biological damage.

PSAN developed this report for the main reason to learn from what went wrong at the Deepwater Horizon accident, with both direct and indirect causes. The PSAN report's conclusion was based on multiple independent investigation reports. This is again used as a basis for increasing the level of health, safety and environmental focus in the Norwegian petroleum industry.

Information, data and literature used in this continuing analysis are based on PSAN's report from the accident (PSAN, 2011).

PSAN's report is divided into two parts:

- **1.** Areas of learning potential regarding safety and contingency in drilling and well operations on the Norwegian continental shelf.
- **2.** Areas of learning potential in general for preventing any major accidents.

In this analysis the focus will be at *why and how,* in accordance to both parts where appropriate.

The overall summary and conclusion from PSAN, is that the accident at DwH demonstrates the needs for more resilient and robust solutions. The safety margins should be wider, and manage more resistance before breaking down. This could be deviations and errors as:

- ❖ Human errors
- ❖ Technical errors
- ❖ Operational deviations
- ❖ Unexpected and high pressure situations

Some important identifications done in PSAN's report regarding this thesis' objectives, are listed below in Table 7. The most essential and relevant identifications, are listed in Table 8 at page 86.

Table 7- Important identifications from DwH accident.

▪ *Weaknesses/errors regarding well barriers and the corresponding monitoring.*
▪ *Weaknesses/errors regarding performance requirements to barriers and barriers establishment, testing, maintenance and monitoring.*
▪ *Weaknesses/errors regarding abandoned wells and plugging.*
▪ *The need for updating procedures, methods and technology in the NORSOK-standards.*
▪ *Be prepared for the unexpected and to be able to identify it when it occurs.*
▪ *40 minutes from the first indications of well abnormalities, to the first reaction of the personnel.*
▪ *Weaknesses/errors in the BOP (blowout preventer).*
▪ *Weaknesses/errors regarding lifeboat procedures.*
▪ *Inadequate maintenance has been an essential contributing factor to the accident. Especially regarding the BOP including maintenance, testing, errors etc., but also the general status of maintenance is mentioned in several reports.*
▪ *Inadequate maintenance of the BOP. It was not in compliance with the vendor's recommended interval. Non-genuine parts were used in the management system with other specifications than the original ones.*
▪ *Weaknesses/errors in operational management functions, both on and offshore.*
▪ *Weaknesses/errors in the compliance of procedures and practices, the understanding of risks, modifications in procedures and plans, communication, involvement and in interaction.*
▪ *Weaknesses/errors and many indicators of challenges regarding the safety culture at DwH.*
▪ *Weaknesses/errors in the learning ability from earlier accidents and incidents.*
▪ *Favouritism of saving time and money, rather than the focus at safety.*
▪ *DwH must be associated as a system - accident, meaning that errors involving several actors, systems and processes over time, resulted in the accident.*
▪ *Clear, repeated and apparent signals in relation to barrier elements were not registered or identified by the company, or any related actors or authorities.*

From BP's overview of barrier breaches which contributed to the DwH accident (BP, 2010). This is a direct and actual example of Reason's *Swizz Cheese model* from chapter 3.1.5, and is an important illustration of the breaches which were identified in the DwH accident.

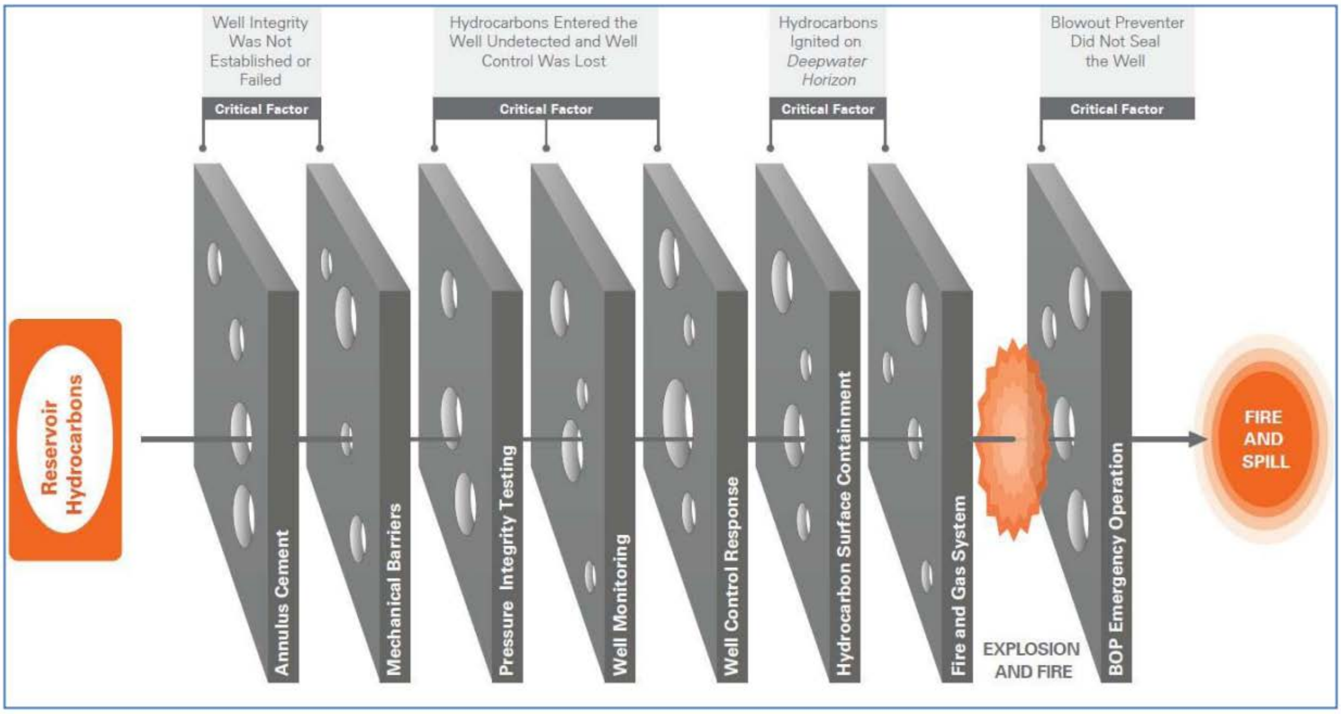


Figure 49 - Barrier breaches from the DwH accident (BP, 2010).

How can maintenance be blamed in this process, how has maintenance influenced or affected the breaches, and why?

On basis of the several identifications of weaknesses and errors regarding maintenance, barrier breaches and the corresponding management, a general approach of how the two disciplines affects each other, their corresponding role and the importance of maintenance are further analysed. The analysis is based on the description done earlier in this chapter, as well as related theory from the theory section.

PSAN argues that robust solutions will contribute to identify weaknesses and dangerous conditions in an earlier phase, making the process of ***maintenance*** more efficient and essential of preventing barrier breaches. This is logically managed through the barrier management. This is important at every level in an organisation:

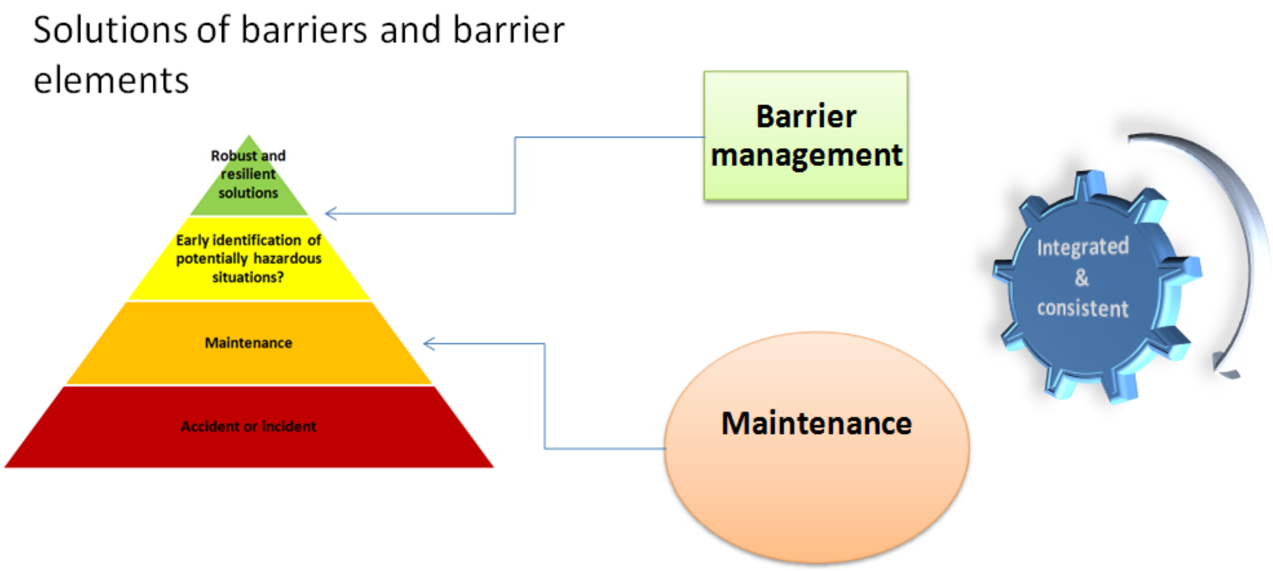


Figure 50 - Solutions of barriers and barrier elements.

From the Energy & Barrier perspective as described in chapter 3.1.5, Reason's Swizz cheese model illustrates that the strategy of barrier management and maintenance shall be evaluated using organisational, environmental and individual factors. These should again be evaluated against the three classes of protection:

- Organisational factors
- Task/environmental factors
- Individual/team action.

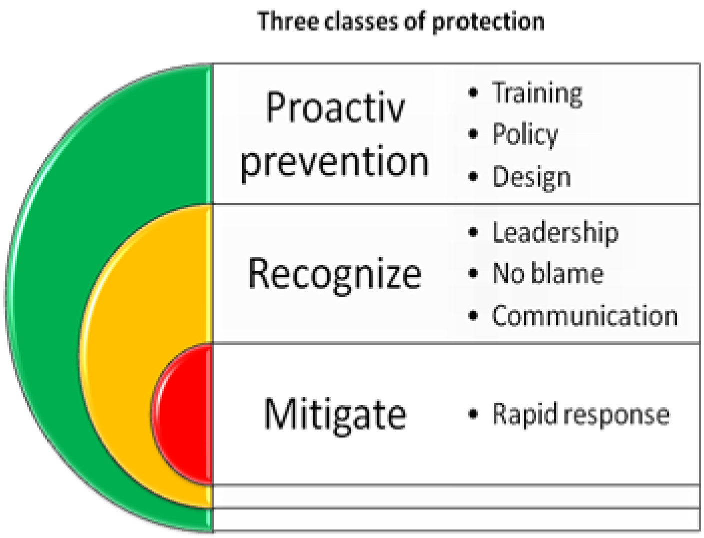


Figure 51 - Three classes of protection.

When considering the weaknesses and errors identified in the report from PSAN, there most certainly could be drawn fundamental and significant connections between the barrier breaches related to weaknesses and flaws in the barrier management. Several breaches may be investigated at the basis of maintenance, and linked to absences or errors/weaknesses in maintenance performance.

As analysed earlier in this chapter, maintenance is important in the continuous process of ensuring the barrier function's stability and reliability, as well as monitor, improve and update the barrier elements during a specific period of time. Many of the errors from DwH are either a direct or indirect cause of inefficient solutions and priorities.

Based on the analysis, literature and result evaluations from the DwH report, several assumptions of weaknesses are established:

Not be able to:

---

1. Identify and indicate weak/absent points related to different levels in barriers and barrier management.

2. Maintain barriers.

3. Improve and develop better solutions using barrier management with maintenance as an efficient, relevant and robust tool/process.

4. Implement new solutions.

5. Establish a solid and overall resilient management.

Some relevant examples of errors and weaknesses from the DwH accident are listed in Table 8, which are essential arguments and results in accordance to the 5 points above:

Table 8 - Relevant examples of weaknesses and errors from the DhW accident.

Proactive prevention	Recognize	Mitigate
- Inadequate maintenance. - Weaknesses/errors regarding performance requirements to barriers and barriers establishment, testing, maintenance and monitoring.	- Clear, repeated and apparent signals in relation to barrier elements were not registered or identified by the company, or any related actors or authorities. - Weaknesses/errors in the compliance of procedures and practices, the understanding of risks, modifications in procedures and plans, communication, involvement and in interaction.	- 40 minutes from the first indications of well abnormalities, to the first reaction of the personnel. - Weaknesses/errors regarding lifeboat procedures.

Robust and resilient solutions and strategies are vital to all areas and phases, including:

- Technology and capacity
- Competence
- Organisation
- Management in all phases

As one can see from the last of the four point above, robust and resilient solutions are just as important in the management of every phase, including ***barrier management***.

It is therefore important that maintenance management and maintenance is fully integrated and evaluated from every necessary perspective in the barrier management. Maintenance is a reaction of the actions determined and established in maintenance management, so both terms are essential in this analysis, hence the usage of both approaches.

"... The Deepwater Horizon accident confirms the importance of maintenance to ensure that critical safety equipment is able to perform their functions when needed. The accident also confirms that the focus and need of continuous improvement of maintenance in the Norwegian petroleum industry, remains a high priority..." (PSAN, 2011, p. 17).

The top priority is to proactively prevent any incident from occurring, through establishing necessary barriers and obstacles at as many levels as required. A proactive and generative organisation as described in chapter 2.4.2, will also have procedures for how to decrease any potential consequences during, and after the occurrence of an unwanted situation, primarily to prevent recurrence.

Integrate maintenance in barrier management to ensure and maintain the barriers required function, efficiency and value:

Figure 52 - Maintenance in barrier management

Prioritised order of endeavoured and desired organisational status:

- **1.** Proactively prevent any unwanted incidents or accidents with maintenance as a integrated tool to continuously monitor, evaluate, maintain and improve existing solutions, strategies and systems in barrier management.

- **2.** Reduce consequences and damage if occurrence of an incident or accident, regardless of its scope, though more serious accidents obviously needs more attention and regulations. From the barrier management point of view, maintenance is frequently used to ensure the barriers acting and functional status, especially when needed.

- **3.** Learn and improve from earlier/historical events, to optimise the resilience and efficiency of the barriers. Maintenance is used as a perspective (measure of quality, absence or error in performance) in the process of identifying possible errors and causes. It may be both before, during or after a maintenance procedure is performed, and there may be several causes linked to insufficient maintenance work involved.

5.2.4 Importance, relation and causation between the DwH accident identifications/probable causes, and PSAN's priorities for the petroleum industry in Norway - 2014.

From the analysis, there is a clear link between PSAN's priority and what the Deepwater Horizon accident report reveals. Errors in barriers, both the implementation of the different barrier elements, the competence of the personnel using and understanding them, as well as the absence of different maintenance activities in several processes indicates that this is, and shall continue to be an important priority in the industry.

To make the barriers as efficient, relevant and robust as possible, the integration and performance of maintenance is clearly important. To develop the maintenance procedures as suitable and relevant as possible, a well established barrier management is necessary, both in term of planning, execution and monitoring for further development and optimisation of maintenance.

6. Maintenance indicators in the barrier management

***Barrier management** is the overall process of developing, establish and continuously improve barrier solutions. Maintenance is an important and essential phase of barrier management, especially over a given period of time in relation to maintaining the barrier's function and efficiency, as well as resilience against modifications and changes in the environment.*

6.1 Maintenance indicators in the barrier management.

Regarding the work of proactive maintenance, monitoring and analysis of already existing barriers are necessary. Performance requirements (PR) are developed in barrier management, as mentioned in chapter 3.1.2., to increase the management's ability to evaluate the efficiency of barriers, and to ensure the systems functionality. PR are also established to help identify weaknesses and areas of inefficient or insufficient barrier solutions.

Maintenance is an important aspect of this process, contributing with the continuous or frequent monitoring of the already established and integrated barriers. The strategy for barriers is developed in barrier management, including integrated maintenance indicators, which are one of the bases in the development of relevant, efficient and resilient barriers.

Maintenance indicators reveals areas of weaknesses, since they often are directly related to the monitoring of existing barriers and barrier elements through performance requirements. This connects maintenance indicators to barrier management in the development of new and improved solutions of barriers, especially in the establishment of performance requirements, as well as the management around further monitoring and potential improvement.

Maintenance indicators in barrier management are determined as an asset in barrier management, with the primarily purpose of:

- **1. Indicate and ensure the barrier's present functionality .**
- **2. Improving the barrier when necessary (when potentially indicated).**

- **3. Quality and optimisation analysis of new solutions against earlier or present maintenance indicators, as well as developing new and more relevant indicators.**
- **4. Testing and verification of the new barrier strategy or solution.**

Before presenting some maintenance indicators in barrier management, a selection of barrier elements are going to be presented. This is done to illustrate the barrier elements relation to maintenance, and to bring out and directly connect maintenance indicators to one or more specific areas of barrier management.

In relation to several of the following barrier elements, maintenance quality is an important factor when considering the reliability of the barrier element. Maintenance quality could possibly be indicated by the rate of revealed failures during maintenance and testing. One example is the Blind shear ram (BSR) in the blowout preventer (BOP), adapted from Hauge (2012):

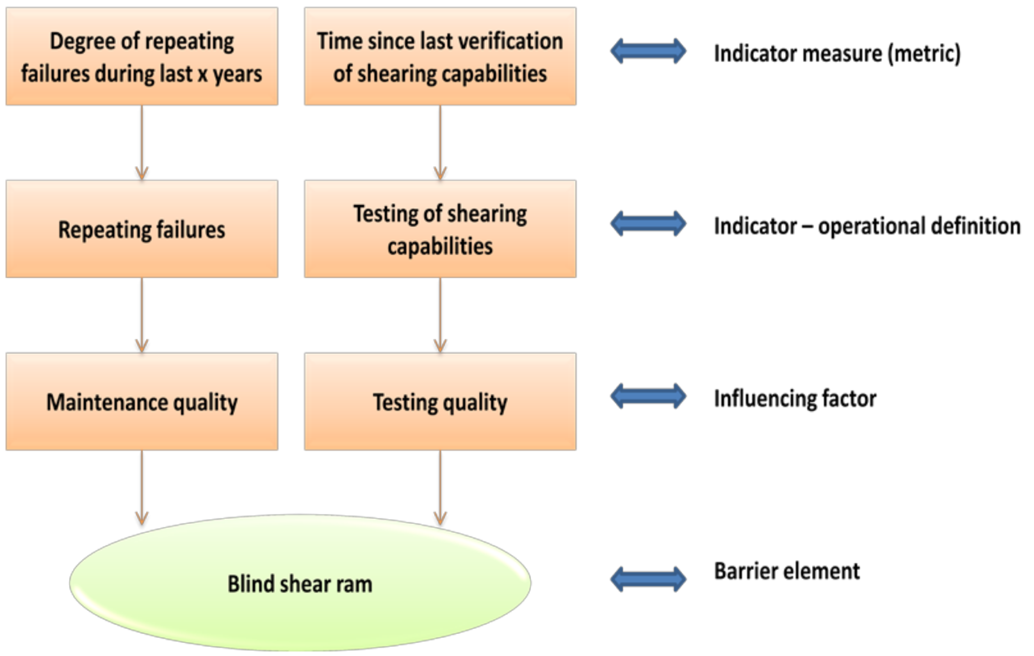


Figure 53 - From indicator measure and indicator definition, to maintenance and barrier element.

<u>Operational definition:</u> what is being measured.

<u>Metric measure:</u> how the indicator is being measured.

The following table is adapted from the test data collected by PSAN during 2012 and 2013, in accordance with barrier testing in the Norwegian petroleum industry (PSAN, 2013e, p. 122). The barrier elements in Table 9 are mentioned to present some examples of elements, as well being applied in some further arguments and illustrations.

Table 9 - Examples of barrier elements (PSAN, 2013e)

Barrier element	2012		2013	
	Number of tests	Number of errors	Number of tests	Number of errors
Fire detection	56.043	114	58.239	119
Gas detection	27.300	141	29.960	201
<u>Close down:</u> - Riser ESDV	1.256	27	1.510	22
-Wing and master	15.780	75	17.191	130
-DHSV	8.848	135	8.782	149
Pressure Relief Valve (BDV)	3653	79	3.695	61
Safety valve PSV	11.990	248	12.569	311
Isolating with BOP	3.524	24	2.796	4
<u>Active fire protection:</u> -	2.021	10	2.154	18
-	8.319	17	8.759	12

The tests on the different barrier elements are a part of the entire strategy of maintenance related to barriers. In Table 9, most of the barriers are typical technical and physical barriers, where the differences and distinctions are discussed more in chapter 7.

As described, maintenance quality may be appropriate as an influencing factor for a physical barrier element, such as the blind share arm, as well as the BDV and BOP from Table 9.

A maintenance indicator (operational level) regarding maintenance quality, which is an important area of the development in barrier management, may be as follows:

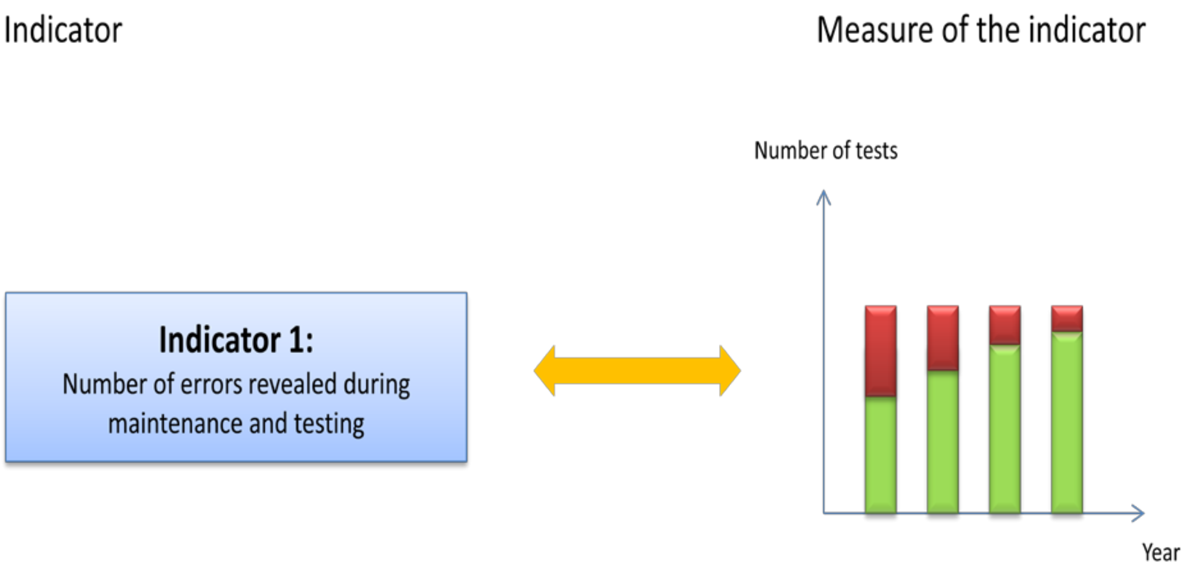


Figure 54 - Indicator 1

The red area at the bars in Figure 54 indicates the number of errors revealed in the barriers, compared to the total number of tests, thus their error ratio. This is also how the indicator is ***measured***. An example from Table 9**.**:

PSV failure ratio in 2013 =311/12569 = 0,0247. This is the same as approximately 2,5%.

As Figure 54 illustrates, the number of errors shall ideally decreases during the years, due to possible factors as:

- Better barrier development in accordance with its reliability.
- Higher priority in the barrier and maintenance management.
- Higher integration and barrier focus regarding its specific maintenance activity.

A very low failure rate indicates ***good maintenance quality*** at the existing barrier, which also indicates that the barrier is very likely functional when needed, and is necessary information during the planning and potential improvement of solutions and strategies in barrier management.

This indicator will contribute to indicate the level of ***readiness and reliability*** in the barrier, which is one of the most vital properties for a barrier, and therefore an essential factor in barrier management. The measure and number of tests, as well as the determined tolerable failure rate, is typically assessed to the barrier's function, purpose, relevancy and integrity.

Another indicator regarding maintenance in barrier management is *backlogging.* This indicator reveals if planned and preventive maintenance activities as described in chapter 2.1, is performed in accordance with the scheduled plan:

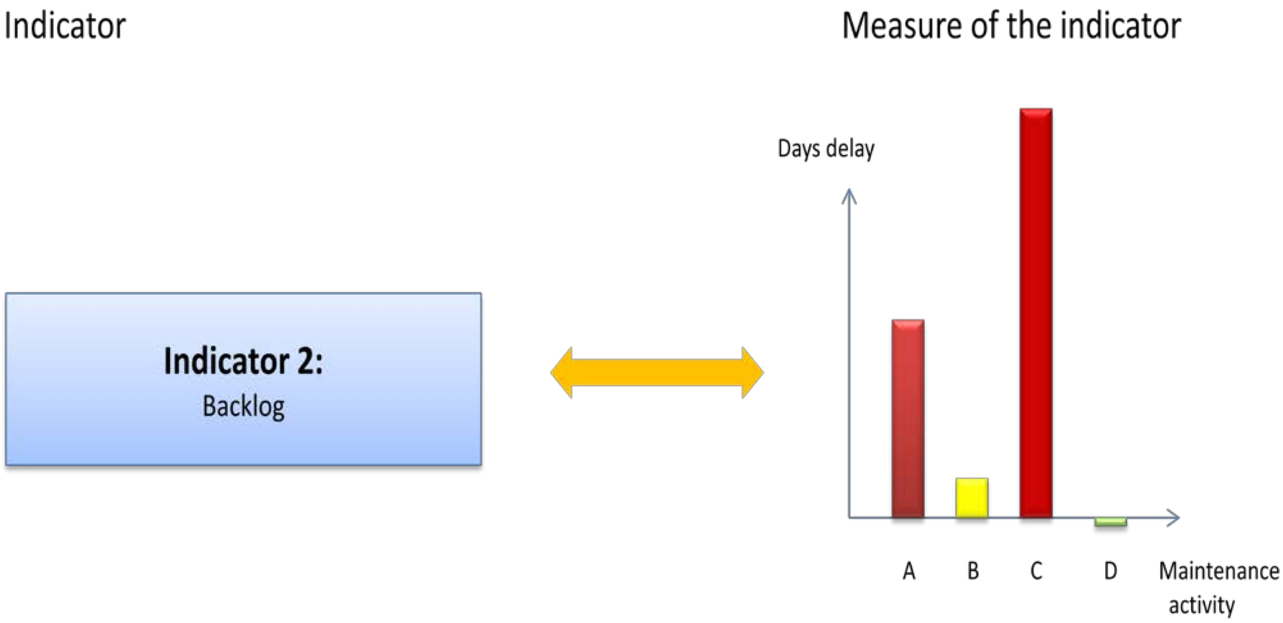


Figure 55 - Indicator 2

If the measurement of the indicator shows that it is continuously delayed, there is a clear indication that the ***maintenance activity*** and its corresponding planning suffers from an insufficient management and performance.

The ***measure*** of the indicator in relation to the number of days, weeks, months or even years, depends on the specific maintenance activity and the organisation's strategy in accordance with both internal and external requirements.

If an indicator indicates an exceeding and intolerable number of delayed hours, days, weeks etc. over the scheduled plan, the maintenance activity in accordance with barrier management shall be evaluated.

In this indicator, operational and organisational factors are more in focus, which is further discussed in chapter 7.

Potential causes and areas of interest/evaluation in barrier management should be:

- Lack of staffing.
- Low quality of maintenance planning.
- Lack of a good monitoring system.
- Inefficient working routines.
- High ratio of unplanned maintenance activities, which pushes planned activities ahead.
- Importance/criticality of the activity (low, medium, high). Low priority maintenance is often accumulated, making the potentially combined effect increase.

Backlogging is often used in accordance with just planned maintenance activities, and does not include unplanned activities. It could therefore be appropriate to use indicators that illustrate the ratio of preventive maintenance:

$$= \frac{\text{hours of preventive maintenance}}{\text{hours of total maintenance}}$$

---

7. Maintenance and technical, operational and organisational barrier elements

Maintenance functions *and maintenance indicators in barriers may possible be considered as technical, operational and organisational barrier elements. The potential deviations, differences and characteristics between the three perspectives are going to be analysed and presented in this chapter, including the usage of a hypothetical industrial scenario.*

7.1 Technical, operational and organisational maintenance functions and indicators in barrier elements

As described in the previous chapters, maintenance is an important aspect of barrier management and barriers. This is during the planning phase, as well as the monitoring and continuously works of improvement and optimisation.

In the theory section 3.1.1 of barriers, the difference between technical, operational and organisational barrier elements is presented. Physical barrier elements are often featured as physical barriers, like eye protection, fire walls etc. Operational and organisational are featured as non-physical, typically like competence, experience, task delegation etc.

As presented in chapter 5.2.2, maintenance has an important role in ensuring the different factors (as shown in Figure 56) ***reliability and continuity***. At this basis, the relation between maintenance functions and indicators are going to be presented from a technical, operational and organisational barrier element's perspective.

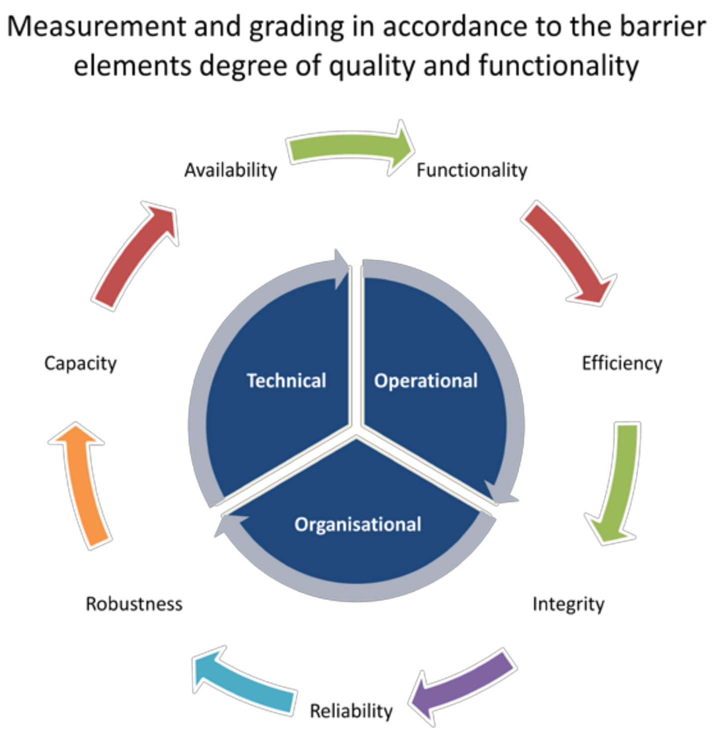


Figure 56 - Measurement and grading in accordance to the barrier element`s degree of quality and functionality.

Figure 56 illustrates every aspect where maintenance has a significant role in ensuring the barrier element's level of performance. Maintenance must be integrated in a sufficient level, to ensure every technical, operational and organisational elements degree of quality over time.

An organisations overall ***strategy of business***, will influence the concept of barrier elements through several aspects. From technical equipment and data, to how the different personnel perform their delegated tasks in accordance to the safety policy and culture. To better illustrate this, an example of a fictive scenario will be presented, with actual inputs of earlier analysed elements and situations from e.g. the DwH accident. It is essential to emphasise that this is just a fictional illustration, and not from an actual real incident.

The potential correlation between *maintenance functions, maintenance indicators* and the *barrier elements* will be drawn:

"... *At an oil rig on the Norwegian continental shelf, there was performed a maintenance operation on a blowout preventer (BOP), because of technical indications of abnormalities. The maintenance activity was scheduled to start at 02.00 AM and to be finished at 04.00 AM, but was delayed 8 hours due to the weather condition prediction. The performance was additionally delayed in 3 hours, due to the absence of qualified personnel.*

At 13.00 PM the maintenance begins, after getting a ready signal from the control room. This means that every emergency system in case of an accident is checked and intact, like the rescue procedure, fire distinguisher systems, medical crew, life boat readiness etc.

During the maintenance, the device that measures one specific pressure in the sub-system, starts increasing. The most experienced operator knows what is going on, and adjust another valve to stabilise the process. He contacts the control room, which confirms that the pressure is decreasing. He says that this often happens if the earlier maintenance performances are done in a "hurry". The incident qualifies as an error at the device.

The maintenance operation is finished at 15.30 PM, without any major incidents or situations, and the responsible person registers the operation data in the data system..."

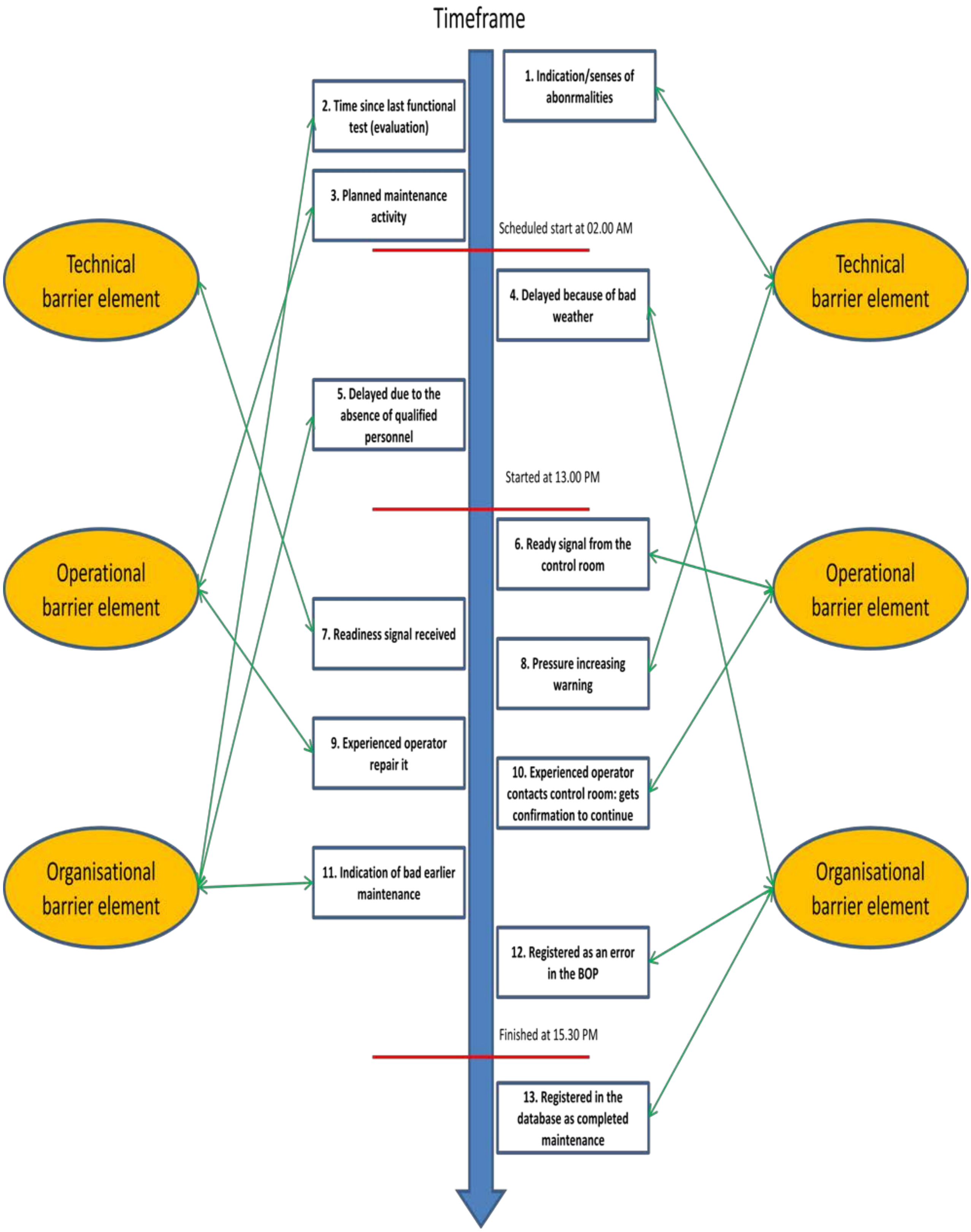


Figure 57 - Fictive case study of barrier elements

The different barrier elements are indicated as white boxes along the timeframe line.

In most situations where extended barriers are needed, the system requires several integrated barriers with both technical, operational and organisational elements. A technical alerting barrier will not be at any help, if there is no qualified person to evaluate and control the barrier and system. Based on the theory and this scenario, one could assume that:

- **Technical elements** in this case, indicates and alerts digitally if something (or someone) exceeds any predetermined limit or barrier value, like the pressure in the valve.

- **Operational elements** are personnel who monitor or react if there are any alerts or warnings. The specific tasks and actions. The *human detection and reaction.*

- **Organisational elements** are personnel/routines that implements necessary actions when needed, as when the pressure actually increased above the limits. The "role" in any performance of a function, based from management and procedures, as well as any predictions.

In the report from PSAN about barrier management (PSAN, 2013b), they describe the difference and deviation between operational and organisational elements as less relevant. The essential and most important part is that the elements are developed and actually established in the system, with the corresponding and correct performance requirements.

However, maintenance processes are just as important to correctly delegate and establish to ensure the elements function and capability over time. Every maintenance function must be determined and established in accordance with the PRs and barriers to ensure their complete compliance.

At this basis, there may be debatable if all the elements are connected to the "correct" technical, operational and organisational area in the scenario (Figure 57), particularly the operational and organisational elements.

So, where do the maintenance functions and maintenance indicators belong? And which are potentially technical, operational and organisational barrier elements?

Maintenance activities are as presented in this thesis, one of the most important aspects of barrier management, particularly in the proactive phase of monitoring and improvement. This is managed through ensuring the barrier's continuous functionality regarding maintenance operations, as well as the development of new and resilient solutions.

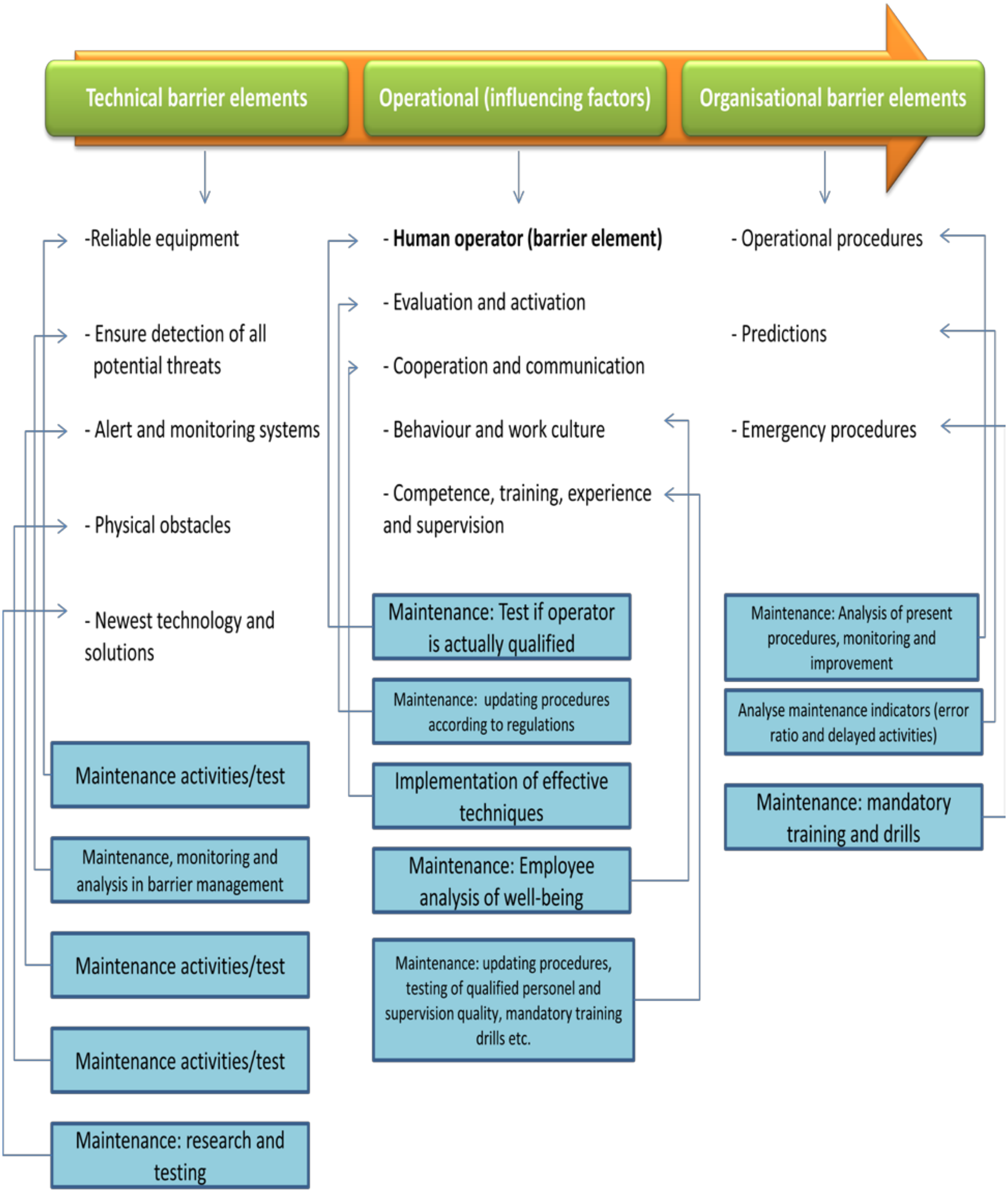


Figure 58 - Barrier elements and maintenance activities.

As Figure 58 illustrates, the maintenance functions and indicators are not a directly or specific barrier element in itself, but they are highly necessary for the main reason to maintain and ensure the different barrier elements performance in accordance with the determined requirements.

PSAN argues that maintenance has no particular definition as a barrier element, but is more like a *necessary function* to maintain and improve the elements (PSAN, 2013b, p. 21):

"... Maintenance is a necessary prerequisite for a barriers performance over time. Maintenance in itself in this relation is NOT to be considered as a barrier function or barrier element..."

When that being said, maintenance indicators like failure ratio (during maintenance testing) and backlogging, ***may*** be defined as a barrier element from ***some*** point of views. The indicators are a way of "alerting", preventing and decreasing the probability of an accident or incident, and could in that way be interpreted as a barrier in itself. However, the direct barrier function is to actually perform the tests and gather the indications with the usage of maintenance, rendering the complete definition or interpretation a little fused and alternating, depending on which perspective or phase the barrier is assessed from.

8. Next generation barrier management concept

As written *in the introduction, DNV GL is an international and well established classification society, with business connections and cooperation contracts over the entire world. They operate within several different areas, including maritime, food and health care, energy and the oil & gas industry.*

Throughout this chapter, based on the thesis' analysis and findings, a conceptual discussion or reflection for DNV GL, regarding barrier management and maintenance is presented. This includes several proposed suggestions for improvements and future ambitions.

DNV GL is working across 100 countries and 300 offices around the globe. They combine both technical and operating expertise with the main reason to optimize the safety in relation to all aspects of the entire process. In this thesis, the focus has been at the petroleum industry, and how maintenance operations and management may affect the functionality and efficiency of barriers and barrier management.

Figure 59 - DNV GL

DNV GL has many different customers and collaboration partners, as well as several areas of counselling. The establishment of a more general and overall form of ***guideline principles*** regarding barrier management and maintenance would be more appropriate and efficient, given this thesis objectives and scope limits. This means that no specific barrier will be emphasised or prioritised in this concept, but a general approach and integration of maintenance will be discussed and appointed.

The objective of this concept is to establish a basis for DNV GL to further contribute in their work of making flexible and precise solutions, regulations and counselling in the future.

At the basis of this, a barrier management concept for DNV GL is going to be presented, emphasising maintenance activities.

8.1 Concept development: new ideas and suggestions for DNV in relation to barrier management, with focus at maintenance.

Maintenance is as analysed in chapter 4, an important role of ensuring the continuity and safety in a process. This again, as presented in chapter 5, is dependent on a well established barrier management, with the integration of maintenance.

- The analysis from these chapters indicated several areas of weaknesses regarding earlier (e.g. DwH accident) management of maintenance and barriers.

- It is also one of the four major areas in PSAN's future ambitions and focuses of improvement.

The main focus should be at using maintenance in barrier management to optimise the proactive approach and significance of barriers.

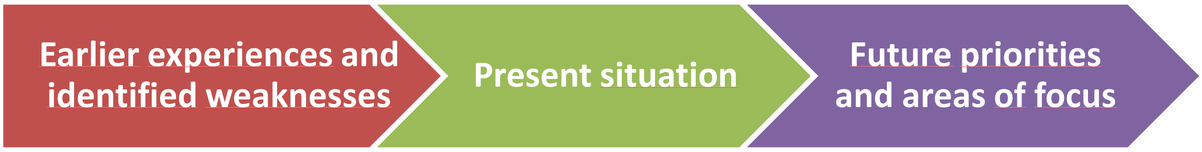


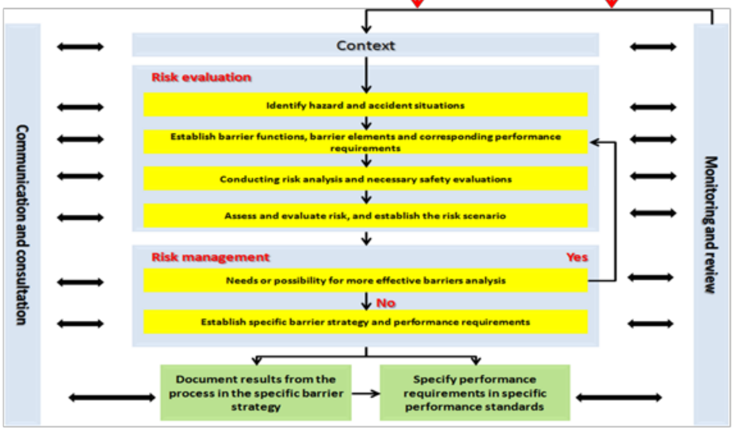
Figure 60 - Using maintenance as a proactive approach and significance of barriers.

From the analysis in chapter 5, there were identified weaknesses in the barrier management regarding:

Not be able to:

1. Identify and indicate weak/absent points related to different levels in barriers and barrier management.
2. Maintain barriers.
3. Improve and develop better solutions of barriers using barrier management with maintenance as an efficient, relevant and robust tool.
4. Implement new solutions.
5. Establish a solid and overall resilient management.

Potential suggestions on how to improve the areas as listed in Figure 61. This figure consists primarily of suggestions related to the (proactive) planning phase of barrier management, as well as the process of monitoring (over time):



Measures and initiatives

- Use maintenance as an asset in proactively ensuring the competence of those operating and controlling the monitoring systems.

-Improve and more strictly track and follow up planned and scheduled maintenance, regardless of its level of predetermined priority.

-Actively organise, analyse, use and utilize the maintenance indicators like backlog and number of errors.

-Distinguish unplanned and planned maintenance in the barrier management, since those may influence each other MORE than predicted. Organise and systemise to more efficient indicate and predict any particular area of weakness.

-Implement better solutions of monitoring with the emphasize at ALERTING AS EARLY AS POSSIBLE, regardless of the priority or degree of the threat.

-Develop specific routines of how to handle and who to contact in case of any maintenance indication of any weak points, both in physical, operational and organisational barrier elements.

- Actively perform maintenance tests of the barrier elements to approve/decline their functionality.

Measures and initiatives

-Establish and integrate an already well documented and efficient maintenance program within the barrier management, like WCM and RCM. Implement efficient techniques to improve the overall barrier management system.

-Prioritise maintenance at a required minimum level in barrier management, in accordance with delegated time, resources, personnel and importance/criticality (since it`s essential to the barriers continuous functionality over time).

-Establish additional/different qualitative maintenance indicators using RCA- analysis.

- Actively perform maintenance risk analysis within the barriers monitoring to reveal potential new risks or risk contributors.

- Be more focused at the area of proactive barriers, particularly related to and within organisational barrier elements, and how to use maintenance to increase the relevancy of the elements.

- Establish better and more suitable performance requirements to ensure the barrier elements functionality, primarily based on maintenance indications of weaknesses, like high error ratios, repeated delayed maintenance performances etc.

Figure 61 - New measures and initiatives

In accordance with Figure 61 and the earlier analysis in chapter 6, the four overall focuses of maintenance in relation to barrier management (with a significant emphasis at number 1) should be of DNV GL's further and future interest:

- **1. Proactively prevent any unwanted incidents or accidents with maintenance as a integrated tool/process to continuously monitor, evaluate, maintain and improve existing solutions, strategies and systems in barrier management. Evaluate the risk in every situation and operation individually. Then analyse the total potential risk effect and corresponding maintenance requirements when establishing the barriers in the planning phase of barrier management.**

- **2. Reduce consequences and damage if occurrence of an incident or accident, regardless of its scope, though more serious accidents obviously needs more attention and regulations. From the barrier management point of view, maintenance is frequently used to ensure the barriers acting and functional status, especially when needed.**

- **3. Learn and improve from earlier/historical events, to optimise the resilience and efficiency of the barriers. Maintenance is used as a perspective (measure of quality, absence or error in performance) in the process of identifying possible errors and causes. It may be both before, during or after a maintenance procedure is performed, and there may be several causes linked to insufficient maintenance work involved.**

In relation to point 3 above, but also as an additional contribution regarding point 1, a developed suggestion for a typical web style "click and request" system is presented in Figure 62, Figure 63 and Figure 64. The system is explained in point 4:

- **4. Utilize experience and experts internally in the classification society to ensure that state of the art barrier management and maintenance is performed.**

  This could e.g. be done through an internal and abroad network within DNV GL, separated in relevant and appropriate "groups". Personnel working in the same area of expertise and dealing with the same type of problems could easily contact each other if desired. DNV GL could in this way improve their cooperation and efficiency, regarding barrier management and maintenance. Every employee registers their own profile in a database, making the required resources in the development as small as possible.

Step A: *Entering the internal network to initiate the process:*

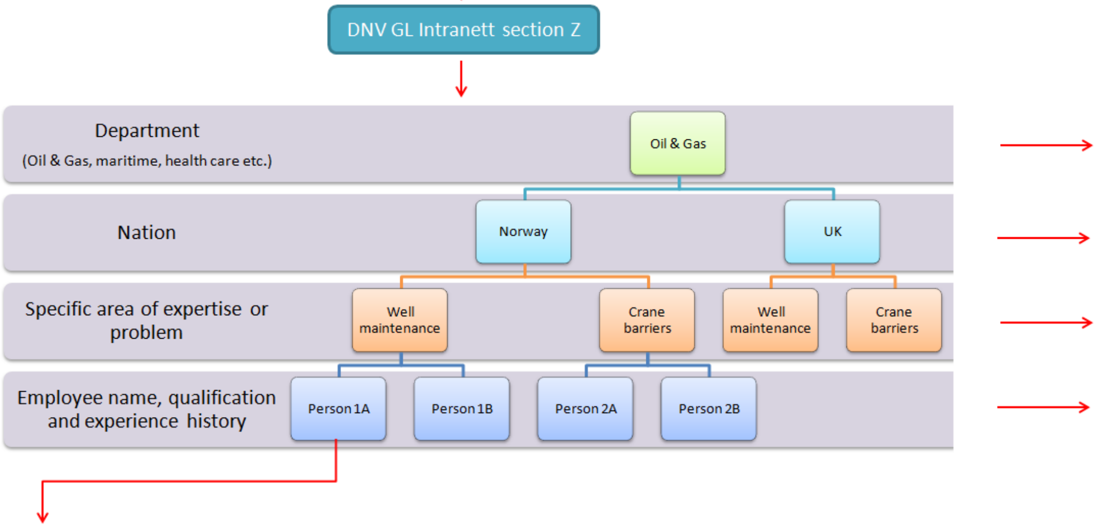


Figure 62 - Step A in requesting internal counselling.

Step B: *After identifying the most appropriate person, send him/her a request:*

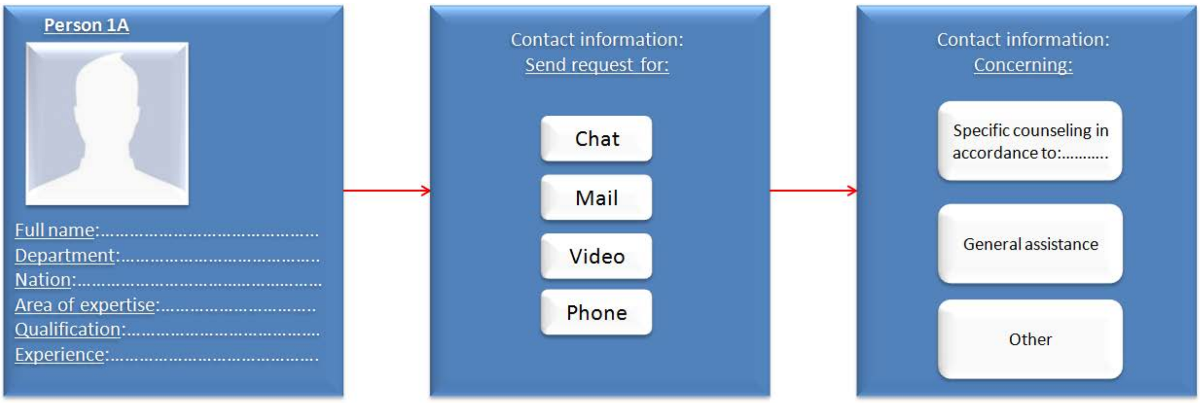


Figure 63 - Step B in requesting internal counselling.

Step C: *The person contacted/requested will get an instant notification at his/her computer:*

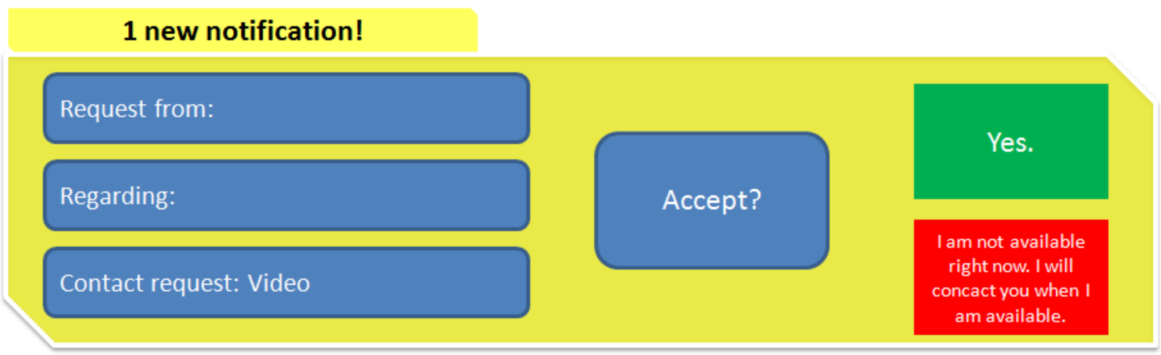


Figure 64 - Step C in requesting internal counselling.

9. Conclusion

Safety has the intention of safeguarding every value such as personnel, environment, equipment and the economic interests in an organisation. As analysed, there are evidence of a strong relation between safety and maintenance activities, especially when it comes to the degree of the maintenance quality. A function designed and developed to maintain safety is dependent on frequent maintenance to maintain its functionality and capability. In addition, the safety function's complexity and relevancy will influence the degree of necessary maintenance.

PSAN monitors and works towards improving the Norwegian petroleum industry's level of preserving health, environment and safety. Barriers and barrier management are also highly important aspects of preserving the safety. Today, in the Norwegian petroleum industry, the concept of barrier management is alternating, and PSAN's reports indicate deficiencies regarding a common understanding and usage of barrier management. Based on this, barriers and barrier management is one of PSAN's top four priorities for focus and improvement.

Maintenance has a fundamental role as an integrated tool or process for continuously monitor, evaluate, maintain and improve existing solutions and strategies in barrier management. The maintenance quality and degree within barrier management will develop the barrier's strength of proactively maintain its relevancy, efficiency and resiliency in accordance to the barrier's performance requirements. PRs in barrier management are specific measures which establish a basis, not only for further analysis and improvement, but also for each barrier element and its functionality. That is, their main purpose is to reveal any form of weaknesses, and maintenance indicators are vital contributors in revealing potential malfunctions. Analysis and information of e.g. delayed maintenance and revealed errors during maintenance activities in BM are, as such, relevant indicators which could be utilized in relation to both the development of more efficient and relevant PR and barrier elements.

Maintenance functions and maintenance indicators are conclusively an essential prerequisite in maintaining and improving both technical, operational and organisational barrier elements. However, as particularly concluded by PSAN, maintenance functions alone are not considered as a direct barrier element, but as one of the most necessary performances/processes in relation to the barrier's functionality over time.

The future concept developed for DNV GL focuses at improving the proactive prevention of any occurrence of an accident, using maintenance in barrier management. Such an approach is based on the results of the analysis done throughout the thesis, as well as PSAN's future ambitions of improvements. The thesis has also presented a program whose goal is to improve the internal cooperation and exchange of competence within DNV GL, e.g. in relation to those working with barrier management and maintenance.

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Appendix I

Pre-study report

NTNU
Norwegian University of Science and Technology

Faculty of Engineering Science and Technology

Department of Production and Quality Engineering

MASTER THESIS - TPK4900

Maintenance and barriers

Endre Fylling Moen

Spring 2014

Preface

In accordance with the course TPK4900 and the final master's thesis assignment, this pre-study report shall submit an overall oversight over the progress during the work of the thesis, in addition to a planned schedule with defined work packages and deadlines.

This pre-study report is written by stud. techn. Endre Fylling Moen under the faculty of Engineering Science and Technology at NTNU.

My gratitude to Per Schjølberg (NTNU), John Kristijan Hermann (DNV GL) and Astrid Rydock (DNV GL) for their help and counselling during the early phase of the thesis.

Trondheim, 09.09.2013

Endre Fylling Moen

Table of contents

Introduction

In the master's program - Mechanical engineering - at NTNU, at the 10th and last semester, every graduating student shall prepare and submit a master's thesis. This is the final task before finishing the integrated education program of five years, and is in many ways, a summary of your profound expertise. It is weighted 30 study points of the total of 300 in the entire engineering degree. The pre-study report is a detailed plan on how to further gather information, and how to dedicate daily working hours in relation to the different subtasks in the master's thesis.

The master's thesis and its related subtasks are developed by my responsible supervisor Per Schjølberg at the department of Production and Quality Engineering, in cooperation with my supervisors at DNV GL, Jon Kristijan Hermann and Astrid Rydock. In accordance with the different subtasks, it may be necessary or reasonable to emphasis one or more specified selections. The pre-study report will at first endeavour to indicate this, with a full elaboration in the introduction of the thesis, linking it to its desired objectives.

The master's thesis structure and contents is a further specialization based on my 9th semesters project task, which was "Maintenance and Safety related to the offshore industry". In this task, the headline is "Maintenance and barriers", pointing the focus in another direction. This is a discipline that is becoming more and more important in the offshore industry.

Assignment description

Through this assignment, or thesis, the main objective is to achieve a great understanding and knowledge about how maintenance influences and affects the different types of barriers in relation to its management and safety level, mainly in the petroleum industry.

At first, the "state of the art" for barrier management in the Petroleum Safety Authority Norwegian shall be presented. Further in corporation with DNV, and probably based on some real time cases and reports, the importance of maintenance and barrier management is to be analyzed. The final objective based on the analyses and presentations, is to develop the next generation barrier management concept, primarily focused on maintenance for DNV GL. It is appropriate to announce that this will be a concept of preparatory suggestions, not a detailed and highly specific type of sketch.

Thesis tasks and formulation

Principles for barrier management in the petroleum industry will be more and more important and It is fundamental to understand the maintenance function in the barrier management.

Barrier management within maintenance is about ensuring, on a systematic and continuous basis, the maintenance barriers are relevant, effective and robust.

In this thesis the candidate shall:

- Present the relation between maintenance and safety.
- Present the “state of the art” for barrier management in Petroleum Safety Authority Norway.
- Analyse the importance of maintenance in barrier management.
- Present some maintenance indicators in the barrier management. Analyse how the indicators can be measured (the state/condition of the indicator).
- Analyse how maintenance function and maintenance indicators can me technical, operational and organisational barriers elements.
- Present the next generation barrier management concept (focus on maintenance for DNV).

Involved actors

NTNU

NTNU, Norwegian University of Science and Technology, is the second largest university in Norway, with an approximation of 22000 students. About 50 percent of the students are studying technical, or scientific subjects (NTNU, 2014), and around 3600 students yearly graduate from the university, including bachelor's-, master's- and doctoral candidates.

This master's thesis is being written in collaboration with the Department of Production and Quality Engineering, which is under the faculty of Engineering Science and Technology at NTNU. The department has a good connection with the offshore industry, in addition to being closely involved with the leading research facility in Scandinavia, SINTEF (2014). This creates a well founded fundamental base for the development of a useful and up to date thesis.

DNV GL

Det Norske Veritas was founded in Oslo in 1864, and was established as a membership organisation to provide more reliable and uniform classification and taxation of Norwegian ships (DNV GL, 2014). The shipping industry in Norway was a growing commerce, making different classifications and international regulations more essential. In 2013, DNV and GL formed the DNV GL Group, with employees and other operating forces in over 100 different countries.

DNV GL is a company which combine both technical and operating expertise, with the ambitions to optimize the safety in relation to the environment, society and the customers. DNV GL offers expertise consulting in several different industrial areas, with the main focus on maritime, oil and gas, energy industries as well as food and health care.

Thesis objectives

The master's thesis primarily objective is to evaluate and analyse different approaches between maintenance and barriers in the all ready existing literature, linked to the offshore industry. This will be used to develop and contribute to a potentially new and improved barrier management concept for DNV GL, with the main focus at maintenance.

Thesis administration and plan

The workload distribution in affiliation to the subtasks size and weight, has to be systematically classified with the elements of cost, time and resources. This will be shown in several CTR- forms in appendix C. The different subtasks will be divided into single work packages, and illustrated in a WBS (2014) in appendix B. A progress form, with the individual subtasks estimated start- and finishing date, will be obtained in a Gantt-diagram (Microsoft , 2014) in appendix D. Along with the thesis, a status report shall be submitted, where the status of the thesis compared to the plan is to be evaluated. The exact date for this status report will be announced later during this semester.

Limitations and terms

Time

The thesis was released 6th of February. The pre-study report shall be delivered within three weeks, i.e. 27th of February. The thesis original submission deadline is 10th of June, but since there was some delay on the release date, the deadline for the submission will be sat to 30th of June. This is an approximation of 15 weeks. The thesis is a 30 study point subject, which in this case, indicates an estimated workload of 50 hours a week, making it in total of 750 working hours, excluding the pre-study report.

Literature

There is much available literature in relation to maintenance and barriers individually, but there is not a sufficient amount when it comes to the direct link between them. This will present challenges in locating the newest and most relevant literature, however, it is rewarding to write about something that is not "old and exhausted".

Literature recommendations from both NTNU and DNV GL will be followed, in addition to potentially other people with appropriate expertise.

Contribution for DNV GL

Since the field of this expertise is a relatively new and growing discipline, my highest aim is to develop, or at least highlight some new ideas for DNV GL, regarding barrier management with focus on maintenance.

Temporarily literature

DNV GL. (2014). *DNV GL about*. Retrieved from http://www.dnvgl.com/about-dnvgl/history.aspx

Microsoft . (2014). *Gantt diagram*. Retrieved from http://office.microsoft.com/nb-no/excel-help/presentere-data-i-et-gantt-diagram-i-excel-HA010238253.aspx

NTNU. (2014). *NTNU*. Retrieved from https://www.ntnu.no/tall-og-fakta

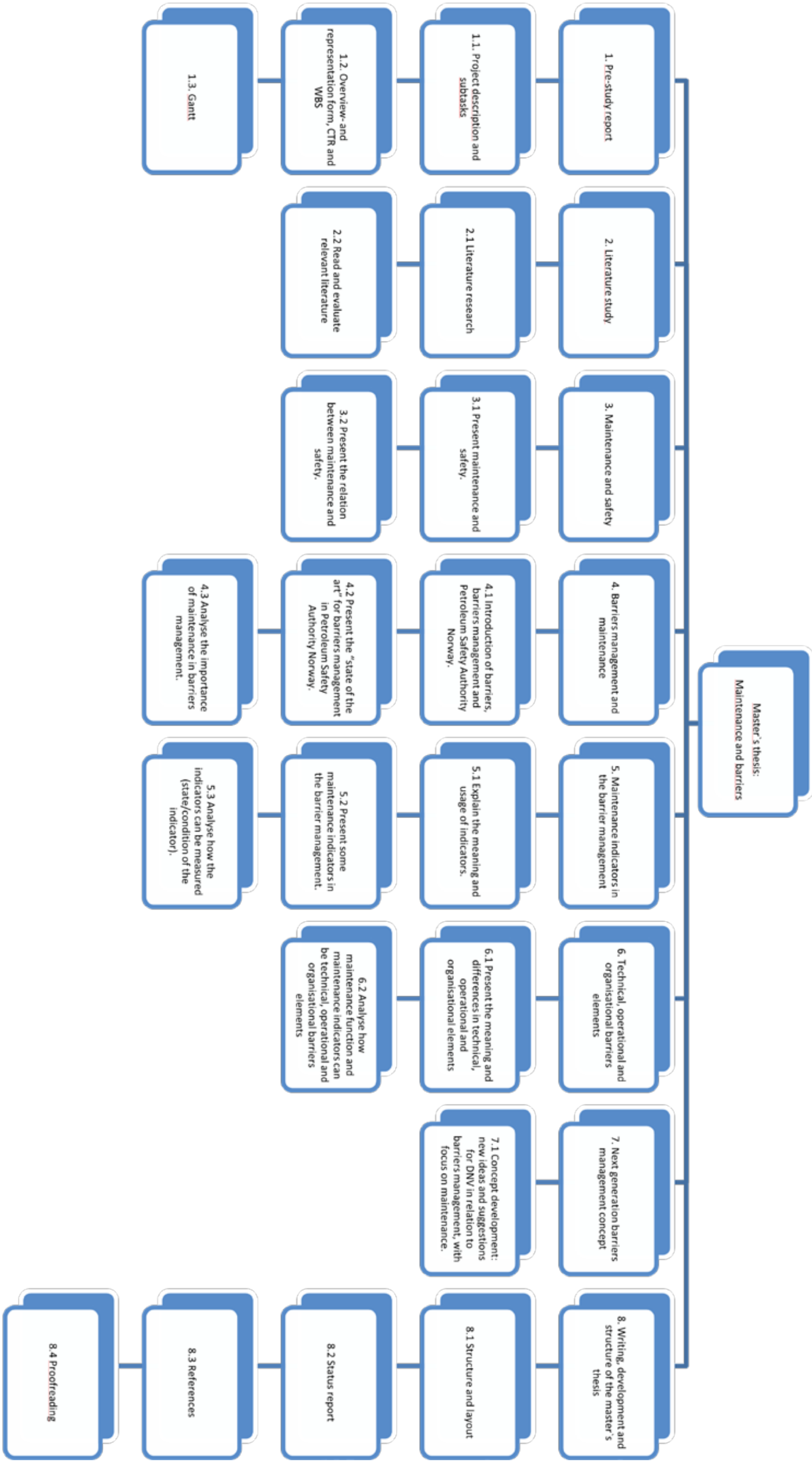
SINTEF. (2014). *SINTEF*. Retrieved from http://sintef.no/Om-oss/

WBS. (2014). *WBS*. Retrieved from https://www.workbreakdownstructure.com/

Appendix A - Overview and representation

Master's thesis overview and representation			
Master's thesis:	Maintenance and barriers		
Responsible person :	Endre Fylling Moen	**Date:**	24.02.2014
Task and formulation:			
To present an understanding of how the maintenance function affects and influences the barrier management. With the illustrations and descriptions of maintenance, safety, barriers, indicators and their corresponding relation, the next generation barrier management concept shall be developed for DNV GL.			
Purpose:			
To achieve a great understanding of the different subjects and disciplines, and hopefully contribute to a new and improved barrier management concept for DNV GL, with the focus on maintenance.			
Deadlines and objectives:			
Submission of the pre-study report: 27th of February Submission of the status report: To be announced later Submission of the thesis: 20th of June Milestone 1: The gathering of the "state of the art" literature. Milestone 2: To determine some maintenance indicators, and how they can be measured. Milestone 3: Development of the improved barrier management concept. Milestone 4: Submission of the master's thesis			
Success criteria:			
Achieve an excellent grade. Both DNV and the university department supervisor are satisfied with the result. Deliver on time.			
Assumptions, risks and obstacles:			
Assumptions: - Reliable supervisors - Good communication with involved actors - Some simple and commonly expressions and abbreviations are self implied. Risks and obstacles: - That my health maintains at a reasonable level during the work. - Underestimated workload of some of the work packages.			

Appendix B - Work breakdown structure (WBS)



Appendix C - CTR

C.1 - Pre-study report.

Cost, Time and Resources (CTR)			
Master's thesis:			**Date:**
Maintenance and barriers			24.02.2014
Work package no.:	**Work package:**		**Responsible person:**
1	Pre-study report		Endre Fylling Moen
Work package/tasks:			
1.1. Project description and subtasks 1.2. Overview- and representation form, CTR and WBS 1.3. Gantt			
Objective:			
Develop a detailed plan and schedule for the thesis scope, workload and time requirements.			
Content description and work scope:			
Project description Subtasks Project plan using Overview- and representation form, CTR and WBS Gantt diagram Limitations and terms			
Literature and resources:			
Supervisors recommendations and personal experience from the project assignment.			
Work method:			
Analyse the subtasks and objectives, evaluate the workload and then develop a fitting schedule.			
Challenges:			
Consider the correct amount of time and resources to each subtask			
Result:			
A well done progress plan for the thesis, with illustrated forms and diagrams.			
Estimated time and resources:			
Planned start:	**Planned finish:**	**Work hours:**	**Duration (days):**
06.02.2014	27.02.2014	150	22

C.2 - Literature study.

Cost, Time and Resources (CTR)			
Master's thesis:			**Date:**
Maintenance and barriers			24.02.2014
Work package no.:	**Work package:**		**Responsible person:**
2	Literature study		Endre Fylling Moen
Work package/tasks:			
2.1 Literature research 2.2 Read and evaluate relevant literature			
Objective:			
Search, read and understand relevant literature.			
Content description and work scope:			
Literature content list			
Literature and resources:			
Per Schjølberg, , Jon Kristijan Hermann and Astrid Rydock. Other potential persons with the correct expertise BIBSYS and Google Scholar Petroleum Safety Authority Norway (Ptil).			
Work method:			
Search in different internet databases Study of recommended literature			
Challenges:			
Sort out relevant literature Apply the correct literature Enough time			
Result:			
A complete list with all the used literature and references			
Estimated time and resources:			
Planned start:	**Planned finish:**	**Work hours:**	**Duration (days):**
28.02.2014	19.04.2014	169	51

C.3 - Maintenance and safety.

Cost, Time and Resources (CTR)			
Master's thesis:			**Date**:
Maintenance and barriers			24.02.2014
Work package no.:	**Work package:**		**Responsible person:**
3	Maintenance and safety		Endre Fylling Moen
Work package/tasks:			
3.1 Present maintenance and safety. 3.2 Present the relation between maintenance and safety.			
Objective:			
Achieve knowledge about maintenance, safety and the relationship between them.			
Content description and work scope:			
A written text with illustrations where it is suitable.			
Literature and resources:			
Supervisor Per Schjølberg, Jon Kristijan Hermann and Astrid Rydock. Relevant literature from my project assignment (9th semester) BIBSYS and Google Scholar Ptil			
Work method:			
Evaluation of the literature and research. Analysis of the literature in relation to the work package objectives. Discussions with supervisors			
Challenges:			
To understand the fundamental relation between maintenance and safety, and how to best explain and illustrate it.			
Result:			
Simple, but a satisfactory description of the maintenance and safety relation.			
Estimated time and resources:			
Planned start:	**Planned finish:**	**Work hours:**	**Duration (days):**
14.03.2014	29.03.2014	77	16

C.4 - Barrier management and maintenance

Cost, Time and Resources (CTR)			
Master's thesis:			**Date:**
Maintenance and barriers			24.02.2014
Work package no.:	**Work package:**		**Responsible person:**
4	Barrier management and maintenance		Endre Fylling Moen
Work package/tasks:			
4.1 Introduction of barriers, barrier management and Petroleum Safety Authority Norway. 4.2 Present the “state of the art” for barrier management in Petroleum Safety Authority Norway. 4.3 Analyse the importance of maintenance in barrier management.			
Objective:			
A good description of barriers and barrier management.			
Content description and work scope:			
The "state of the art" in this discipline. Illustration of the importance of maintenance in barrier management.			
Literature and resources:			
Supervisor Per Schjølberg, Jon Kristijan Hermann and Astrid Rydock. Relevant literature from my project assignment (9th semester) BIBSYS and Google Scholar Ptil			
Work method:			
Usage of correct literature Communication with one or more of the supervisors			
Challenges:			
To describe the true and directly importance of maintenance in a barrier management.			
Result:			
An overall good and direct description of barrier management, and how maintenance potentially affects this.			
Estimated time and resources:			
Planned start:	**Planned finish:**	**Work hours:**	**Duration (days):**
31.03.2014	17.04.2014	100	18

C.5 - Maintenance indicators in the barrier management.

Cost, Time and Resources (CTR)			
Master's thesis:			**Date:**
Maintenance and barriers			24.02.2014
Work package no.:	**Work package:**		**Responsible person:**
5	Maintenance indicators in the barrier management		Endre Fylling Moen
Work package/tasks:			
5.1 Explain the meaning and usage of indicators. 5.2 Present some maintenance indicators in the barrier management. 5.3 Analyse how the indicators can be measured (state/condition of the indicator).			
Objective:			
A good description of some maintenance indicators in barrier management, and how they can be measured.			
Content description and work scope:			
Description of indicators Exposition of maintenance indicators, and how they can be measured, linked to the offshore industry.			
Literature and resources:			
Supervisor Per Schjølberg, Jon Kristijan Hermann and Astrid Rydock Relevant literature from my project assignment (9th semester) and Ptil BIBSYS and Google Scholar Real time cases (DNV)			
Work method:			
Usage of correct literature Usage and data collection from real time cases Communication with one or more of the supervisors			
Challenges:			
Determine the most suitable indicators, and how they are to be measured.			
Result:			
A good overview over some maintenance indicators, with an additional description on how they can be measured.			
Estimated time and resources:			
Planned start:	**Planned finish:**	**Work hours:**	**Duration (days):**
18.04.2014	06.05.2014	74	19

C.6 - Technical, operational and organisational barriers elements.

Cost, Time and Resources (CTR)			
Master's thesis:			**Date:**
Maintenance and barriers			24.02.2014
Work package no.:	**Work package:**		**Responsible person:**
6	Technical, operational and organisational barrier elements		Endre Fylling Moen
Work package/tasks:			
6.1 Present the meaning and differences in technical, operational and organisational elements 6.2 Analyse how maintenance function and maintenance indicators can be technical, operational and organisational barriers elements			
Objective:			
A good description on how maintenance function and maintenance indicators can be technical, operational and organisational barriers elements			
Content description and work scope:			
Description of the meaning in technical, operational and organisational elements A further analysis on how maintenance function and maintenance indicators can have a direct, or indirect relation to one or more of these elements.			
Literature and resources:			
Supervisor Per Schjølberg, Jon Kristijan Hermann and Astrid Rydock Relevant literature from my project assignment (9th semester) and Ptil BIBSYS ,Google Scholar and Real time cases (DNV)			
Work method:			
Usage of correct literature and data collection from real time cases Communication with one or more of the supervisors			
Challenges:			
Determine which maintenance indicator that belongs to each of the barrier elements.			
Result:			
A good analyse on how maintenance function and maintenance indicators can be technical, operational and organisational barriers elements			
Estimated time and resources:			
Planned start:	**Planned finish:**	**Work hours:**	**Responsible (days):**
07.05.2014	05.06.2014	131	30

C.7 - Next generation barrier management concept.

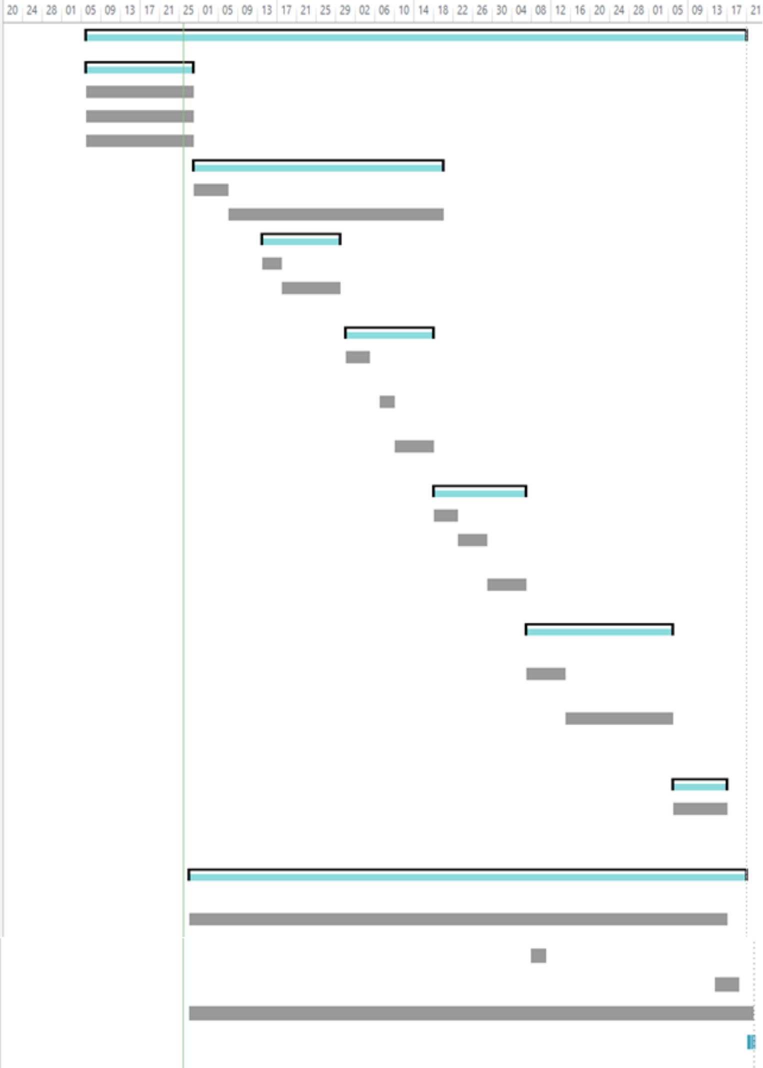
Cost, Time and Resources (CTR)			
Master's thesis:			**Date**:
Maintenance and barriers			24.02.2014
Work package no.:	**Work package:**		**Responsible person:**
7	Next generation barrier management concept		Endre Fylling Moen
Work package/tasks:			
7.1 Concept development: new ideas and suggestions for DNV in relation to barrier management, with focus on maintenance.			
Objective:			
A good, flexible and reliable concept development.			
Content description and work scope:			
Suggestions and ideas with text and illustrations			
Literature and resources:			
All literature and findings			
Work method:			
Evaluations of the thesis analysis and temporarily conclusions.			
Challenges:			
Time and representation			
Result:			
A good, flexible and reliable concept for DNV.			
Estimated time and resources:			
Planned start:	**Planned finish:**	**Work hours:**	**Duration (days):**
06.06.2014	16.06.2014	79	11

C.8 - Writing, development and structure of the master's thesis.

<table>
<tr><th colspan="4">Cost, Time and Resources (CTR)</th></tr>
<tr><td colspan="3">Master's thesis:</td><td>Date:</td></tr>
<tr><td colspan="3">Maintenance and barriers</td><td>24.02.2014</td></tr>
<tr><td>Work package no.:</td><td colspan="2">Work package:</td><td>Responsible person:</td></tr>
<tr><td>8</td><td colspan="2">Writing, development and structure of the master's thesis</td><td>Endre Fylling Moen</td></tr>
<tr><td colspan="4">Work package/tasks:</td></tr>
<tr><td colspan="4">8.1 Structure and layout
8.2 Status report
8.3 References
8.4 Proofread</td></tr>
<tr><td colspan="4">Objective:</td></tr>
<tr><td colspan="4">Write an excellent thesis, with a good language and relevant/evolving result.</td></tr>
<tr><td colspan="4">Content description and work scope:</td></tr>
<tr><td colspan="4">Writing and illustrating with Microsoft office
Status report and literature content list</td></tr>
<tr><td colspan="4">Literature and resources:</td></tr>
<tr><td colspan="4">Microsoft Office 2007
Harvard reference system</td></tr>
<tr><td colspan="4">Work method:</td></tr>
<tr><td colspan="4">Follow the pre-study report, and take notes of potentially deviations</td></tr>
<tr><td colspan="4">Challenges:</td></tr>
<tr><td colspan="4">To follow the pre-study report correct.
Find all necessary literature.</td></tr>
<tr><td colspan="4">Result:</td></tr>
<tr><td colspan="4">Status report
Excellent thesis, with all its correct belongings (pictures, diagrams, figures, text etc.)</td></tr>
<tr><td colspan="4">Estimated time and resources:</td></tr>
<tr><td>Planned start:</td><td>Planned finish:</td><td>Work hours:</td><td>Duration (days):</td></tr>
<tr><td>27.02.2014</td><td>20.06.2014</td><td>120</td><td>114</td></tr>
</table>

Appendix D - Gantt

Task Name	Start	Finish	Work
Master`s thesis	**Thu 06/02/14**	**Fri 20/06/14**	**750 hrs**
1. Pre-study report	**Thu 06/02/14**	**Thu 27/02/14**	**0 hrs**
1.1. Project description and subtasks	Thu 06/02/14	Thu 27/02/14	0 hrs
1.2. Overview- and representation form, CTR and WBS	Thu 06/02/14	Thu 27/02/14	0 hrs
1.3. Gantt	Thu 06/02/14	Thu 27/02/14	0 hrs
2. Literature study	**Fri 28/02/14**	**Sat 19/04/14**	**169 hrs**
2.1 Literature research	Fri 28/02/14	Thu 06/03/14	50 hrs
2.2 Read and evaluate relevant literature	Fri 07/03/14	Sat 19/04/14	119 hrs
3. Maintenance and safety	**Fri 14/03/14**	**Sat 29/03/14**	**77 hrs**
3.1. Present maintenance and safety	Fri 14/03/14	Mon 17/03/14	22 hrs
3.2. Present the relation between maintenance and safety	Tue 18/03/14	Sat 29/03/14	55 hrs
4. Barriers management and maintenance	**Mon 31/03/14**	**Thu 17/04/14**	**100 hrs**
4.1. Introduction of barriers, barriers management and Petroleum Safety Authority Norway	Mon 31/03/14	Fri 04/04/14	21 hrs
4.2. Present the "state of the art" for barriers management in Petroleum Safety Authority Norway	Mon 07/04/14	Wed 09/04/14	17 hrs
4.3 Analyse the importance of maintenance in barriers management	Thu 10/04/14	Thu 17/04/14	62 hrs
5. Maintenance indicators in the barrier management	**Fri 18/04/14**	**Tue 06/05/14**	**74 hrs**
5.1 Explain the meaning and usage of indicators	Fri 18/04/14	Tue 22/04/14	24 hrs
5.2 Present some maintenance indicators in the barrier management.	Wed 23/04/14	Mon 28/04/14	24 hrs
5.3 Analyse how the indicators can be measured (state/condition of the indicator)	Tue 29/04/14	Tue 06/05/14	26 hrs
6. Technical, operational and organisational barrier elements	**Wed 07/05/14**	**Thu 05/06/14**	**131 hrs**
6.1 Present the meaning and differences in technical, operational and organisational elements	Wed 07/05/14	Wed 14/05/14	57 hrs
6.2 Analyse how maintenance function and maintenance indicators can be technical, operational and organisational barriers elements	Thu 15/05/14	Thu 05/06/14	74 hrs
7. Next generation barriers management concept	**Fri 06/06/14**	**Mon 16/06/14**	**79 hrs**
7.1 Concept development: new ideas and suggestions for DNV in relation to barriers management, with focus on maintenance	Fri 06/06/14	Mon 16/06/14	79 hrs
8. Writing, development and structure of the master`s thesis	**Thu 27/02/14**	**Fri 20/06/14**	**120 hrs**
8.1 Structure and layout	Thu 27/02/14	Mon 16/06/14	37 hrs
8.2 Status report	Wed 07/05/14	Fri 09/05/14	13 hrs
8.3 References	Fri 13/06/14	Tue 17/06/14	25 hrs
8.4 Proofread	Thu 27/02/14	Fri 20/06/14	45 hrs
9. Deliver	Fri 20/06/14	Fri 20/06/14	0 hrs



Appendix II

Status report 1 as of 14.03.2014

MASTER THESIS

TPK4900

Maintenance and barriers

Faculty of Engineering Science and Technology

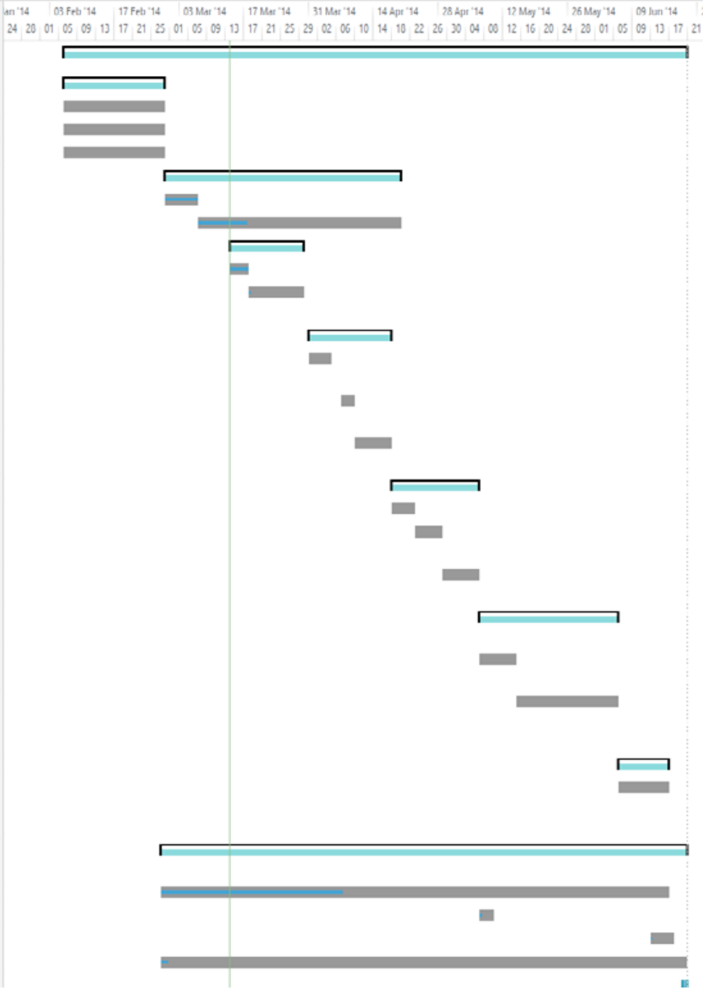
Department of Production and Quality Engineering

Endre Fylling Moen

Spring 2014

NTNU
Norwegian University of
Science and Technology

Task Name	Start	Finish	Work	Actual Work
Master`s thesis	**Thu 06/02/14**	**Fri 20/06/14**	**750 hrs**	**118 hrs**
1. Pre-study report	**Thu 06/02/14**	**Thu 27/02/14**	**0 hrs**	**0 hrs**
1.1. Project description and subtasks	Thu 06/02/14	Thu 27/02/14	0 hrs	0 hrs
1.2. Overview- and representation form, CTR and WBS	Thu 06/02/14	Thu 27/02/14	0 hrs	0 hrs
1.3. Gantt	Thu 06/02/14	Thu 27/02/14	0 hrs	0 hrs
2. Literature study	**Fri 28/02/14**	**Sat 19/04/14**	**169 hrs**	**76 hrs**
2.1 Literature research	Fri 28/02/14	Thu 06/03/14	50 hrs	50 hrs
2.2 Read and evaluate relevant literature	Fri 07/03/14	Sat 19/04/14	119 hrs	26 hrs
3. Maintenance and safety	**Fri 14/03/14**	**Sat 29/03/14**	**77 hrs**	**26 hrs**
3.1. Present maintenance and safety	Fri 14/03/14	Mon 17/03/14	22 hrs	22 hrs
3.2. Present the relation between maintenance and safety	Tue 18/03/14	Sat 29/03/14	55 hrs	4 hrs
4. Barriers management and maintenance	**Mon 31/03/14**	**Thu 17/04/14**	**100 hrs**	**0 hrs**
4.1. Introduction of barriers, barriers management and Petroleum Safety Authority Norway	Mon 31/03/14	Fri 04/04/14	21 hrs	0 hrs
4.2. Present the "state of the art" for barriers management in Petroleum Safety Authority Norway	Mon 07/04/14	Wed 09/04/14	17 hrs	0 hrs
4.3 Analyse the importance of maintenance in barriers management	Thu 10/04/14	Thu 17/04/14	62 hrs	0 hrs
5. Maintenance indicators in the barrier management	**Fri 18/04/14**	**Tue 06/05/14**	**74 hrs**	**0 hrs**
5.1 Explain the meaning and usage of indicators	Fri 18/04/14	Tue 22/04/14	24 hrs	0 hrs
5.2 Present some maintenance indicators in the barrier management.	Wed 23/04/14	Mon 28/04/14	24 hrs	0 hrs
5.3 Analyse how the indicators can be measured (state/condition of the indicator)	Tue 29/04/14	Tue 06/05/14	26 hrs	0 hrs
6. Technical, operational and organisational barrier elements	**Wed 07/05/14**	**Thu 05/06/14**	**131 hrs**	**0 hrs**
6.1 Present the meaning and differences in technical, operational and organisational elements	Wed 07/05/14	Wed 14/05/14	57 hrs	0 hrs
6.2 Analyse how maintenance function and maintenance indicators can be technical, operational and organisational barriers elements	Thu 15/05/14	Thu 05/06/14	74 hrs	0 hrs
7. Next generation barriers management concept	**Fri 06/06/14**	**Mon 16/06/14**	**79 hrs**	**0 hrs**
7.1 Concept development: new ideas and suggestions for DNV in relation to barriers management, with focus on maintenance	Fri 06/06/14	Mon 16/06/14	79 hrs	0 hrs
8. Writing, development and structure of the master`s thesis	**Thu 27/02/14**	**Fri 20/06/14**	**120 hrs**	**16 hrs**
8.1 Structure and layout	Thu 27/02/14	Mon 16/06/14	37 hrs	13 hrs
8.2 Status report	Wed 07/05/14	Fri 09/05/14	13 hrs	1 hr
8.3 References	Fri 13/06/14	Tue 17/06/14	25 hrs	1 hr
8.4 Proofread	Thu 27/02/14	Fri 20/06/14	45 hrs	1 hr
9. Deliver	Fri 20/06/14	Fri 20/06/14	0 hrs	0 hrs



Work package:

<u>1. Pre-study report:</u> OK.

<u>2. Literature study:</u> Research OK. I am still working with the evaluation of the literature, OK.

<u>3. Maintenance and safety:</u> Finished before schedule with part 3.1. OK.

<u>4. Barrier management and maintenance:</u> Not started. OK.

<u>5. Maintenance indicators in the barrier management:</u> Not started. OK.

<u>6. Technical, operational and organisational barriers elements:</u> Not started. OK.

<u>7. Next generation barriers management concept:</u> Not started. OK.

<u>8. Writing, development and structure of the master`s thesis:</u> Have spent some additional hours compared to the scheduled progress. Overall OK.

Comments:

- The research and analysis of literature is relatively after schedule, and I am not concerned with any major exceedance.

-Work package 3.1 is finished before schedule. However, important to ensure the quality of the work.

- The writing, structure and layout part has required some additional work hours compared to the schedule. It is acceptable since I have written 3.1 already, and the first part of writing and structure lays the "layout basis" for the rest of the thesis, and hence is an essential phase.

- Overall: in schedule/track.

Appendix III

Status report 2 as of 12.05.2014

MASTER THESIS

TPK4900

Maintenance and barriers

Faculty of Engineering Science and Technology

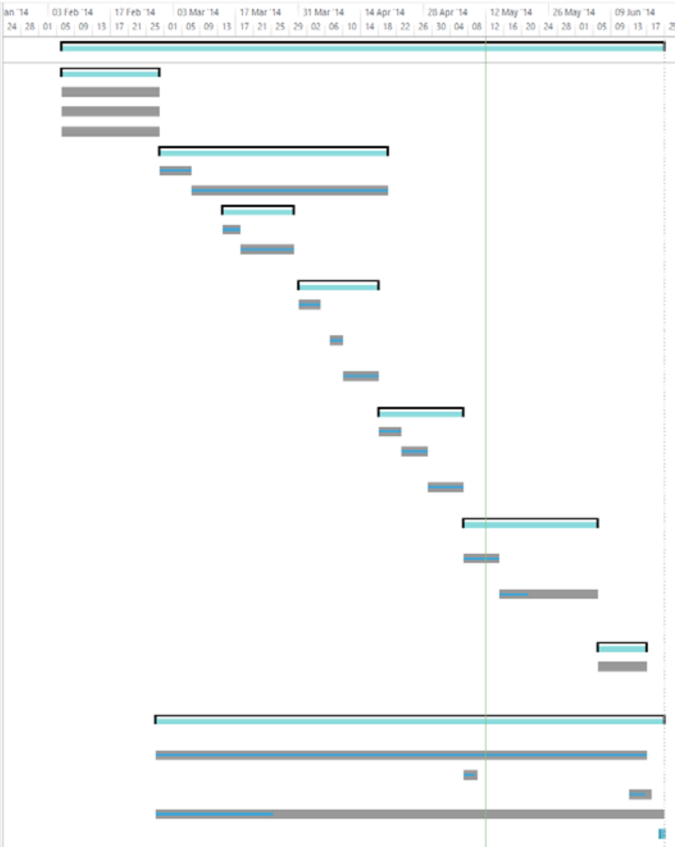
Department of Production and Quality Engineering

Endre Fylling Moen

Spring 2014

Norwegian University of Science and Technology

Task Name	Start	Finish	Work	Actual Work
Master`s thesis	**Thu 06/02/14**	**Fri 20/06/14**	**760 hrs**	**576 hrs**
1. Pre-study report	**Thu 06/02/14**	**Thu 27/02/14**	**0 hrs**	**0 hrs**
1.1. Project description and subtasks	Thu 06/02/14	Thu 27/02/14	0 hrs	0 hrs
1.2. Overview- and representation form, CTR and WBS	Thu 06/02/14	Thu 27/02/14	0 hrs	0 hrs
1.3. Gantt	Thu 06/02/14	Thu 27/02/14	0 hrs	0 hrs
2. Literature study	**Fri 28/02/14**	**Sat 19/04/14**	**169 hrs**	**169 hrs**
2.1 Literature research	Fri 28/02/14	Thu 06/03/14	50 hrs	50 hrs
2.2 Read and evaluate relevant literature	Fri 07/03/14	Sat 19/04/14	119 hrs	119 hrs
3. Maintenance and safety	**Fri 14/03/14**	**Sat 29/03/14**	**77 hrs**	**77 hrs**
3.1. Present maintenance and safety	Fri 14/03/14	Mon 17/03/14	22 hrs	22 hrs
3.2. Present the relation between maintenance and safety	Tue 18/03/14	Sat 29/03/14	55 hrs	55 hrs
4. Barriers management and maintenance	**Mon 31/03/14**	**Thu 17/04/14**	**100 hrs**	**100 hrs**
4.1. Introduction of barriers, barriers management and Petroleum Safety Authority Norway	Mon 31/03/14	Fri 04/04/14	21 hrs	21 hrs
4.2. Present the "state of the art" for barriers management in Petroleum Safety Authority Norway	Mon 07/04/14	Wed 09/04/14	17 hrs	17 hrs
4.3 Analyse the importance of maintenance in barriers management	Thu 10/04/14	Thu 17/04/14	62 hrs	62 hrs
5. Maintenance indicators in the barrier management	**Fri 18/04/14**	**Tue 06/05/14**	**74 hrs**	**74 hrs**
5.1 Explain the meaning and usage of indicators	Fri 18/04/14	Tue 22/04/14	24 hrs	24 hrs
5.2 Present some maintenance indicators in the barrier management.	Wed 23/04/14	Mon 28/04/14	24 hrs	24 hrs
5.3 Analyse how the indicators can be measured (state/condition of the indicator)	Tue 29/04/14	Tue 06/05/14	26 hrs	26 hrs
6. Technical, operational and organisational barrier elements	**Wed 07/05/14**	**Thu 05/06/14**	**139 hrs**	**84 hrs**
6.1 Present the meaning and differences in technical, operational and organisational elements	Wed 07/05/14	Wed 14/05/14	65 hrs	65 hrs
6.2 Analyse how maintenance function and maintenance indicators can be technical, operational and organisational barriers elements	Thu 15/05/14	Thu 05/06/14	74 hrs	19 hrs
7. Next generation barriers management concept	**Fri 06/06/14**	**Mon 16/06/14**	**79 hrs**	**0 hrs**
7.1 Concept development: new ideas and suggestions for DNV in relation to barriers management, with focus on maintenance	Fri 06/06/14	Mon 16/06/14	79 hrs	0 hrs
8. Writing, development and structure of the master`s thesis	**Thu 27/02/14**	**Fri 20/06/14**	**122 hrs**	**72 hrs**
8.1 Structure and layout	Thu 27/02/14	Mon 16/06/14	39 hrs	39 hrs
8.2 Status report	Wed 07/05/14	Fri 09/05/14	13 hrs	9 hrs
8.3 References	Fri 13/06/14	Tue 17/06/14	25 hrs	14 hrs
8.4 Proofread	Thu 27/02/14	Fri 20/06/14	45 hrs	10 hrs
9. Deliver	Fri 20/06/14	Fri 20/06/14	0 hrs	0 hrs



Work package:

1. Pre-study report: OK.

2. Literature study: OK.

3. Maintenance and safety: OK.

4. Barrier management and maintenance: OK.

5. Maintenance indicators in the barrier management: OK.

6. Technical, operational and organisational barriers elements: Started working with 6.1, and also 6.2 which is before schedule.

7. Next generation barriers management concept: Not started. OK.

8. Writing, development and structure of the master`s thesis: Have already exceeded the number of scheduled hours. Overall OK.

Comments:

- The first parts (work package 1-5) are overall OK and in schedule.

- After counselling with my supervisor, Per Schjølberg, the submission date was deferred to the 30th of June, 2014. This was because of some delay in the beginning of the semester regarding the thesis' formulation. I will, however, just follow the scheduled plan and use the additional time as a buffer if desired/necessary.

- Spent several more hours writing and improving the structure/layout (part 8.1).

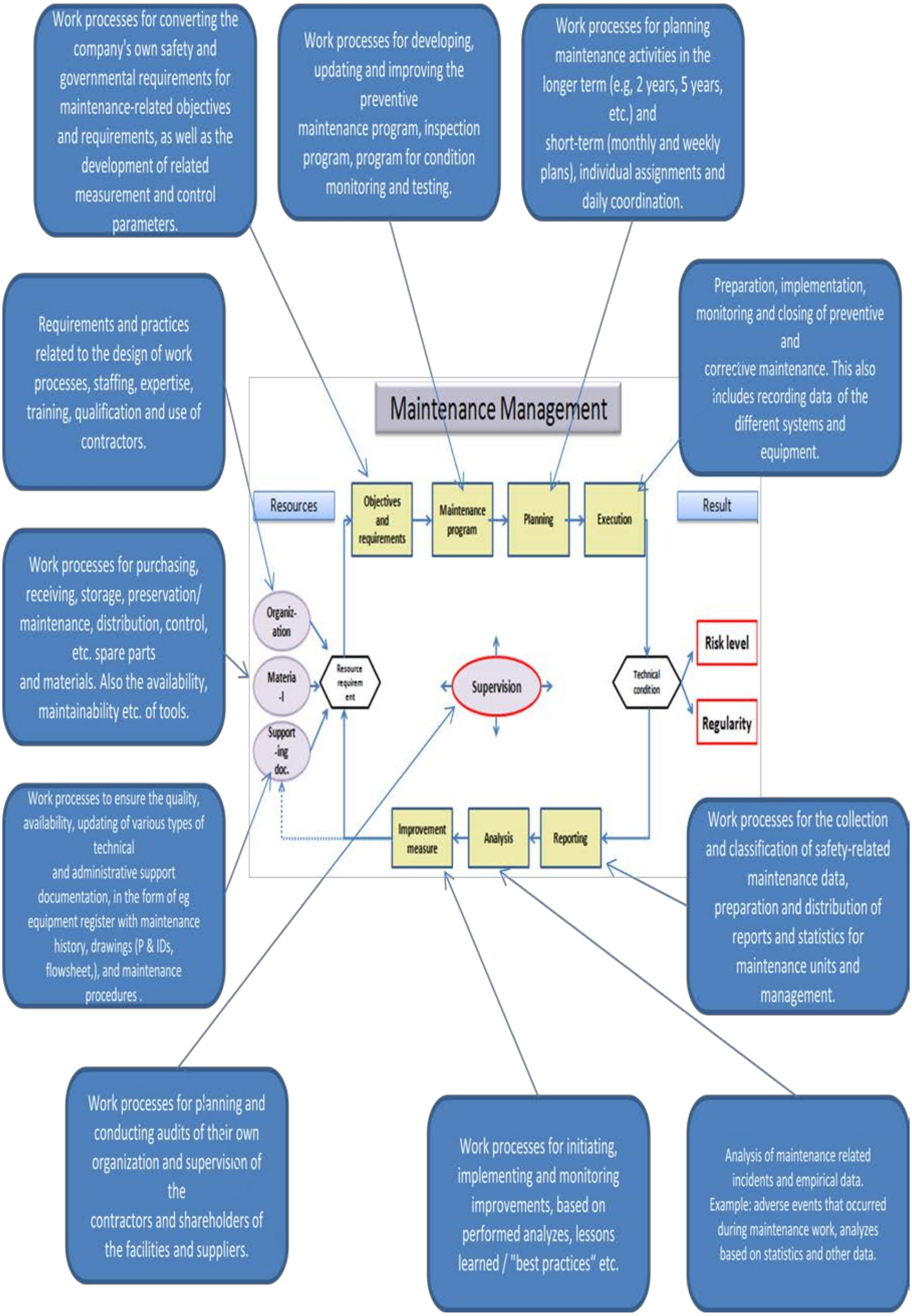
- Have not spent the number of scheduled hours doing proof reading (part 8.4)

- References control has also already exceeded its scheduled number of hours, before it even should have started. This is in the larger picture OK, since I will compensate it with less hours spent in Proofreading.

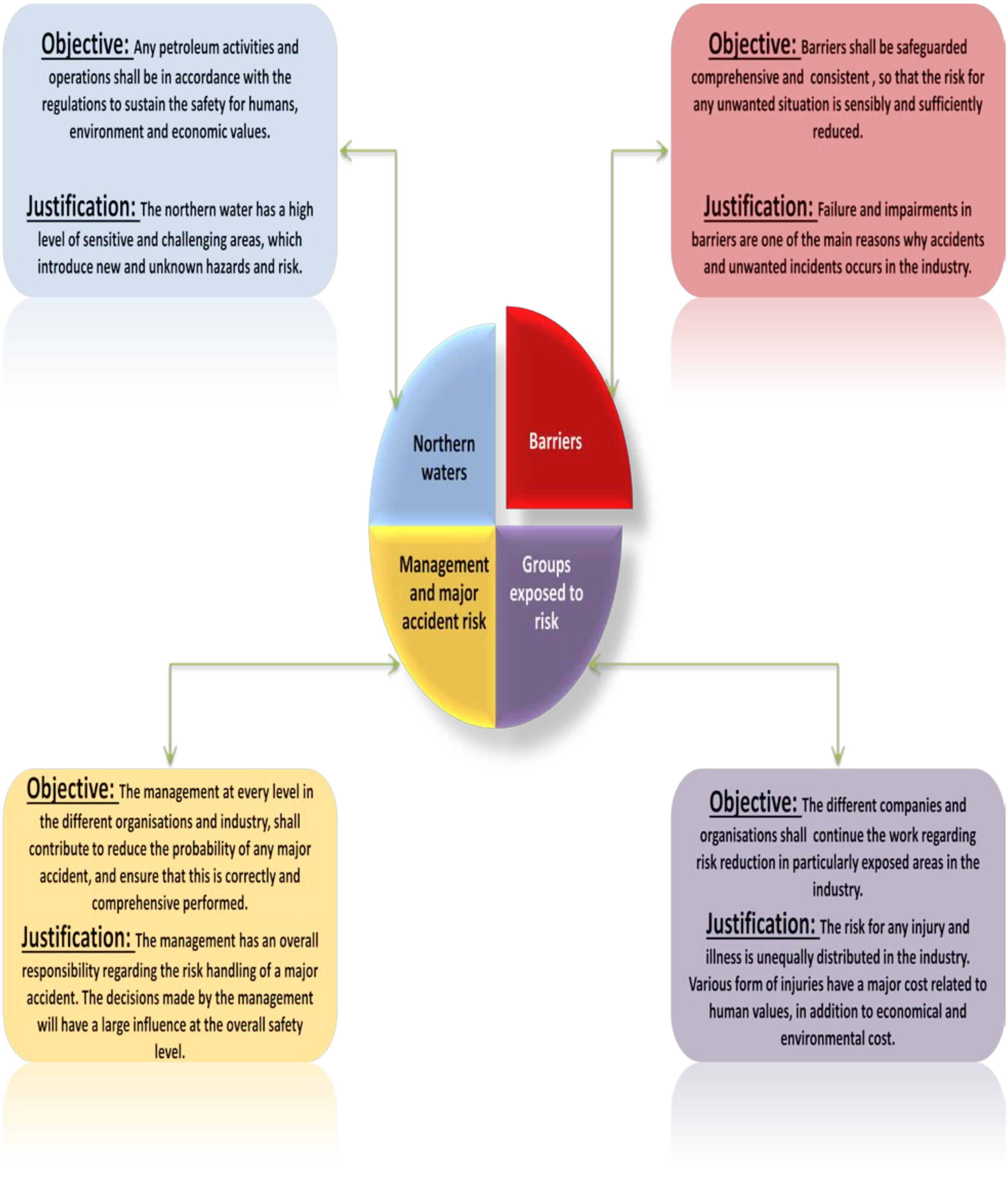
- At this stage in the process of writing, I started to comprehend that some chapters probably will "naturally" merge together, and that some information/theory is not necessary. The structure will probably be modified (to some minor level) in the final report. This is often a natural part of writing a larger report, especially during the last phase. As long as the quality of the work is sufficient (improved) and the time frame is not exceeded, the status and progress is satisfying and OK.

Appendix IV

Appendix IV1: Enlarged picture of the Maintenance Management Figure 3.



Appendix IV2: PSAN's four main determined objectives and priorities Figure 38.



Appendix IV3: PSAN`s main disciplines divided into six areas of expertise Figure 37.