NTNU – Trondheim
Norwegian University of
Science and Technology

Development of Operational and Organizational Barrier Indicators for a Man Overboard Scenario

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Mechanical Engineering
Submission date: June 2015
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Norwegian University of Science and Technology
Department of Production and Quality Engineering

RAMS
Reliability, Availability,
Maintainability, and Safety

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MASTER THESIS

Department of Production and Quality Engineering

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Supervisor 1: Professor Jørn Vatn (NTNU)

Supervisor 2: Lars Bodsberg (SINTEF - Technology and Society)

Problem description

“Development of Operational and Organizational Barrier Indicators for a Man Overboard Scenario”

Master thesis, spring 2015 for stud. techn. Marius Thøgersen

In the offshore oil and gas industry, where safety is number one priority, the importance of barriers cannot be underestimated. The focus of barrier monitoring has traditionally been technical barriers, but recent years have demonstrated the need to monitor operational and organizational barriers as well. However, monitoring operational and organizational barriers have proven difficult, and several challenges remains unsolved. This thesis should identify and contribute to solving some of these.

In the Project thesis, the candidate gained knowledge of risk and barrier management/analysis. The candidate should use this knowledge and investigate operational and organizational barriers in detail. A case study of a chosen accident scenario should be conducted. Scenarios where personnel are especially important in realizing barrier functions are of interest.

The candidate should:

1. Perform a literature survey to identify existing literature on barrier terminology, barrier status monitoring and operational and organizational barriers.

2. Investigate classification of barrier elements.

3. Select a scenario to investigate and use as a case study. Present the basics of the chosen scenario. Identify barrier functions and elements, assign performance influencing factors and develop indicators. Focus on development of indicators for operational and organizational barrier elements.

4. Use the case study findings to present possibilities for further work.

5. Conclude the project with a detailed report (deadline: June 10, 2015).

Because of time restrictions, it will probably not be possible to do a practical implementation of any models or findings. The focus should rather be to prepare for such an implementation.

Comment (2015-06-09): This year the problem description was written, and updated throughout the project, by the candidate. The initial problem description and title given in the “Master thesis contract” was changed and specified throughout the project. The changes involved taking a more detailed look at identifying and monitoring operational and organizational barriers instead of attempting to incorporate these barriers in a risk model. The final problem description and title is the one shown above.

An early agreement were made with the supervisors, allowing changes to the problem description throughout the project.

Marius Thøgersen

Preface

This report is a master thesis in RAMS, carried out during the spring semester of 2015 as part of the "Mechanical engineering" study program at NTNU. The thesis is carried out for SINTEF Technology and Society with cooperation from Total E&P Norway.

The initial project idea was conceived in discussions with the external supervisor from SINTEF. SINTEF performs active research on operational and organizational barriers and the intention was for this master thesis to contribute to this research. It was decided that a case study could be valuable and contact with Total E&P Norway was established. They suggested that investigating barriers in a man overboard scenario would make a reasonable case study.

Cooperation with Total have been effective and rewarding. Through a series of e-mails, phone calls and meetings they have contributed with expert opinions and provided most of the information used in the case study. Through the external supervisor, SINTEF provided valuable guidance, literature and the possibility to discuss investigation specifics on a week to week basis.

This master thesis presents models, methods, considerations and specific suggestions for monitoring operational and organizational barrier elements. This was obtained through theoretical investigations, a comprehensive case study and several literature reviews.

The intended reader of this Master's thesis is a fellow student with a background in RAMS, but without a detailed knowledge of barriers, operational and organizational barrier elements and man overboard accidents. Most importantly, the intended reader has a passion for safety research.

"There's no harm in hoping for the best as long as you're prepared for the worst."

- Stephen King

Trondheim, 2015-06-10

Marius Thøgersen

Acknowledgment

I would like to thank my external supervisor Lars Bodsberg (Senior Research Scientist at SINTEF Technology and Society - Department of Safety) for exceptional guidance and patience throughout my ordeal of writing this master thesis. Next, I would like to express my gratitude for both the financial support and other contributions TOTAL E&P Norway have provided this spring. Their Asset Integrity Manager, Risk & HSE Engineer and Operations Methods Manager have shown great interest for the work I have performed and provided me with important information and input through a series of meetings, workshops, emails and phone calls. Without their support, the investigations conducted would've not been possible. I would also like to thank my NTNU supervisor Professor Jørn Vatn (Department of Production and Quality Engineering) for valuable input.

Lastly, I want to express my appreciation for all the support my family and closest friends have provided during the last six months; you provide a safe harbor when the seas are raging.

M.T.

Summary and conclusions

For years, minimizing accident risk by managing operational and organizational barriers have been a top priority for the Petroleum Safety Authority Norway. This holds true for 2015 as well, and this report is aligned accordingly.

Three recent reports have been reviewed to investigate the chaos of terms surrounding barriers. Each report suggests a classification for barrier elements with corresponding definitions. Based on a pros and cons study, the most suitable classification was selected to use in the case study. It was decided to use three classes of barrier elements; organizational (personnel with defined roles and functions), operational (the description of actions or activities carried out by the personnel) and technical (equipment and systems). Relevant parts of the case study was used as examples to provide context to the selection process.

Literature reviews of recent projects and articles were conducted to determine the most commonly used performance influencing factors and indicator evaluation criteria. The results were applied in the case study.

A theoretical foundation for a man overboard (MOB) case study was created by investigating the basics of MOB accidents. The case study was limited to man overboard accidents during planned work over open sea. Preconditions and required safety measures for work over open sea was investigated, and an examination of how required MOB preparedness is kept was conducted.

The case study was carried out to investigate barrier functions, and especially operational and organizational barrier elements. Models and illustrations were created to effectively communicate intermediate analysis results step by step. Both the phases leading up to a MOB accident, and the phases succeeding a MOB accident were investigated. Most time and effort were used to investigate the latter. Knowledge gained from the earlier literature reviews were applied. It was chosen to focus solely on the consequence reducing *rescue and recover* barrier function. The MOB-crew was determined to be the most important organizational barrier element for this function, and their “fluctuating” competence was determined to be the main performance influencing factor. The main result was the development of a set of three indicators to monitor the MOB-crew’s competence (developed through a series of workshops with a collaborating oil and gas company):

1. Fraction of MOB-personnel with valid certification.

2. Fraction of successful exercises.

3. Fraction of successful exercises conducted close to maximum allowed weather conditions.

Because of the rather narrow focus, the findings might not be as valid for the overall MOB scenario, as they are for the specific *rescue and recover* barrier function.

All in all this report contributes by defining a set of indicators to monitor organizational barrier elements. The report also makes considerable contributions towards formalizing barrier functions, barrier elements and performance influencing factors in a MOB scenario. Due to time restrictions, a set of indicators for operational barrier elements was not developed.

Oppsummering og konklusjoner (Norwegian)

I flere år har reduksjon av ulykkesrisiko gjennom styring av operasjonelle og organisatoriske barrierer vært blant Petroleumtilsynets topp prioriteringer. Dette stemmer også for 2015 og denne rapporten er innrettet deretter.

Gjennom en litteraturstudie av tre nylige rapporter har begrepskaoset rundt barrier blitt undersøkt. Hver rapport foreslår en klassifisering av barriereelementer med tilhørende definisjoner. Basert på en sammenligning av fordeler og ulemper, ble den mest relevante klassifiseringen valgt ut og senere brukt i case studiet. Det ble besluttet å bruke tre klasser for barriereelementer; organisatoriske (personell med definerte roller og funksjoner), operasjonelle (beskrivelsen av handlinger og aktiviteter utført av personell) og tekniske (utstyr og systemer). Deler av casestudiet er benyttet som eksempler for å etablere kontekst for de teoretiske vurderingene.

En litteraturstudie av tidligere prosjekter og artikler ble utført for å undersøke de mest brukte ytelsespåvirkende faktorene og de mest brukte evalueringskriteriene for indikatorer. Resultatene ble benyttet i case studiet.

Grunnlegende teori om mann over bord (MOB) ulykker har blitt undersøkt for å danne et grunnlag til case studiet. Case studiet ble begrenset til å omfatte kun mann over bord ulykker ved planlagt arbeid over åpen sjø. Forutsetninger og sikkerhetstiltak for arbeid over åpen sjø ble også lagt frem.

Et case studie ble utført for å undersøke barrierefunksjoner og spesielt operasjonelle og organisatoriske barriereelementer. Modeller og illustrasjoner ble utviklet for å sikre effektiv kommunisering av analysens resultater, steg for steg. Både fasene før og etter en MOB ulykke ble undersøkt. Mest tid og innsats ble brukt på å undersøke fasene etter en MOB ulykke. Kunnskap fra utførte litteraturstudier og evalueringer ble benyttet. Det ble besluttet å kun fokusere på den konsekvensreduserende barrierefunksjonen *rescue and recover*. MOB-mannskapet ble evaluert til å være det viktigste organisatoriske barriereelementet for denne funksjonen, og deres "svingende" kompetanse ble ansett som den viktigste ytelsespåvirkende faktoren. Hovedresultatet er utviklingen og evalueringen av et sett med tre indikatorer som kan benyttes til å overvåke MOB-mannskapets kompetanse. Indikatorene ble utviklet i en workshop i samarbeid med et bidragsytende oljeselskap:

1. Fraksjon av MOB-mannskap med gyldig sertifisering.

2. Fraksjon av vellykkede treningsøvelser.

3. Fraksjon av vellykkede treningsøvelser utført tett opp mot maksimalt tillatte værforhold.

På grunn av et nokså snevert fokus, så er ikke funnene i oppgaven nødvendigvis like relevante for MOB scenariet sett over ett som de er for den spesifikke barrierefunksjonen *rescue and recover*.

Sett over ett så bidrar denne rapporten med å foreslå indikatorer for overvåkning av organisatoriske barrierelementer. Rapporten bidrar også til å formalisere barrierefunksjoner, barriereelementer og ytelsespåvirkende faktorer i et mann over bord scenario. På grunn av tidsbegrensninger ble det ikke utviklet indikatorer for overvåkning av operasjonelle barriereelementer.

Contents

Chapter 1

Introduction

This chapter will set the background and frame for the master thesis.

1.1 Background

In an industry where safety is the number one priority, the importance of barriers and barrier management cannot be underestimated. Barriers are planned measures to regain control, to mitigate development of defined situations of hazard and accident, or to mitigate consequences (Øien et al., 2015). How each barrier is managed during operation is thus a very important part of keeping accident risk at an acceptable level. However, before barriers can be managed, they need to be developed and defined. This is where the chaos of terms surrounding the barrier terminology comes into full effect. Sklet (2006) puts it like this: *"in spite of the fact that the concept of safety barriers is applied in practice, discussed in the literature, and even required in legislation and standards, no common terminology that is applicable across sectors have been developed of the concept of safety barriers"*. Although recent efforts to bridge the terminology gap have shown progress, an ideal set of barrier definitions remains elusive. Chapter 2 is dedicated to exploring this problem area as well as selecting a suitable set of definitions to use in the execution of a specific case study. In accordance with the PSA (2015b) main priorities for 2015, the main focus of chapter 2 is classification of barrier elements as either operational, organizational or technical.

Monitoring barrier elements from each class is crucial to make sure that activities on an installation are not conducted if required safety barriers cannot perform their function upon demand. Using performance indicators is one approach that makes this possible. Approaches for using indicators to monitor technical barrier elements are well established within the offshore industry, but applying the same methods for operational and organizational barrier elements have proved difficult. This is especially due to not having automatically retrievable information from systems like the maintenance management system. Available information for operational and organizational barrier indicators relies heavily on manual input from for example yearly audits, making monitoring of their performance on a daily basis difficult.

To properly investigate challenges related to identifying, classifying and measuring the status of operational and organizational barrier elements, a case study was developed. As chapters 4 and 5 shows, it was decided to use a man overboard (MOB) scenario as a case study. When the offshore industry continuously prioritizes reduction of major accident risk, it might seem strange to investigate an accident scenario that falls outside the major accident boundary[1]. However, in certain emergency preparedness situations barrier functions are performed almost exclusively by operational and organizational barrier elements. MOB is such a scenario, making it a reasonable choice after all (NSA, 2014). The case study was conducted in collaboration with Total E&P Norway.

Another argument speaking for the value of conducting a MOB scenario case study, is that little or no literature exist on the identification of barrier functions and barrier elements in a MOB scenario on offshore installations. Hence, the case study can contribute to more than just the main case study objective of identifying barrier indicators to monitor operational and organizational barrier elements.

Since literature reviews are applied on several occasions throughout this thesis, only a short overview of the most important literature will be given here. In the investigation into the "status quo" of barrier functions and elements research, three comprehensive reports from important actors in the offshore industry were reviewed; PSA (2013), NSA (2014) and Øien et al. (2015). These reports were especially examined for suggested definitions for technical, operational and organizational barrier elements. To get a better grasp of how MOB accidents could occur, and which elements are involved in the ensuing emergency response, two accident investigation reports were reviewed; PSA (2007) and PSA (2015a). To identify the most commonly used performance influencing factors, a literature review of five projects from the last 15 years was performed; **SPAR-H:** Gertman et al. (2005), **BORA:** Sklet et al. (2005), **OTS:** Vinnem et al. (2007), **Risk OMT:** Gran et al. (2012) and Vinnem et al. (2012) and **ORIM:** Øien (2001b). Evaluating the case study findings was an important part of the investigation. To identify the most commonly used indicator evaluation criteria, a literature review of five research articles (from the last six decades) was carried out; Rockwell (1959), Kjellen (2000), Hale (2009), Vinnem (2010) and Haugen et al. (2012). Although not a part of any formal literature review, the PSA management and facilities regulations (PSA, 2014a and PSA, 2014) as well as the NOG guidelines (NOG, 2005, NOG, 2012, NOG, 2013a and NOG, 2013b) are used throughout the thesis.

The literature used are mostly written by well known and respected authors within the field of safety

[1] The PSA (2014) defines a major accident as *an acute incident, such as a major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets.* The most severe consequences of a MOB accident is usually limited to one fatality. More on this in chapter 6

research. With few exceptions, the literature is of Scandinavian origin with focus on the offshore oil and gas industry. The quality of the literature is considered more than sufficient. However, the ideal case would have been to identify more literature from other parts of the world and other industry disciplines.

As mentioned, there are several gaps in the literature pertaining to operational and organizational barrier elements. In addition there are gaps identified in the chosen MOB case study. This thesis will attempt to bridge some of these gaps and contribute to an important, but difficult and confusing area of research. Examples of gaps identified, but considered outside the boundaries of the thesis, are for instance human error probabilities in performing barrier functions, measuring psychological factors when personnel realize barrier functions etc.

1.2 Objectives

The main objective of this master thesis is to investigate operational and organizational barriers through the development of operational and organizational barrier indicators for a man overboard scenario. More specifically, the following sub-objectives apply:

1. Investigate operational and organizational barriers through a literature study of possible classifications and definitions of barrier elements.

2. Investigate man overboard accidents during planned work over open sea, and present the importance of operational and organizational barrier elements in this scenario.

3. Conduct a case study in cooperation with TOTAL E&P Norway to investigate barriers in a man overboard scenario.

4. Present a discussion of possibilities for further work based on the findings throughout the thesis.

Case study

1. Identify and highlight barrier functions and barrier elements in place both before and after a MOB accident.

2. Identify the most important performance influencing factors in the chosen MOB scenario.

3. Identify possible barrier performance indicators for the most important operational and organizational barrier elements in the chosen MOB scenario.

4. Identify and select a set of indicator evaluation criteria to assess which of the possible barrier performance indicators are most suitable in the chosen scenario.

5. Develop, evaluate and present a set of the most important barrier performance indicators for monitoring operational and organizational barrier elements in the chosen scenario.

1.3 Limitations

The most prominent limitation of this thesis is time. The master thesis is limited to a time frame of 20 weeks, with work taking place from January 14 to June 10 in 2015 (one week compensation is given for the easter holiday). This limits both the amount of possible research as well as verification of any findings. The weekly workload is estimated to be 40 hours. This is in accordance with the normative weekly workload for a class worth 30 points at NTNU.

Another profound limitation is the author's limited practical experience in the field of barrier management and analysis. As a result some challenges, limitations or considerations in the following investigations could be unintentionally overlooked or treated poorly. However, available literature, expert opinions and regular supervision will be used in an attempt to counteract this limitation.

1.4 Approach

The approach used to reach the stated objectives rely heavily on thorough literature reviews and discussions with industry experts. All relevant literature have either been provided by TOTAL E&P Norway and SINTEF, or obtained through literature searches in databases such as Compendex and ScienceDirect. A theoretical approach, actively applying database searches and relevant library resources, was necessary to reach the first two objectives. Reaching all objectives in the case study required both a detailed theoretical approach (a series of literature reviews) and a more practical approach (workshops and discussions).

The following meetings and workshops were conducted with personnel from TOTAL:

1. **2015-02-11** Developing MOB scenario for a case study.

2. **2015-04-15** Workshop: revising barrier models and PIFs.

3. **2015-05-13** Workshop: revising barrier models, evaluating indicators.

1.5 Report structure

The remaining chapters in this thesis are divided into the following three parts:

- Theoretical study.
- Case study.
- Discussions, conclusions and suggestions for further work.

Chapters 2, 3 and 4 makes up the theoretical studies, investigating classifications and definitions of operational and organizational barrier elements, identifying performance influencing factors and indicator evaluation criteria, and laying a theoretical foundation for the case study. Chapter 5 is probably the most important chapter where all steps in the case study are explained in detail and the intermediate findings are presented and discussed. Chapter 6 provides broad and general discussions of the thesis findings, an overall conclusion and some suggestions for further work.

Remark: The argumentation and discussions provided in chapter 2 does not necessarily reflect the opinions of any individuals or companies having contributed to this report. Only the authors subjective interpretation of available literature is presented.

Chapter 2

Fundamentals - Barrier elements

Each year the PSA presents a set of high priority issues to encourage advancements from the academic community and the industry. In 2015, one of these priority issues is barrier management, or more specifically: *"maintaining operational, organizational and technical barriers in an integrated and consistent manner to minimize risk"* (PSA, 2015b). Focus is thus on solving a rather complex issue involving several smaller challenges. Some of these challenges will be investigated in this thesis. In accordance with the PSA priority stated above, this chapter will be limited to handle the challenges of classifying and defining barrier elements. Finding a commonly acceptable barrier terminology in the midst of the chaos of possible definitions, is no easy task. However, three recent reports (PSA, 2013, NSA, 2014 and Øien et al., 2015) have made attempts to do just that. Each report presents somewhat different perspectives and the intention is for the following sections to compare these and select the most suitable terminology for this thesis.

2.1 Definitions

The following list represents some general definitions important to barrier management and analysis presented by the PSA (2013) (definitions from other sources are in some cases used throughout the thesis):

Barrier: *Technical, operational and organizational elements which are intended individually or collectively to reduce possibility for a specific error, hazard or accident to occur, or limit its harm/ disadvantages.*

Barrier management: *Coordinated activities to establish and maintain barriers so that they maintain their function at all times.*

Barrier function: *The task or role of a barrier.*

Barrier element: *Technical, operational or organizational measures or solutions which plays a part in realizing a barrier function.*

Performance influencing factor: *Conditions which are significant for the ability of barrier functions and elements to perform as intended.*

The first reviewed report is the *Principles for barrier management in the petroleum industry* (hereby: "Principles") report by the PSA (2013). This is a product of the PSA's main barrier priorities based on findings in surveys of the risk level in Norwegian petroleum activities. One of the main findings inspiring this report was the lack of a common understanding of, and as such the compliance with, regulatory requirements for barrier management (PSA, 2013). In this manner, the "Principles" report is an attempt at making regulatory requirements for barrier management more easily accessible. Although not a formal part of the petroleum regulations, the "Principles" report does play a part in connecting barrier management regulations and their respective guidelines.

The main finding of interest is the suggested classification of barrier elements. The PSA (2013) argues the use of three classes (operational, organizational and technical) in an attempt at capturing all relevant barrier elements involved in realizing established barrier functions. The following definitions are suggested (PSA, 2013):

Technical barrier element

Equipment and systems which constitute a part of realizing a barrier function.

Operational barrier element

Actions and activities the personnel have to perform which constitute a part of realizing a barrier function.

Organizational barrier element

Personnel with defined roles or function which constitute a part of realizing a barrier function.

Traditionally barrier analyses have focused on technical elements like the ESD- and PSD systems, but the last decade have turned more attention towards the "softer"[1] elements involved in realizing barrier functions. The PSA is probably the main party advocating for this change in focus; to separately highlight operational and organizational barrier elements on the same level as technical elements.

Looking at the definitions above, we observe that all barrier elements must "constitute a part of realizing a barrier function". This entails that to be considered as a barrier element, either equipment, personnel or specific actions taken must be actively involved in realizing a safety function. Take for example the MOB-boat in the case study presented in chapter 5. The MOB-boat is an important technical barrier element as it is actively used to realize the *rescue and recover* barrier function. The MOB-crew

[1]Operational and organizational barrier elements are often referred to as *"soft"* barriers/barrier elements.

(using the MOB-boat) is an example of an organizational barrier element, and the specific actions they take, like picking up a person from the water (using the MOB-boat), are considered as operational barrier elements. For example maintenance is thus not a barrier element as it doesn't actively participate in the realization of a barrier function upon demand. Instead the PSA (2013) puts it like this; *"The quality of maintenance - including its planning and its ability to sustain the performance of the various barriers - will be a key condition affecting performance"*. In other words maintenance is to be considered as a factor influencing performance.

Being the regulatory authority for all petroleum activity on the Norwegian continental shelf, the PSA holds a rather strong position. This implies that their opinion, on matters such as terminology, carry considerable weight. Nevertheless, the NSA (2014) offers some criticism to the PSA three class split in their own report: *Barrier management in operation for the rig industry; Good practices* (hereby: "Good Practices"). The NSA (2014) argues that the use of three classes might be too detailed and rather than putting things in perspective, it could add to the already significant confusion surrounding barriers. Due to the considerable interrelationship and overlap between operational and organizational barrier elements in the PSA (2013) classification, the NSA (2014) suggests unifying these categories into one "human" element class; denoted *operational barrier elements*. In that case the operational barrier elements are considered the actions performed to realize a barrier function (the personnel performing the actions are seemingly implicitly covered). On one side this might be beneficial, as distinguishing between personnel and actions might be an unnecessary detail in the given situation. On the other hand, distinguishing between the personnel and the actions they perform secures a greater awareness of the smaller elements involved in realizing a barrier function. This awareness could be an important part of complying with § 5 in the PSA management regulations (PSA, 2014a):

> [*"...Personnel shall be aware of what barriers have been established and which function they are intended to fulfill, as well as what performance requirements have been defined in respect of the technical, operational or organisational elements necessary for the individual barrier to be effective. Personnel shall be aware of which barriers are not functioning or have been impaired. The responsible party shall implement the necessary measures to remedy or compensate for missing or impaired barriers"*].

In the third report (*Towards a holistic approach for barrier management in the petroleum industry*), Øien et al. (2015) suggests a minor adjustment to the operational barrier element definition in the three class split presented by the PSA (2013). Breaking down a barrier function with three classes of barrier elements (as suggested by the PSA (2013)) entails a breakdown until a level is reached where the function can be "materialized" as a solution to the question *how* (and is no longer a function). An action (defined by the PSA (2013) as an operational barrier element) is not a materialization of a sub-function, and it's possible to break it down further into smaller actions where the lowest level is a *description* of how to perform the action. Therefore, Øien et al. (2015) proposes the following modified definition for operational barrier elements: *"The **description** of the actions or activities that must be carried out by the personnel in order to realize a barrier function"*. According to Øien et al. (2015), the description of an action (the procedure), is considered an operational barrier element, the described action itself is a barrier sub-function and the person performing the described action is an organizational barrier element. A possible reasoning behind such an interpretation of the barrier element classification is discussed in the following section.

Making the "right" choice

As initially stated, finding a suitable classification for barrier elements is no easy task. The three options presented above all have their respective pros and cons (summarized in table 2.1), and the best option at any given time seems to be dependent upon the situation. Given that the situation is the chosen scenario in the case study, a decision was made to apply the third option presented by Øien et al. (2015).

Table 2.1: Summary of pros and cons for each barrier element classification option.

PSA (2013) Three classes	**NSA (2014) Two classes**	**Øien et al. (2015) Three classes (with a twist)**
Pros: - Highlights sharp end personnel and actions separately. - Good degree of detail.	**Pros:** - "Simple and easy to use". - Avoids some confusion.	**Pros:** - Highlights sharp end personnel and actions separately. - Great degree of detail. - Highlights important procedures.
Cons: - Little difference between barrier functions and operational barrier elements.	**Cons:** - A little too simplified.	**Cons:** - Recently developed option (little tested) - Time-consuming method.

Reasoning behind choice: Firstly, the two class approach suggested by the NSA (2014) was excluded, because even though it might be simple and easy to use, it lacks the necessary degree of detail needed in the case study. Choosing between the two remaining approaches came down to a case of simple logic. A barrier function could in many cases be considered as an action, or put simply; a *verb*. Barrier elements could then be considered as *nouns*; either physical personnel, equipment or as suggested by Øien et al. (2015); documents with descriptions of how to perform actions. With the *verb/noun* distinction as a basis, it is observed that actions (or operational barrier elements according to the PSA (2013)) could now be considered as barrier sub-functions. This makes the PSA (2013) definition somewhat peculiar and made the classification suggested by Øien et al. (2015) the "best" choice. Choosing a classification which works to identify specific operational procedures is also valuable because these procedures often play an important part in preparing for operations (such as in emergency preparedness analyses).

It is important to clarify that when including procedures as operational barrier elements, it cannot become a source of false safety (which is often the case). This means that actually having a procedure for e.g. work over open sea makes up only one small part of the operational barrier element. What the procedure actually contains in the form of work task descriptions, required safety measures, its format and accessibility is probably of higher importance. However, care must be taken because a small change in the context of an activity can render a procedure invalid. Having this procedure as a barrier element can thus promote a false sense of safety. The resilience of a procedure then becomes even more important. For example having well developed procedures makes little difference if they don't apply in the given situation. The procedure could describe how to operate a manual lever system while the system in place is actually operated with a touchscreen. Regular activities to make sure that procedures (describing actions vital to realize barrier functions) are "relevant" is thus important. Whether or not such activities should be considered as barrier functions is not considered any further in this thesis.

An example taken from the MOB case study can be seen in figure 2.1 and 2.2. As discussed above, it is observed that operational barrier elements according to the PSA (2013) classification becomes barrier sub-functions according to the Øien et al. (2015) classification. The provided example might not be the best, but it serves to show the principle differences between the two approaches.

Plenty of opinions regarding barrier element classification exist, and only three have been considered in this chapter. The fact that there are so many disagreements in this field off research only serve to prove the importance of researching it further. The most important thing is not the label given each element, but actually having protective/reactive barriers in place with a system to monitor and manage their performance (PSA, 2013). As mentioned, the conclusions drawn in this chapter reflects the author's understanding of available literature, and not necessarily the opinions of all the individuals and companies that contributed in the development of this thesis.

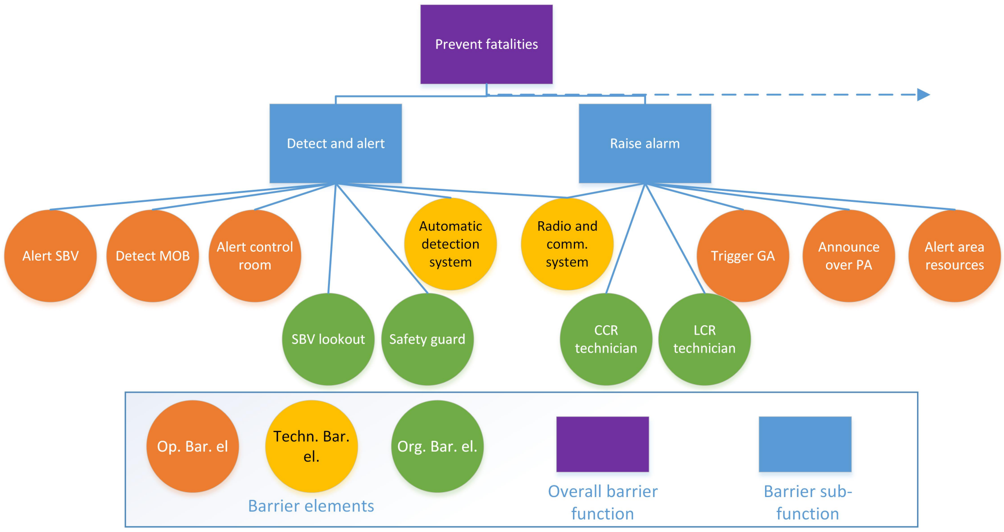

Figure 2.1: Barrier functions and barrier elements in accordance with the PSA (2013).

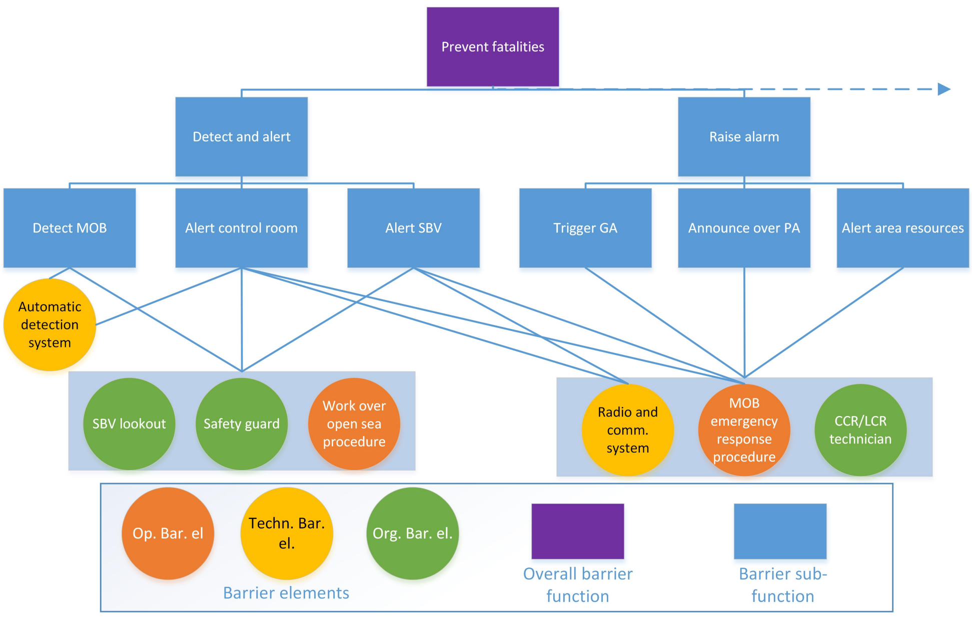

Figure 2.2: Barrier functions and barrier elements in accordance with Øien et al. (2015).

Chapter 3

Performance influencing factors and indicators

This chapter will outline two literature reviews conducted in preparation of the case study. One is on the identification of the "most common" performance influencing factors, and the other is on the identification of the "most common" indicator evaluation criteria. However, the first section will provide a short explanation of how the factor and indicator terms are used in this thesis.

3.1 Factor vs. indicator

There are two principal ways of looking at the relationship between a performance influencing factor and an indicator. One is to say that the status of a set of indicators determines the condition of a factor, which again influences the performance of a barrier (the common understanding of the relationship). The other is to say that indicators are considered as resultant observations from the underlying factor (the risk modeling understanding). As explained in the project thesis, they both have their relevant uses in different situations (Thøgersen, 2014).

In this thesis the common understanding is mostly used; the status of the indicator determines the condition of the PIF which again influences the performance of a barrier. As already established in chapter 2, a possible definition for performance influencing factors is; *conditions which are significant for the ability of barrier functions and elements to perform as intended* (PSA, 2013). A possible definition for indicators is *"a measureable/operational variable that can be used to describe the condition of a broader phenomenon or aspect of reality"* (Øien, 2001a). Although a thorough discussion on the implications of choosing to apply one definition over the other could be of value, it is not a part of this thesis. This discussion had to down-prioritized due to time restrictions.

The next section presents a literature review conducted to determine the most commonly used performance influencing factors.

3.2 Performance influencing factors

When faced with the challenge of choosing which performance influencing factors to include in case study, the obvious solution is to consult available literature. Since there are potentially hundreds of factors influencing the way a barrier element performs its part of realizing a barrier function, some limiting decisions had to be made. A set of influencing factors to include in the analysis was identified trough a literature review of five relevant projects, and through expert opinions input from the second workshop.

Of the reviewed projects, one is from the nuclear industry (SPAR-H: Gertman et al., 2005) and the remaining four are from the offshore oil and gas industry (BORA: Sklet et al., 2005, OTS: Vinnem et al., 2007, Risk OMT: Gran et al., 2012 and Vinnem et al., 2012 and ORIM: Øien, 2001b). The common denominator for the reviewed projects is the presentation of a set of influencing factors they consider as most important in analysis of risk, human performance and barrier performance. See table 3.1 for a comparison of the suggested indicator sets.

Table 3.1 shows which PIFs that are identified as "most common", what they are called in the case study and where the "most common" PIFs were determined to be the focus before and after MOB. For a PIF to be considered as "most common" it was decided that the factor must be found among the most important PIFs in at least three of the five reviewed projects (except from the *weather conditions* PIF). The decision of whether the PIFs are important before or after MOB was based on expert opinions from TOTAL representatives.

The result: *competence*, *condition of governing documents*, *time-pressure* and *workload* should be the focus before a MOB accident, and *competence*, *condition of governing documents*, *communication*, *HMI* and *weather conditions* should be the focus after a MOB accident.

Table 3.1: Performance influencing factors from literature review

Influencing factors	**OTS**	**Risk_OMT**	**BORA**	**ORIM**	**SPAR-H**	**Most common**	**This project: terminology**	**For barriers before MOB**	**For barriers after MOB**
Competence	X	X	X	X	X	X	Competence	X	X
Governing documents	X	X	X	X	X	X			
Technical documents	X	X	X	X	X	X	Condition of governing documents	X	X
Disposable work descriptions		X	X						
Communication	X	X	X			X	Communication		X
Supervision	X	X	X			X		-[a]	
Time-pressure	X	X	X		X	X	Time pressure	X	
Workload	X	X	X			X	Workload	X	
Work motivation		X							
HMI (human-machine interface)		X	X		X	X	HMI		X
Design		X		X					
Management (high level)	X	X							
Management of change	X		X						
Work practice	X		X						
Fatigue			X		X				
Stress					X				
Task complexity			X		X				
Work process					X				
Planning				X					
PM-program/inspection				X					
Work environment	X		X				*Weather conditions*[b]		X

[a]Excluded because supervision is determined as an action performed by the safety guard and the SBV lookout.
[b]Included based on a hypothesis that the weather has significant influence on the performance of organizational barrier elements.

3.3 Indicator evaluation criteria

To properly evaluate suggested indicators, a set of criteria is needed. Indicator evaluation have been researched in literature for quite some time, and to obtain knowledge about early and recent findings another literature review was necessary. Table 3.2 shows the comparison of five reviewed articles from the last five decades. The following criteria were identified as “most commonly used”: *measurability, validity, sensitivity, cost effectiveness, robustness against manipulation* and *show trends*. All evaluation criteria considered as “most common” were mentioned in at least three of the five articles (except from the *show trends* criteria). The evaluation of which of the indicators were most relevant for this case study, was conducted as part of the case study in third workshop described in section 5.6.2.

Possible definitions of each “most commonly used” evaluation criteria: (based on articles listed in table 3.2).

Validity: The indicator must be a valid measurement of the factor it is an indicator for (it measures what you intend to measure).

Measurability: It must be possible to express the status of the indicator through the gathering of information.

Comprehensibility: It must be easy to comprehend the link between the indicator and the factor. It must be intuitive and transparent.

Cost effectiveness: Measuring and collecting needed information for the indicator should not be more costly than the value you get from measuring it (safety gained vs. money spent).

Sensitivity: The indicator must be sensitive to change.

Robustness against manipulation: It should not be possible to easily affect the indicator to make the status look better than it really is (cheating).

Show trends: In order to monitor progress of the indicator, it should be easy and useful to display trending over time.

The above list presents the outcome of the literature review, which serves as an important input into the indicator evaluation process described in section 5.6.

Table 3.2: Safety performance indicator selection criteria

Indicator evaluation criteria	Rockwell (1959)	Kjellen (2000)	Hale (2009)	Vinnem (2010)	Haugen et al. (2012)	**Most common**	**This project: terminology**
Measurable	X	X			X	X	Measurability
Permit statistical inferential procedures	X						
Validity	X	X	X	X	X	X	Validity
Minimum variability when measuring the same conditions	X		X		X		
Sensitivity to change	X	X	X	X		X	Sensitivity
Cost effectiveness	X		X		X	X	Cost effectiveness
Comprehensive	X	X	X	X	X	X	Comprehensibility
Observable		X		X			
Robust against manipulation		X	X	X		X	Robust against manipulation
Combination of leading and lagging indicators				X			
Not require complex calculations				X			
Not influenced by campaigns that give conflicting signals				X			
Reflect hazard mechanisms				X			
Show trends				X		X	Show trends[a]
Useful					X		
Broadly applicable across company operations			X				

[a]The *show trends* criteria was included based on a hypothesis that most indicators in the MOB scenario will have problems showing usable trends due to lack of valid data points.

Chapter 4

Man overboard

For as long as man have ventured the seven seas, sailors have had the tendency to once in a while fall overboard. In today's industry not only sailors are exposed to the risk of falling overboard, but offshore installation workers as well. The risk of offshore installation workers falling overboard is especially high when performing planned work over open sea. In preparation for the case study, this chapter will outline the basics of work over open sea and man overboard (MOB) accidents.

Man overboard is considered by the PSA as a defined hazard and accident condition (DFU - 13)[1]. DFU 13 is used as a basis to dimension the preparedness for personnel falling overboard during work over open sea on every offshore facility on the Norwegian continental shelf (PSA, 2014b). In other words, man overboard is a critical situation where an immediate response is required to preserve life. A man overboard accident could happen for a myriad of reasons and to reduce the scope of the thesis, the focus will be limited to MOB accidents during planned work over open sea on offshore oil and gas installations.

4.1 Previous accidents

Man overboard accidents from offshore facilities are rare occurrences. According to the PSA (2014b), MOB accidents have occurred on average once per year over the last 14 years (see figure 4.1). Two recent additions to the statistics are the MOB accidents on Saipem 7000 in 2007 (PSA, 2007) and Scarabeo 8 in 2015 (PSA, 2015a). Investigations into these two accidents, carried out by the PSA, have been thoroughly reviewed as a part of the case study (see section 5.4).

According to the PSA (2014b), MOB accidents happen so infrequently that making out a clear trend is not considered possible at present time. Therefore it is difficult to say whether or not barriers protecting against MOB accidents have improved or worsened over the years.

[1]Corresponding to DFU 1 - MOB during work over open sea in the NOG (2012) guidelines.

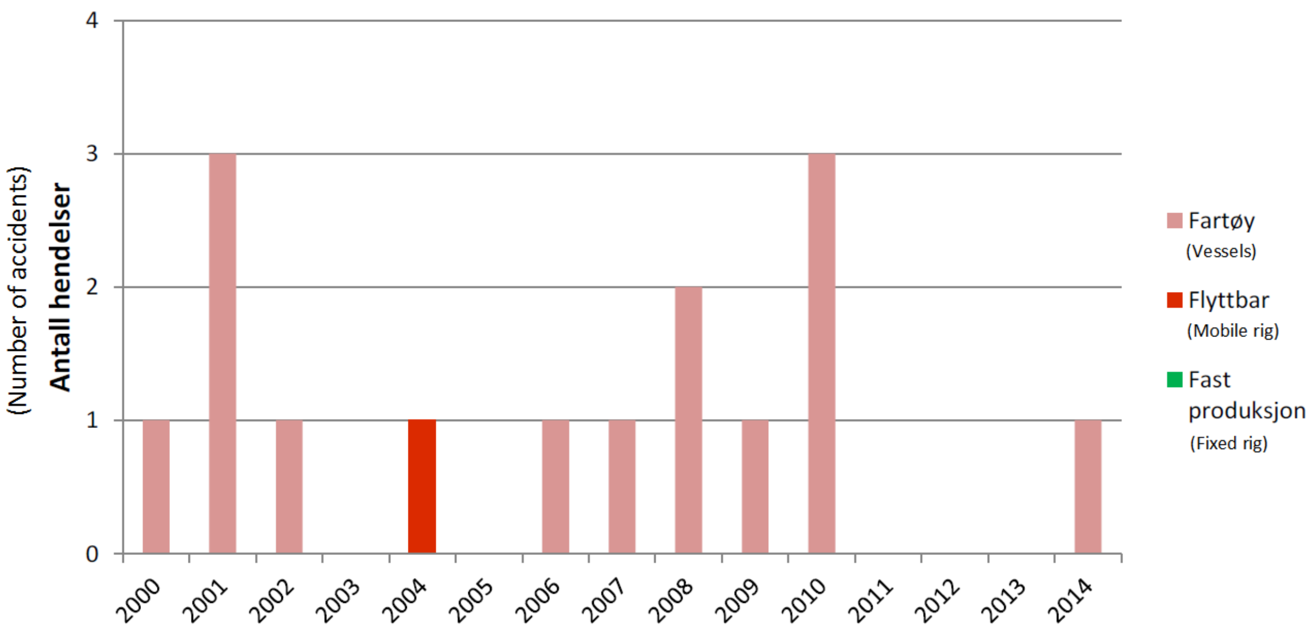

Figure 4.1: Man overboard accidents; 2000 - 2014 (PSA, 2014b).

4.2 MOB preparedness - In general and for Installation A

Although MOB accidents are rare occurrences, they do actually happen. Therefore it's important to be prepared and have implemented protective measures ensuring that MOB accidents does not lead to severe consequences. Man overboard preparedness is defined by the NOG (2005) as the *"preparedness to pick up personnel having fallen overboard during work over open sea"* on offshore installations. The emergency preparedness for MOB is dimensioned from the ability to pick up one person from the water within 8 minutes of the first detection and alert (NOG, 2005). Common practice is to assume that pick-up of a second person in the water can be done in quick succession of the first person without much added time. According to the NOG (2012) the required 8 minutes response time can in theory be increased somewhat. This is because an immersion protection suit to limit exposure to the elements is required when working over open sea. Since MOB accidents are so rare, the 8 minute response time performance requirement have to be verified through exercises. MOB preparedness is usually maintained by installation preparedness, such as the production unit (PU) and the SBV stand-by vessel (SBV), but in some cases the use of other field and area resources are necessary.

The PSA facilities regulations are governing the technical aspects of MOB preparedness (PSA, 2014). According to § 41 of the PSA facilities regulations, two independent man overboard boat systems (MOB-boat systems) are required to keep the MOB emergency preparedness sufficiently available. For the case study (installation A) this requirement is met by having both the primary and secondary MOB-boats and crew on the stand-by vessel (SBV). One MOB-boat is a fast rescue craft (FRC) while the other is a larger daughter craft (DC) with a small steering cabin serving as shelter for the crew and rescued survivors. Thus there is no designated MOB-crew or MOB-boat on the production unit itself. This significantly increases the importance of having the SBV in close stand-by when there is a heightened risk of personnel falling overboard (such as when working over open sea).

The SBV operates with 28 days long shifts and is unavailable for about 36 hours during crew change. During this time, a designated platform supply vessel (PSV) takes over all SBV duties with the same MOB preparedness. Naturally the SBV also have other responsibilities in addition to serving in close stand-by for work over open sea. Such responsibilities includes e.g. firefighting and environmental inspections around the installation. Assigning too many responsibilities to the SBV will complicate the planning of work over open sea.

4.3 Work over open sea

Work over open sea is defined as *"work conducted outside of permanent railings"* (NOG, 2013b). As discussed, working outside of permanent railings involves an increased risk of the executing worker falling overboard. This is one of the reasons why you need an approved level 1 work permit[2] (WP) to legally perform work over open sea. Work over open sea is usually described in operator specific procedures where work tasks, preparations, preconditions, barriers and other safety measures are detailed. The following list contains relevant safety measures extracted from a procedure for work over open sea (Anonymous, 200X *(outdated)*). Since the procedure is outdated, it might not reflect all of todays standards. However for the purpose of the case study, it does give a broad indication of safety measures when working over open sea:

- Wind conditions (max 30 knots wind measured at 10 m above sea level).
- Wave conditions (max 5 m wave height, 3 m significant wave height).
- Emergency response (MOB-boat must be operational and possible to launch/retrieve).

[2]WP level 1 is required for activities representing a potential high risk and for work that requires coordination and clearance at the installation level (NOG, 2013b).

- Visibility (the work must only take place under sufficient lighting and visibility to allow rescue of personnel).
- Movement (the work must not take place if roll or heave of floating vessel represents a danger to the involved personnel).
- Diving operations (if diving operations are conducted nearby, the responsible person onboard the diving vessel must decide whether work above sea can be allowed).
- Lifebuoy with light and line must be readily available at the work-site.
- Protective equipment shall be according to the specific work; life jackets and/or safety belts are compulsory.
- A safety guard shall always be present at the workplace in radio contact with the SBV and in eye contact with the executing worker.
- The safety guard shall have a backup radio.
- The SBV and the platform control room must be informed of the activity being performed (start and stop).
- During work over open sea the SBV must be in close stand-by so a dedicated lookout can observe the activity and rescue operations can be carried out (in visual range of executing worker).

Normally work over open sea involves either building scaffolding or climbing outside of permanent railings to perform maintenance work. Because of the general nature of "work over open sea" additional work permits are usually needed (for example WPs for scaffolding, hotwork etc.).

Chapter 5

Case study - MOB on installation A

This is a realistic theoretical case study developed and conducted with cooperation from Total E&P Norway. As explained initially, it was decided to use man overboard during planned work over open sea as a scenario to study operational and organizational barrier elements. Section 1.1 established that operational and organizational barrier elements play vital roles in realizing barrier functions when emergency preparedness is required. This speaks for the relevance of the case study.

5.1 Structure

To successfully conduct a case study within such a complex area of research as barrier analysis and management, a properly structured method of approach is required. A set of four main steps were developed to reach the final goal; *find a set of good indicators for operational and organizational barrier elements.* Defining a main goal is not to exclude the equally important intermediate results. An example is the formal naming of barrier functions during the third investigation step (to the author's knowledge this has not been attempted before in literature). All main investigation steps are summarized in figure 5.1.

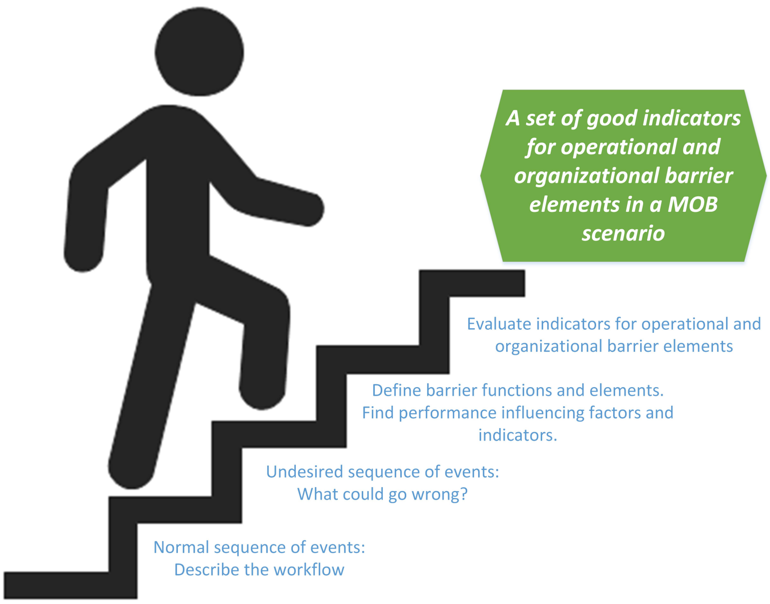

Figure 5.1: Investigation steps in the case study.

The first step is to ensure a proper understanding of the scenario by investigating and describing the normal workflow (both with and without a MOB accident). The second step is to take a look at what might go wrong during the normal sequence of events. Based on what might go wrong, the third step is to investigate which barrier functions and elements are put in place to either prevent MOB accidents or mitigate their consequences. Developing indicators for factors influencing the performance of these barrier elements is also a part of the third step. The fourth and final step is to evaluate the developed indicators for the most important barrier elements against a set of criteria.

The next section will summarize some key points and assumptions about the study object (installation A) before the remaining sections will show methods and results from each step in greater detail.

5.2 Key points and assumptions about installation A

The following list will outline some key points and assumptions important to the investigations conducted in the case study.

- Assuming that the challenge of distinguishing between control measures and barrier functions is outside the boundaries of this thesis. As established in section 5.5, most effort is used to investigate the emergency response after a MOB accident where this discussion is a minor issue. Potential control measures before MOB are designated as barrier functions.

- Assuming that it is only possible for the executing worker to fall overboard in the execution phase of work over open sea (not the preparations phase).

- Assuming that general “work over open sea” (described in operator specific procedure (Anonymous, 200X)) is the focus of this analysis, and not what is actually being performed while working over open sea.

- The focus of the analysis is not the seriousness of the injury sustained from falling overboard. A limitation in the analysis is thus that consequences like impact injuries from hitting parts of the installation of the way down are not considered.

- Two MOB-boat systems are placed on the SBV (FRC + DC) and no MOB-boat systems on the PU.

- The SBV (run by a third party) is responsible for the pickup of personnel in the water. In case of confirmed MOB, actions to take are described in a musterlist (see appendix C). The included musterlist have served as inspiration for the investigations conducted.
- Assuming that the SBV operates with a launch crew of minimum 2 persons: a davit operator (DO) and an observer.
- Assuming that the SBV operates with a MOB-crew of 3 members; 2 crew members (MOB-CM2 and MOB-CM3) and 1 commander (MOB-CM1).

Remark: The color scheme used in figures 5.3, 5.4, 5.5 and 5.6 have no relation to the color scheme used in figures 2.1, 2.2, 5.7, 5.8, 5.9 and 5.10. For the first collection of figures, the chosen color scheme have simply been used to distinguish between each task. For the second collection of figures, the chosen color scheme have a particular meaning. An example is to distinguish between different classes of barrier elements (see explanation in figure 5.7).

5.3 Normal sequence of events

This section will generally explain each task included in the stages before and after a MOB accident (see figure 5.2).

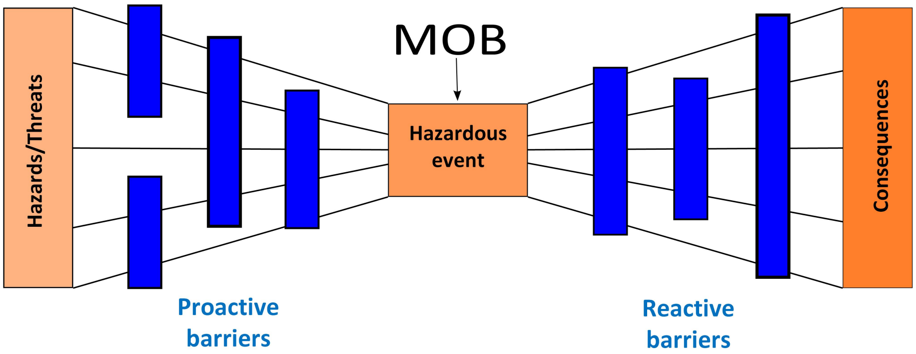

Figure 5.2: Bowtie - dividing the case study into before and after MOB.

5.3.1 Before MOB

When performing any kind of work, a normal sequence of events is one that involves no incidents or accidents. In this section a rather generic sequence of normal events is described, where the executing worker does not fall overboard when conducting work over open sea.

Since a level 1 WP is required to perform work over open sea, the WP application and approval process described by the NOG (2013b), served as a natural starting point. Figures 5.3, 5.4 and 5.5 shows the results from this investigation where the figures represents the planning, preparation and execution phases respectively. In addition, the person involved in the the execution of each task, and a general idea of *what could go wrong?* during that task, is highlighted. In the presentation of the normal sequence of events it was chosen to use a form of task analysis to present a rather coarse breakdown of activities performed to ensure a safe and correct execution of work (with a level 1 WP). Figures 5.3, 5.4 and 5.5 are modified from the task breakdown presented by the NOG (2013b). The suggestions for *what could go wrong?* are mostly based on the identified nonconformances from reviewed accident investigation reports (see sectionwrong), and general ideas of "incidents/accidents" that would break the normal sequence of events.

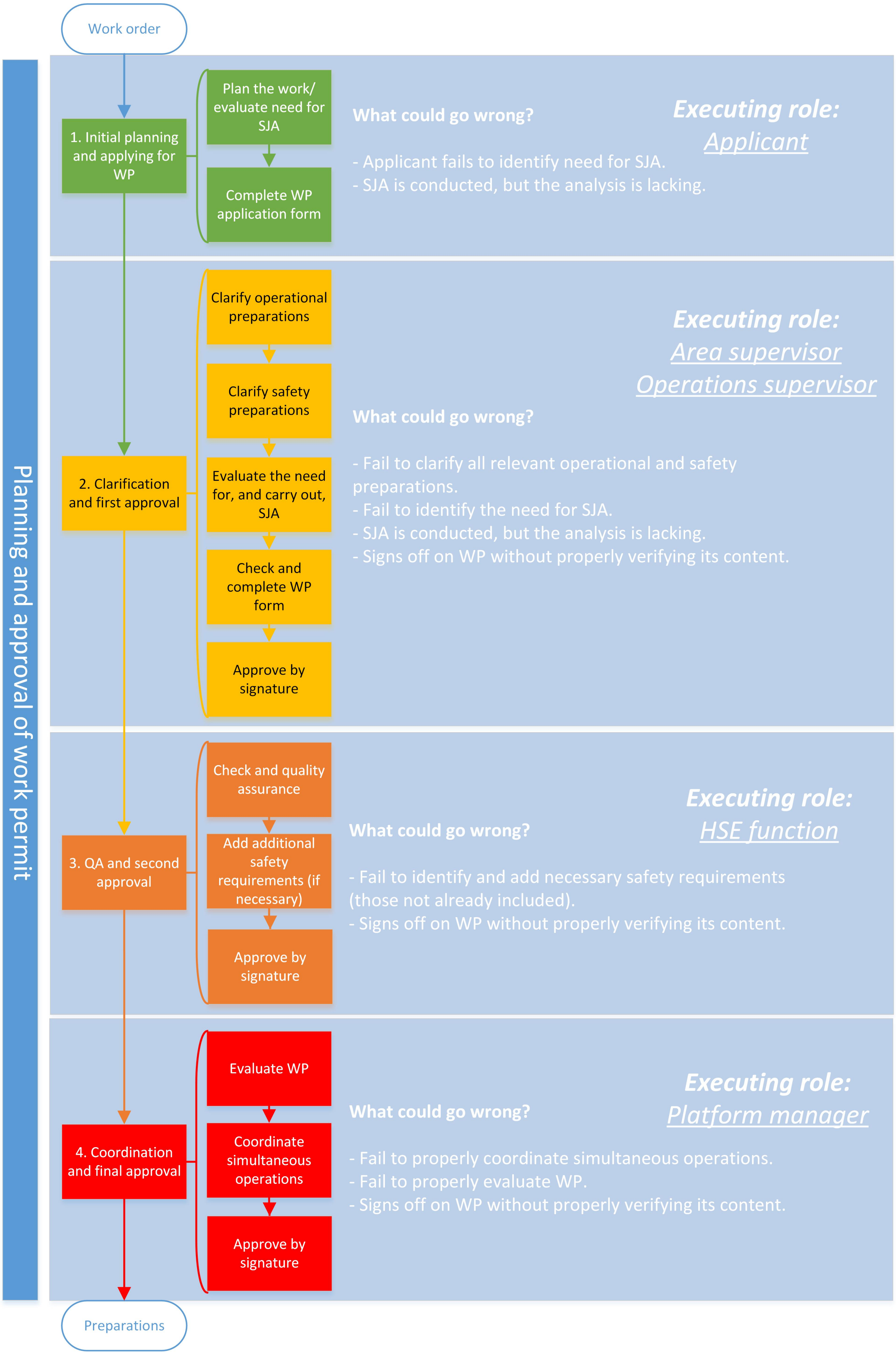

Figure 5.3: Tasks conducted during the planning phase (adapted from NOG (2013b)).

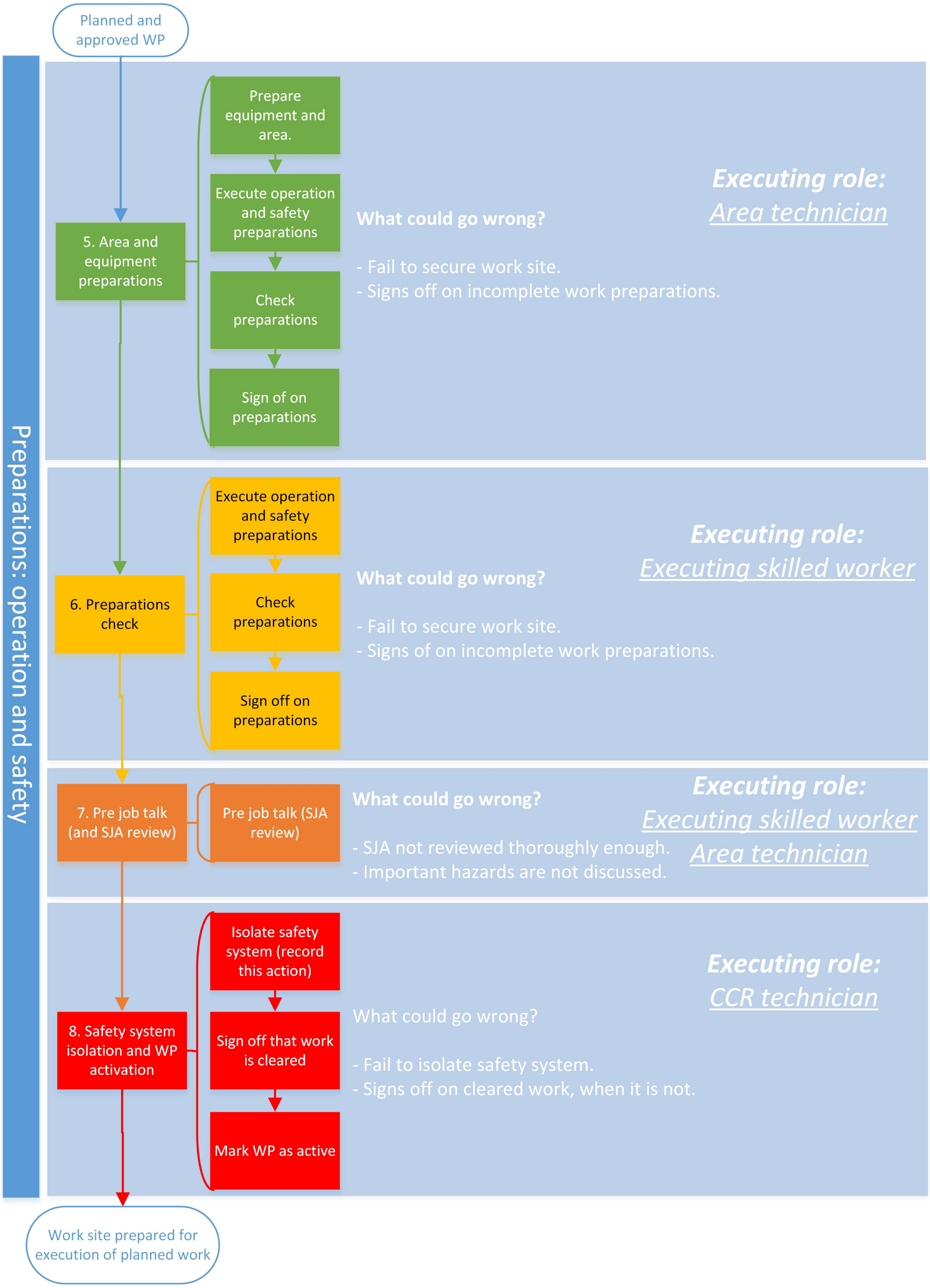

Figure 5.4: Tasks conducted during the preparations phase (adapted from NOG (2013b)).

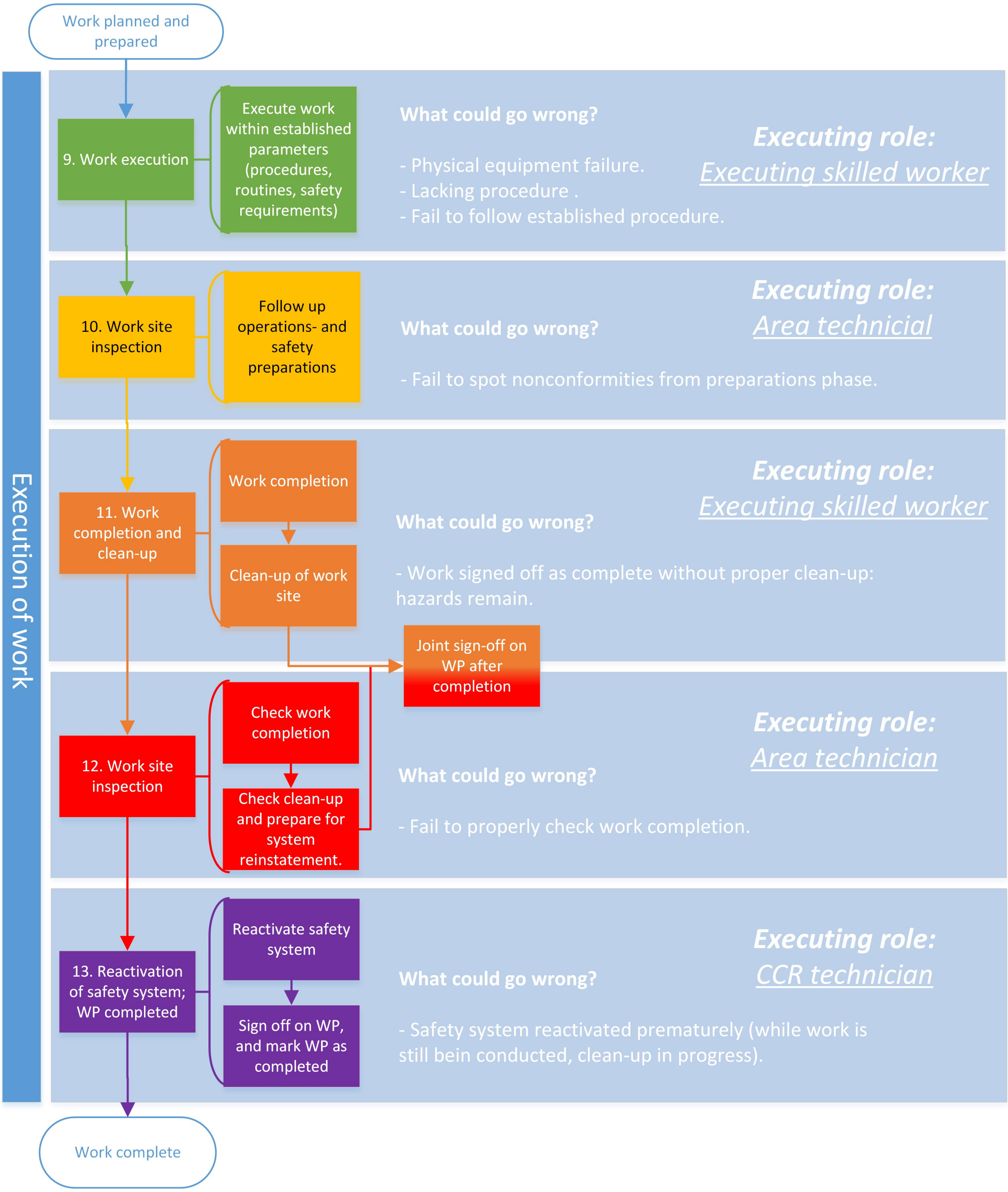

Figure 5.5: Tasks conducted during the execution phase (adapted from NOG (2013b)).

5.3.2 After MOB

As already discussed in chapter 4 there will always be a risk of falling overboard when conducting work over open sea, and MOB preparedness is required. Figure 5.6 shows tasks conducted to ensure that the outcome of a MOB accident is not a fatality. The figure is based on the muster list for SBV A (see appendix C), a general description of duties for a safety guard during work over open sea (see appendix B) and a review of previous MOB accidents (see section 5.4). To determine the sequence of events after an accidental event, it is normal to apply an event tree approach where barrier failures and possible outcomes are listed. For a MOB accident the outcomes are usually "no injury", "hypothermia" or "drowning" (disregarding possible impact injuries) depending on the realization of the "prevent fatalities" barrier function (with sub-functions). However, as explained in section 5.5.2, there is mostly one "line of defense" preventing or mitigating consequences from a MOB accident. As this case study has made the simplification that the only consequence from a MOB accident is "fatality", it becomes an either/or situation. If the mitigating barrier function fails, you get a fatality (hypothermia is not considered separately). Although the event tree way of though has been applied in the analysis, it was determined that the creation of an event tree was not necessary.

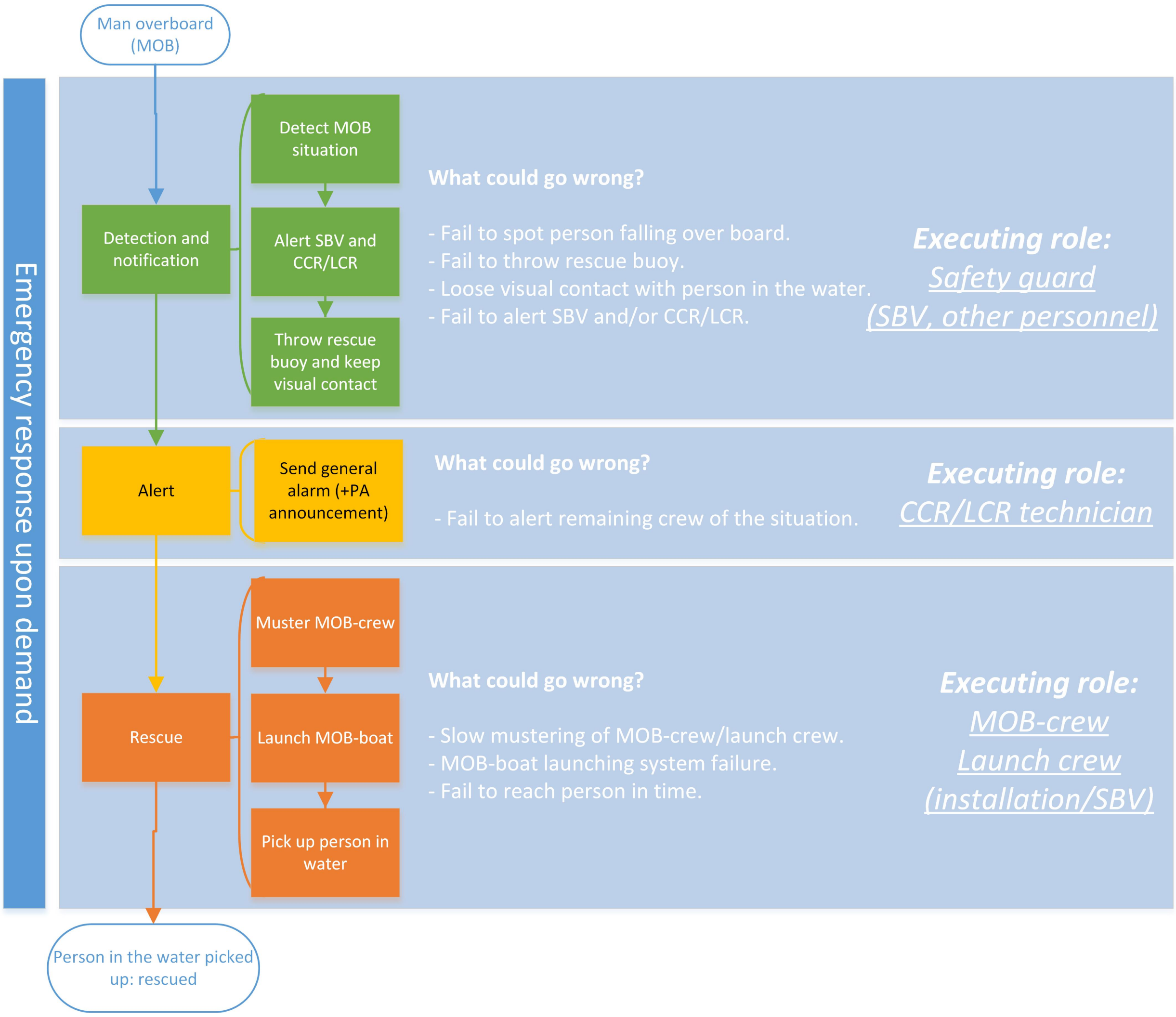

Figure 5.6: Tasks included in the emergency response after a MOB accident.

5.4 What could go wrong?

Determining potential failures in the chosen scenario is an important step to identify barriers preventing them from happening. Two investigation reports (PSA, 2007 and PSA, 2015a) from previous MOB accidents have been reviewed, and a series of smaller STEP (Sequential Timed Events Plotting) analyses conducted. The intention was to get a better grasp of actions and personnel involved in a MOB scenario. The method used in the STEP analyses is based on a combination of traditional STEP analysis and barrier analysis as described by Johnsen et al. (2011). Creating a STEP model for each phase (planning, preparation, execution and emergency response) for the two accidents, required a significant amount of time and yielded an increased knowledge base of potential barrier failures, involved personnel and actions taken. Appendix E shows a small example of a STEP model from the emergency response phase in the Saipem 7000 MOB accident in 2007. Due to the share size of these models only one example is included in the thesis.

The PSA created MTO (Man, Technology, Organization) analyses for both of the reviewed investigation reports, illustrating the accidental "chain of events". Even though MOB accidents are not notorious for involving several chains of simultaneous event, they do sometimes occur. As the first look at the PSA single line MTO analyses seemed chaotic, it was decided to find a method that would enable a presentation of simultaneous events. The supervisor suggested that the STEP analysis had this property, and thus it was chosen to illustrate the actors and actions taken in a STEP analysis. The STEP analysis also gives a rather transparent and neat graphical illustration. The intention was to identify important actors/actions and to get a better grasp of the whole situation. The STEP analysis performed as intended, giving valuable input to the attempt at identifying barrier functions and elements.

Limitation: A limitation to the usefulness of reviewing the two investigation reports is that neither describes a MOB accident that occurred during planned work over open sea. The accidents occurred when work was conducted inside of permanent railings and thus not considered as work over open sea (NOG, 2013b). However, the emergency response initiated after a confirmed MOB is mostly the same (with the exception of different required protective gear for the "fallen" person, and the SBV not being required to be in close stand-by). Therefore the STEP analyses of the emergency response phase were determined to be of highest value to the case study. A short discussion on work over open sea is provided in section 4.3.

Table 5.1 shows the main root causes and nonconformances described in each reviewed investigation report (PSA, 2007 and PSA, 2015a).

Table 5.1: Root causes and nonconformances identified by the PSA in the respective investigation reports.

Accident	Root causes	Consequence
Saipem 7000 (2007)	Insufficient risk assessment. Deficient clarification of responsibility and communication. Deficient handover/communication.	Fatality - Drowning
Scarabeo 8 (2015)	Inadequate work standard/inspection routines after bad weather. Inadequate maintenance: inspection and tagging. Inadequate requirements and guidelines in work order when issued.	No serious injury

Remark: Nonconformances in guidelines, procedures and and routines show up as important root causes for MOB accidents. Applying the chosen definition for operational barrier elements (see section 2.1) will hopefully contribute towards highlighting the importance of having these documents in good condition throughout the case study.

The conducted STEP analyses and reviewed investigation reports indicated that the following aspects should be considered when identifying barrier functions in the next step of the case study: risk assessment of the work to be performed, procedures and guidelines describing the work to be performed, the personnel involved (MOB-crew, observation personnel and platform management). These are important findings which contributed to identify the most important phase of the MOB scenario and the most important organizational barrier element.

5.5 Barrier functions and elements

This section will outline the analysis conducted to identify and name barrier functions with respective barrier elements playing a part in realizing them. As already explained, the analysis is conducted in two stages; before and after MOB. The latter stage have received more attention. This choice was based on the conducted STEP analyses which indicates that this is the critical stage.

5.5.1 Before MOB

In the phases of planning, preparing and executing work over open sea, the main focus is to implement barriers and other safety measures to prevent MOB accidents. Reviewing the description of the normal sequence of events (section 5.3) and the analysis into "what could go wrong?" (section 5.4) gave good indications of barrier functions and elements put in place for this purpose. A model shown in figure 5.7 was constructed to illustrate the workflow of planning, preparation and execution in combination with important barrier functions, elements and performance influencing factors. The following paragraphs will give a brief explanation of the identified barrier functions and elements presented in the model (figure 5.7).

The first barrier function takes place in the initial planning phase where the maintenance manager reviews, checks and approves the scheduled maintenance plan. An example is to check that work over open sea is planned to be performed during the right time of year; during summertime rather than winter time. The realization of this barrier function is an opportunity to put a stop to a chain of events potentially leading to a MOB accident even before the schedule is sent offshore.

The next phase is the execution planning where the responsible offshore personnel have received a maintenance schedule with one or more activities requiring work over open sea. According to the NOG (2013b), work over open sea requires a level 1 WP. Part of the WP application process is to refer to relevant procedures and include all necessary barriers (most described in the procedures). In this case the most relevant procedure is the *work over open sea procedure*. Figure 5.7 shows that barrier elements such as a *safety harness*, a *life jacket* and a *safety guard* are required by the work over open sea procedure. These, and more, barrier elements and preconditions must be in place to "prevent MOB" and to "prevent fatalities" before work over open sea can commence. As figure 5.7 shows, most of the specified barrier elements perform their functions upon demand in the execution phase or after the occurrence of a MOB accident.

The next step is to evaluate the need for extra safety measures, like conducting a safe job analysis (SJA) or executing extra work-site inspections. According to the NOG (2013b), every person involved in the WP application process is responsible for evaluating the need for a SJA. However, a SJA is usually not conducted in situations where clearly defined and frequently used work procedures exist.

When all procedures are referred to, extra safety measures are considered and all necessary barriers are included and specified in the WP, the WP must go through a verification process. The area supervisor/operations supervisor, the platform HSE function and platform manager evaluates the detailed safety measures listed in each WP. They then proceed to add or remove safety measures when necessary and signs off on it when they are satisfied. This is performed prior to a daily meeting where each planned activity is coordinated. When work preparations are scheduled to commence, the WP can be released from the central control room (CCR).

The third barrier function (listed in table 5.2) is realized when the area supervisor or HSE function inspects the work-site to approve that safety measures specified in the WP are actually in place. If extra inspections are included as extra safety measures, they could take place during both the work preparation and execution phases.

During the execution of work over open sea, the safety guard (organizational barrier element specified in the procedure) have an important role. The safety guard's role is to observe the executing worker and to make sure that each precondition is in place. The safety guard shall observe and react to any changes to the preconditions for the work and listen to and follow relevant instructions given to him over the radio (more specific safety guard duties are listed in appendix B).

Discussion and criticism

Table 5.2: Barrier functions performed by barrier elements in the planning, preparations and execution phases.

Barrier function	Barrier element(s)
1. Approval of plan	Maintenance manager
2. Approval of WP	Area/operations supervisor HSE function Platform manager
3. Safety inspection	Area supervisor HSE function

The model presented in figure 5.7 went through an evaluation process in the second workshop, and some questions were raised as to the effectiveness of the second identified barrier function (see table 5.2). Theoretically a verification process where three individuals have to check and sign off on the WP should be rather effective. However, an unsubstantiated example where false WPs could sail straight through this verification process without any comments was brought up. The general tendency of human behavior to more easily approve something if someone else have already approved it, was also used as an argument. Subsequently, voices were raised arguing that the actual value of this barrier function is rather low. Although not a part of this thesis, a detailed investigation into the actual effectiveness of each barrier function could be of value.

When conducting a SJA it is important to clarify that possessing the resulting document is only a small part of its overall value. How the SJA is used to increase the common understanding of risk factors involved in performing work over open sea is clearly the greatest value. It might be wrong to consider a SJA as a safety measure in itself, but it is a tool to assess the risk associated with performing certain work and to identify necessary barriers.

Figure 5.7 shows clearly that the organizational barrier elements (e.g. the platform management and the executing worker) serve the most important roles in the phases leading up to the execution of work over open sea. The technical barrier elements specified in the work over open sea procedure (an operational barrier element) takes effect first in the execution phase as well as after a MOB accident.

An important limitation to the above investigation, is that it's based on the WP application process.

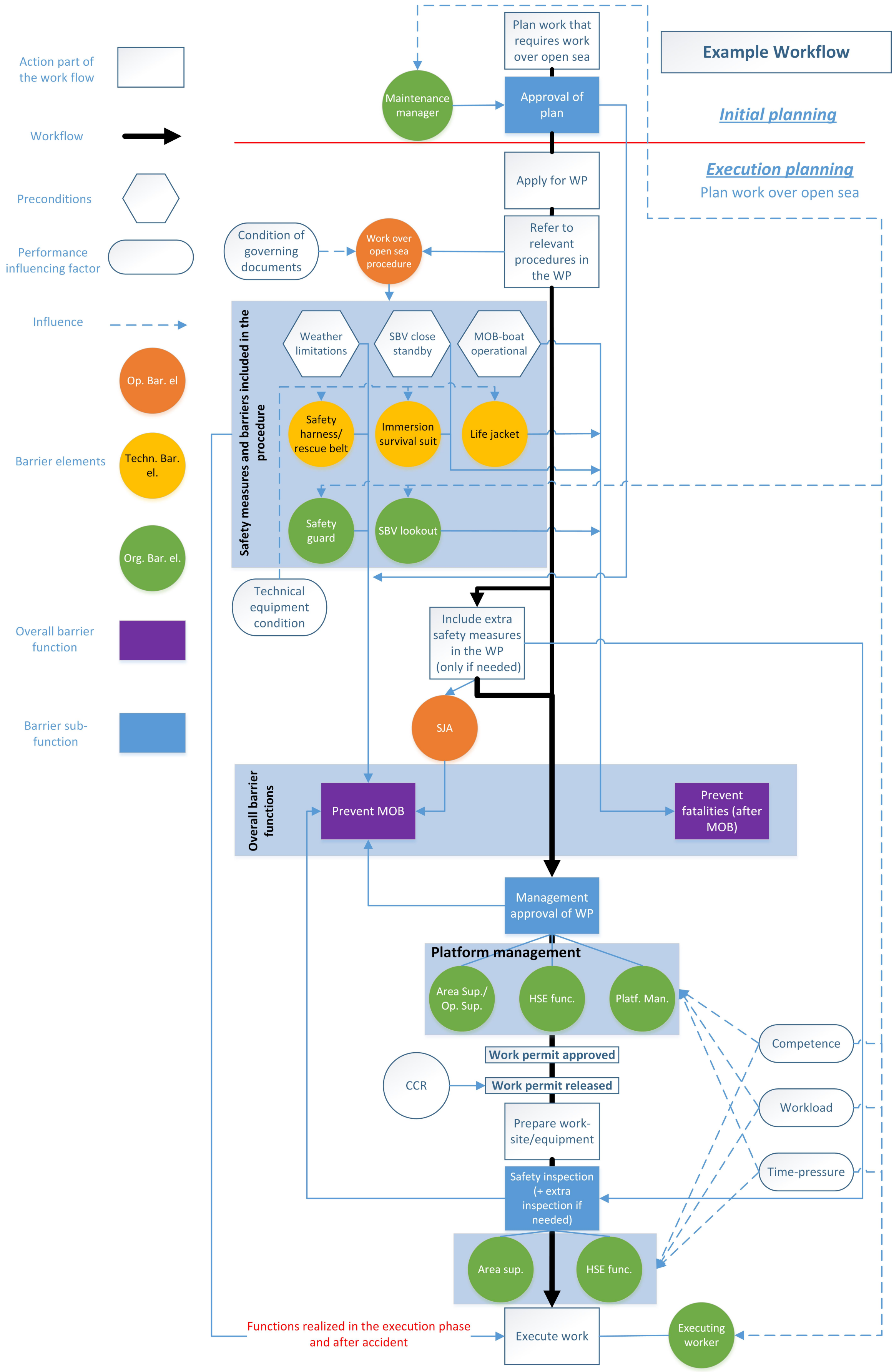

Figure 5.7: Barrier functions, barrier elements and performance influencing factors before MOB.

The ideal case would be to base it on complete insight into the operations of an existing offshore installation, but the best available alternative turned out to be the WP application process (described by the NOG (2013b)). If one were to take another approach, other barrier functions and elements might be identified.

5.5.2 After MOB

In case of a MOB accident, planned barrier functions are performed to mitigate its consequences. One of these is the overall barrier function; *prevent fatalities*[1]. Comparing barriers in the chosen scenario to the classic "defense in depth" model, some differences are observed (Øien et al., 2015). Instead of several lines of defense protecting the worker, this scenario describes in practice one line of defense with several sub-functions working to prevent fatalities. Figure 5.8 shows the following sub-functions working to prevent fatalities: *limit exposure to the elements*, *provide buoyancy*, *detect and alert*, *raise alarm*, *locate person in the water*, *rescue and recover* and *provide first aid/medical attention.*

Although the ideal investigation would be to break down all barrier sub-functions in detail, the limited available time made it necessary to compromise. A decision was made to focus on the *rescue and recover* sub-function. The decision was based on input from the reviewed investigation reports (see section 5.4) and the fact that most MOB training exercises are focusing on performing this exact barrier function (NOG, 2013a). The focus is rather narrow and sets some limitations to the findings. For example the most important barrier elements under the *rescue and recover* function might not be the most important in the scenario as a whole.

Figure 5.9 shows the results from the more detailed investigation into the *rescue and recover* barrier function, highlighting sub-functions, elements and performance influencing factors. As indicated by the figure, there are more operational and organizational barrier elements than there are technical elements working to realize this function. This is in accordance with the NSA (2014) stating that some barrier functions related to emergency preparedness are performed with a limited use of technical equipment. Of these operational and organizational barrier elements, it is observed that the MOB-crew performs several important barrier sub-sub-functions. The MOB-crew also have significant requirements for certification and training, which becomes useful when indicators are developed later in the analysis. For these reasons the MOB-crew was chosen as the focus when developing and evaluating indicators (described in section 5.6.1).

[1]Major and minor injuries can also occur, but in this case they are considered as covered by "prevent fatalities".

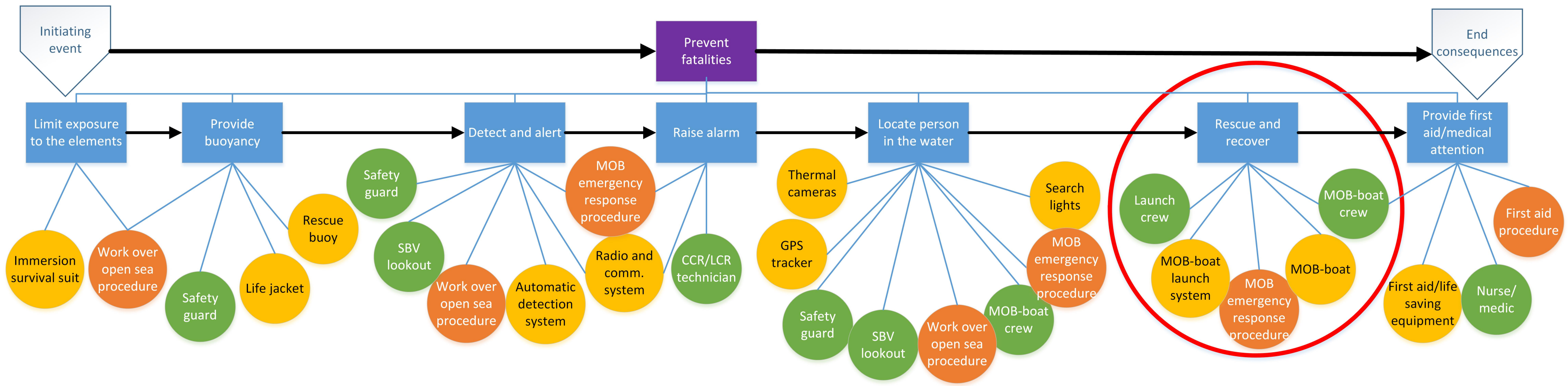

Figure 5.8: Barrier functions and elements after a MOB accident (some barrier elements are presented several times for the purpose of creating a more streamlined model).

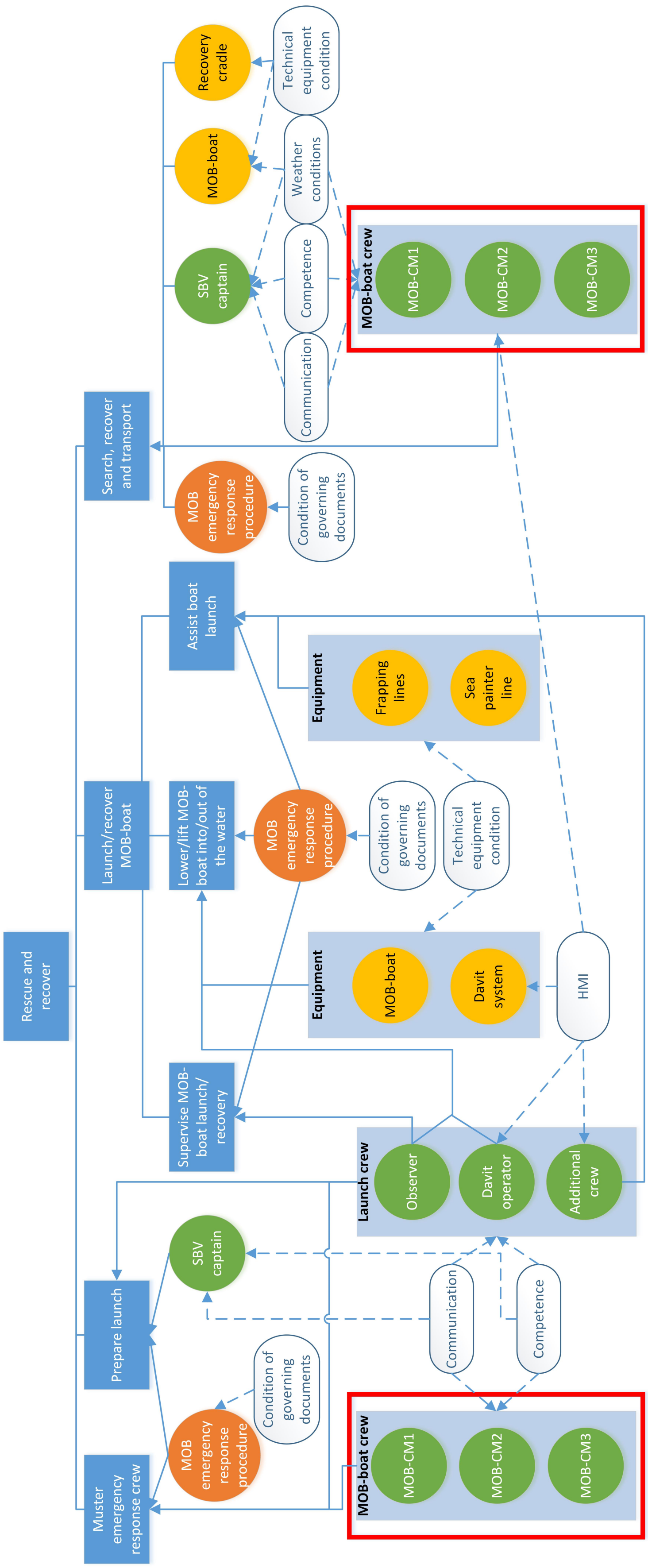

Figure 5.9: More detailed breakdown of the *"rescue and recover"* function with barrier sub-sub-functions, barrier elements and performance influencing factors.

In an attempt of illustrating when the identified barrier functions and elements are performed, figure 5.10 was constructed. The timeline is mostly a summary of the whole investigation so far. Clearly linking barrier elements to barrier functions and the specific time they are to be performed, makes it possible to see where the accident scenario could take a turn for the worse if individual barrier elements are “out of commission”. For example if the *immersion survival suit* is not available, the *limit exposure to the elements* barrier function may not be realized, and the person in the water might succumb to hypothermia long before the MOB-crew have a chance to reach him.

Discussion

A valuable extension of the thesis, based on the above section, could be to perform a criticality assessment where the importance of each barrier element is weighed. A qualitative example: consider the life jacket as a vital part of performing the “provide buoyancy” barrier function, and the rescue buoy as having a more limited value. In a hypothetical case where a rescue buoy is unavailable, it is still a strong possibility that the “provide buoyancy” function can be maintained by the life jacket alone.

Remark: Up until this point, technical barrier elements have been included on the same level as operational and organizational barrier elements. However, since the main objective of the case study is to develop indicators for operational and organizational barrier elements, the technical barrier elements will be excluded from the indicator development process described in the following sections.

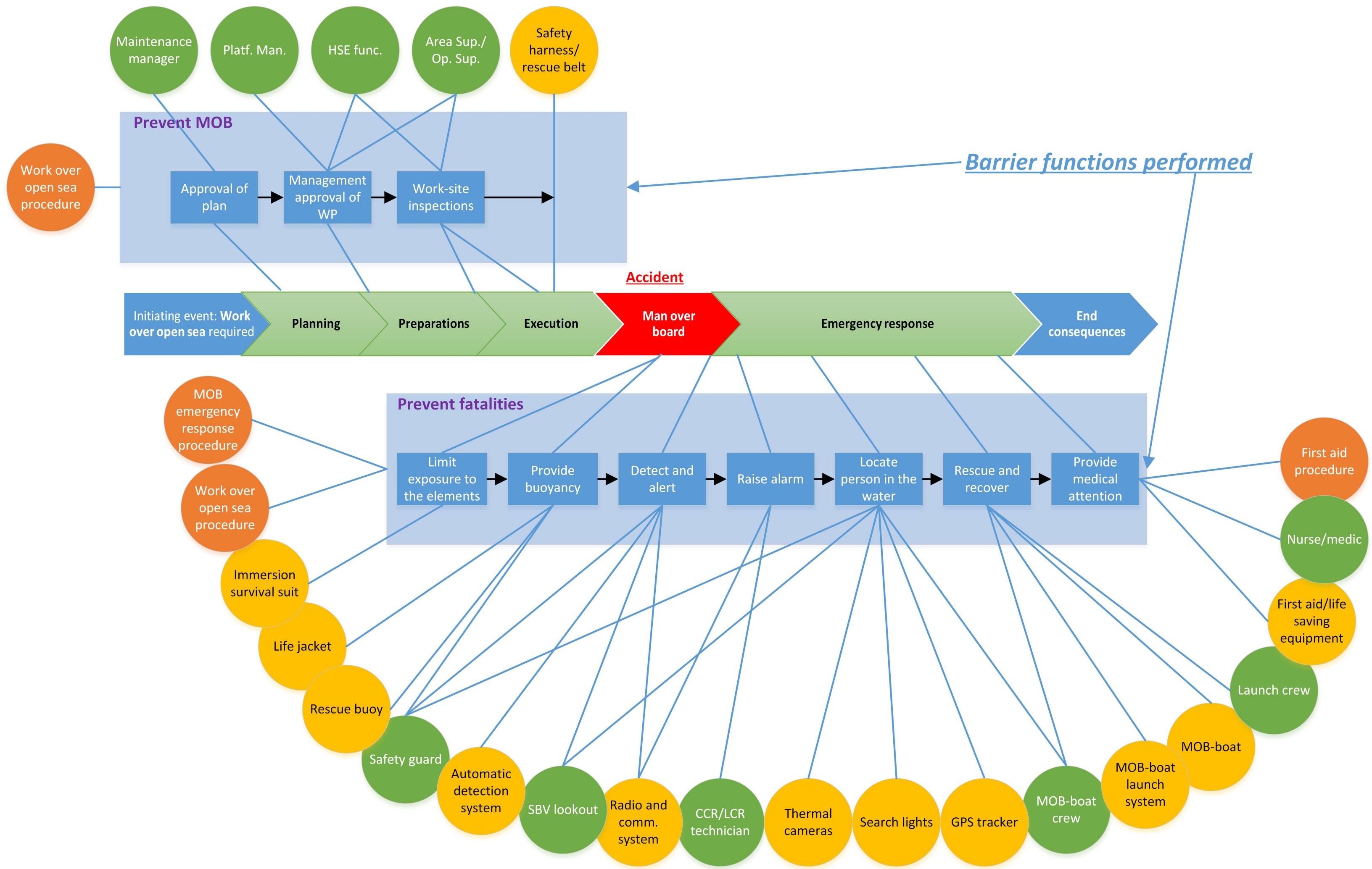

Figure 5.10: Timeline of barrier functions with respective barrier elements showing where they take effect in a MOB scenario.

5.6 Indicator development

The following sections will explain methods and approaches used in the indicator development process.

5.6.1 The starting point

As established in section 5.5.2 the the next parts of the investigation will focus solely on the *rescue and recover* barrier sub-function where the MOB-crew was determined to be the most important organizational barrier element. The MOB-crew barrier element will serve as an example in the process of developing indicators. Due to the time restrictions it was not possible to develop indicators for the other organizational and operational barrier elements.

Table 5.3 shows the initial list of suggested indicators for the "MOB-crew" brought as a starting point to the third workshop. Most of the indicators are suggested for the *competence* PIF. Only one suggested indicator was found for each of the *weather condition* and *HMI* PIFs respectively. No realistic suggestions were found for the *communication* PIF. All indicators where either adjusted from findings in reviewed literature (see reviewed articles in section 3.2), suggested by TOTAL representatives or creatively developed based on personal experiences.

Table 5.3: Proposed indicators for factors influencing the performance of the MOB-crew during realization of the *"rescue and recover"* barrier function.

Competence	**Weather conditions**	**HMI**
Number of MOB training exercises conducted per shift.	Number of degrees below a lower temperature limit.	Number of steps to start the MOB-boats' engine(s).
Fraction of MOB-personnel with valid certification.		
Number of years' experience as MOB-boat commander.		
Number of failed MOB training exercises per year.		
Average number of hours spent yearly on MOB training + actual demand.		
Number of successful training exercises.		
Number of experienced MOB-personnel in crew.		
Number of MOB-crew having undergone recertification in the last 6 months.		

5.6.2 The analysis

The evaluation process for the suggested barrier indicators consisted of two initial rounds of evaluations and one more detailed round (see section 5.6.3) carried out during the third workshop. The first round consisted of an evaluation of the identified indicator selection criteria (see section 3.3) to find the most relevant set to use in the case study. After a short discussion, there was a consensus to remove the *robustness against manipulation* and the *show trends* criteria from the list. This was because they are mostly covered by the remaining criteria; *robustness against manipulation* is covered in *measurability* and *show trends* is covered under *sensitivity*. A criticality analysis of the remaining criteria was conducted to determine the most important criteria for the chosen scenario. As figure 5.11 shows, *validity*, *measurability* and *sensitivity* are considered as important and were given multiplier scores of 10. The remaining two criteria were given multiplier scores of 1.

The first evaluation round also comprised of a short brainstorming session to gather additional indicator suggestions. The following indicators were suggested:

- Number of actual MOB accidents.
- Fraction of successful exercises.
- Fraction of preventive/corrective maintenance activities on MOB equipment involving the MOB-crew.
- Fraction of successful MOB exercises conducted close to maximum allowed weather conditions.

The second round of evaluation consisted of evaluating each suggested indicator against the main criteria; **validity**. Some indicators where removed due to being covered by other “better” indicators and others were removed due to a low score (a score of 1) on the “validity” criteria.

Indicators removed with arguments of why:

- **Number of failed MOB training exercises per year:** Replaced by measuring number of successful exercises per year.
- **Average number of hours spent yearly on MOB training + actual demand:** Low value, covered by another indicator.
- **Number of successful training exercises:** Covered by another indicator.

- **Number of degrees below a lower temperature limit:** Low value indicator.
- **Fraction of preventive/corrective maintenance activities on MOB equipment involving MOB-crew:** Covered by other indicators.
- **Number of experienced MOB personnel in crew:** Low value indicator.
- **Number of MOB-crew having undergone recertification in the last 6 months:** Low value indicator.
- **Number of steps to start the MOB-boats' engine(s):** Low value indicator.

Figure 5.11 shows the scoring scheme used in the evaluation against the respective criteria. Scores between 1 and 5, where 1 is very bad and 5 is very good, were assigned to each indicator in relation to the selected criteria. The evaluation scheme is also considering the weight of the PIF. This is because an indicator could score well on each evaluation criteria and be an excellent indicator for a PIF, but if the PIF is of little influence, then the indicator should not score very high. Therefore a multiplier score of 10 was given to the *competence* PIF. In this scenario it is of little use to assign weights to the PIFs, since no indicators for other PIFs than *competence* made it through the first screening process (reasons why are explained below). Even so, the possibility to weigh each PIF against each other is presented in the evaluation scheme for use in other scenarios. The assigned indicator scores (1-5) are multiplied with the PIF weight and the criteria weight before summing across all criteria to yield the absolute score.

It was determined that no more time and effort should be used on attempts to develop indicators for *communication*, *weather conditions* and *HMI*. *HMI* was excluded due to the static nature of the factor. For an indicator of HMI to change, the physical design or the programming of technical equipment (like the MOB-boat or the davit system) would have to change. This does not happen very often, or at all, during the equipment lifetime. Communication on the other hand is a very abstract factor, and to develop indicators for it proved difficult (the effect of communication differ from person to person/situation to situation). Weather conditions are so thoroughly covered by limitations (preconditions) described in the work over open sea procedure that no indicators were deemed necessary.

5.6.3 The result

To perform the final evaluation and display the results, it was decided to use a modified quality function deployment diagram, see figure 5.11 (the traditional use of a QFD is described by Andersen and Fagerhaug (2001)). Although the QFD has the valuable property of being able to handle a significant amount of information at the same time, it was decided to simplify it to make the evaluation process as understandable as possible. As explained in section 5.6.2 it was chosen to apply multiplier scores to each evaluation criteria and PIF. It was also decided to include information about the time horizon and information input method for each indicator. This was mainly to see if any indicator could fulfill the industry's desire to monitor instant changes based on automatically retrievable information. Some comments such as proposed indicator target values and other considerations are also shown for each indicator. The three indicators that emerged from the evaluation process with highest scores are marked in green. As figure 5.11 shows, the three "winning indicators got relative scores of 20 %, 19 % and 19 % respectively. Comparing the "winning" scores with the "losing" scores show a marginal "win" at best. However, based on experiences from the workshop participants, the author feels confident that the indicators marked in green does indeed represent the preferred outcome.
The following list represents the final result of the case study (extracted from figure 5.11):

1. Fraction of MOB-personnel with valid certification.

2. Fraction of successful exercises.

3. Fraction of successful exercises conducted close to maximum allowed weather conditions.

Figure 5.11 show that a medium time horizon is considered as appropriate for measuring the above indicators. Without having investigated it further, it is suggested that the indicators could be updated from every 6 months to a year (possibly more often if sufficient amount of data can be gathered).

Discussion

As the above results show, there are three aspects of competence to monitor. One is that the MOB-crew have the required certification to serve in a MOB-crew capacity. The second aspect is to monitor how often the MOB-crew perform exercises and the success rate of these. The third aspect is to monitor that the exercises are conducted under realistic conditions. This is an important indicator since the weather rarely offers up a flat sea surface with a light breeze during emergency situations. A generalization of the three indicators shows that monitoring required certification, successful training and training under relevant conditions are applicable for other organizational barrier elements as well. An example is to monitor the competence of the davit operator onboard the SBV. A broader discussion on the value of the findings is provided in chapter 6.

The intention of using the QFD was that it would give some valuable additions to the evaluation process, but in hindsight it is clear that little new was added. Another evaluation diagram could have just as easily been used and probably yielded mostly the same results. The QFD's only real contribution was putting the information in a neat and understandable order.

How can we measure the information needed for the chosen indicators?

The measurability of the three "winning indicators were evaluated to be rather good (see figure 5.11). The next paragraphs will briefly provide some experience based suggestions of how the necessary information can be gathered for each of them.

The first indicator could be measured by extracting information from a competence matrix. A competence matrix enables the operator to keep track of e.g. courses, certifications and recertification intervals for each MOB-crew member individually. The following list shows some of the most relevant certificates to keep track for the MOB-crew in the current case study (based on the Norwegian Oil and Gas Association guidelines for safety and preparedness training (NOG, 2013a)):

- **Basic safety and preparedness course** - Recertification every 4 years.
- **OSE114 Small MOB-boat course (FRC)** - Recertification every 2 years.
- **OSE1141 Large MOB-boat course (DC)** - Recertification every 2 years.
- **OFA101 First aid course** - Recertification every 1-2 years.

The second and third indicator could be measured by extracting information from exercise logs kept weekly on the SBV. For every MOB-exercise the wind strength, wind direction and wave height are logged and an evaluation of the exercise level of success is conducted. An exercise log example is provided in appendix D. Since the SBV in this case is run by a third party, procedures to share these exercise logs must be established. Measuring the second and third indicator will rely heavily on manual input of necessary information, but could be easily accessible to the installation operator if a shared digital input system was developed. Instead of plotting the exercise data in old-school word-documents, the logs could be kept in a shared database. Manual input of weather conditions will then become unnecessary since the weather measurement equipment could be directly interfaced with the database. Further verification of the strength and value of the three indicators is required before any steps are taken to actually gather the required information (as suggested in section 6.3).

Evaluation and prioritization of barrier indicators

Barrier element: MOB-crew (after MOB)

Scoring	
Very good	5
Good	4
OK	3
Bad	2
Very bad	1

					Importance score for evaluation criteria							
					10	10	1	1	10			
					Evaluation criteria							
Score	PIFs	Barrier indicators	Manual/ automatic input	Time horizon	Validity	Measurability	Comprehensibility	Cost effectiveness	Sensitivity	Absolute score	Relative score	Comments
10	Competence	Number of MOB training exercises conducted per shift	M	Medium	400	500	50	40	300	1290	16 %	1 shift = 28 days (target min 1 per week, preferably 2)
		Fraction of MOB-personnel with valid certification	M	Medium	500	500	50	30	500	1580	20 %	Target: 100 %
		Number of years' experience for MOB-boat commander	M	Long	200	500	20	20	300	1040	13 %	Could show the wrong picture. Experience is not allways a good thing (older age).
		Number of actual MOB accidents	M	Long	500	500	50	10	100	1160	14 %	Problem: very few incidents
		Fraction of successful exercises	M	Medium	500	500	50	40	400	1490	19 %	Success = response-time below 8 minutes. Target = 100 %
		Fraction of successful MOB exercises conducted close to maximum allowed weather conditions	M	Medium	500	500	50	40	400	1490	19 %	Train by doing what's relevant. Target = 80 %
								Total		8050	100 %	

Figure 5.11: The final evaluation of competence indicators against selected criteria.

Chapter 6

Discussion, conclusion and further work

The purpose of this chapter is to discuss aspects relevant to the thesis, provide objective specific conclusions and provide suggestions for further work.

6.1 Discussion

As established in section 1.1, a MOB accident is not considered a major accident. This is both because the consequences are at worst one fatality and because of the limited potential for uncontrollable escalation. A MOB accident also consist of mostly single linear event chains, which is a normal characteristic for an occupational accident. Therefore one might consider a MOB accident as a subcategory of occupational accidents, but a very important category as such (Vinnem, 2013). The importance of protecting against a MOB accident is solidified by the PSA and the NOG as they classify a MOB accident as a defined hazard and accident condition. This entails that a MOB accident is included in the emergency preparedness plan for every installation on the Norwegian continental shelf (PSA, 2013 and NOG, 2012).

An interesting question was raised during the development of the case study: "how can we make sure that a MOB-crew performs as well today as they did a year ago?". As with most questions relating to operational and organizational barriers, there are no easy answers. Although, by taking some inspiration from maintaining technical barriers, one could say it's all about "maintenance". Doing maintenance on the MOB-crew should then involve activities to maintain the factor most influential to the crew's performance. In the case study it was decided that *competence* is the most influential performance factor for the MOB-crew. To maintain the *competence* of the MOB-crew, the results from the case study becomes useful. Monitoring of the three suggested indicators makes it possible to determine the current competence level and enforce improvements should it be necessary. Although direct suggestions of how one might improve MOB-crew competence are outside the boundaries of this thesis, some suggestions are easily identified by looking at the indicators (for example more frequent exercises during relevant conditions will give a positive impact on the competence). There are however, a lot more factors influencing the performance of the MOB-crew than those considered in this thesis, and most of them are of a psychological nature. Due to the author's limited knowledge of psychology, it was determined that no further investigation into these factors should be carried out.

Although the MOB-crew was evaluated to be the most important (organizational) barrier element for the *rescue and recover* function, it was observed that the work over open sea procedure and MOB emergency response procedure (operational barrier elements) holds important roles as well. Through the literature review on performance influencing factors, the *condition of governing documents* was identified as the "most common" and relevant PIF for operational barrier elements. Attempts were made to develop indicators for this PIF, but it proved difficult. Although some examples were found, (see below) none were deemed suitable to give actionable indications of the document's status. Example indicators include *"years since last procedure revision"* and *"number of procedure reviews in the last month"*. One result however, was the discovery of three properties that should be secured for every important operational barrier element: a good document condition entails that it is *"up to date"*, *"accessible"* and that relevant employees are *"aware of its contents"*. Any further work to develop indicators for operational barrier elements was not carried out. It is however, listed as a possibility for further work in section 6.3.

Evaluating the value and strength of the findings in the case study have proven difficult. There are few or no comparable literary works discussing man overboard in a barrier context, and there was no time to actually test the identified indicators. The only basis for saying something about the strength and value of the findings is the investigation process itself. Because of a consistent use of available literature, input from experts and the contributions from Total E&P Norway, it is safe to say that the findings have relevance and potential value. Whether or not this holds true, remains to be verified through further studies (as suggested in section 6.3). Since the case study is very specific in nature and only considers a small part of operation on any offshore installation, it is important that the findings can be generalized to get a broader application area. As mentioned, the main result in the case study was a set of three suggested indicators to monitor the MOB-crew's competence. Competence in itself is rather abstract, but it is an important factor influencing the performance of any barrier function where organizational barrier elements have defined roles. The three indicators suggests to monitor the certification of the personnel, the fraction of successful training exercises and the fraction of training exercises conducted under realistic conditions. Monitoring these three indicators are easily transferred to any scenario where regular certification and training is required. A weakness is that a lack of data points will paint a wrong picture and significantly reduce the value of the indicators (for example because required training is very infrequent).

6.2 Summary and conclusions

Investigating the chaos of terms surrounding barriers was a big part of the theoretical studies in this thesis and several possible definitions where identified and discussed (chapter 2). A detailed investigation into different classifications of barrier elements was carried out and a suitable set of definitions was selected to use in the case study. It was determined to apply the three class approach (with a twist) as suggested by Øien et al. (2015). All in all this choice contributed to identifying some important barrier elements in a MOB scenario. The first defined thesis objective was met through the investigations conducted in chapter 2.

Chapter 3 briefly presented the link between performance influencing factors and indicators before delving into two literature reviews. One was to determine the most commonly used performance influencing factors, and the other was to determine the most commonly used indicator evaluation criteria. This chapter contributed towards reaching the second, fourth and fifth defined case study objectives.

Chapter 4 investigated the basics of man overboard accidents to create a theoretical foundation for the case study. The case study was limited to man overboard accidents during work over open sea. Preconditions and required safety measures for work over open sea were investigated, and how MOB preparedness is kept was examined. The second defined thesis objective was met through the investigations carried out in chapter 4.

Chapter 5 presents a case study especially investigating operational and organizational barriers in a man overboard scenario. The case study involved a long back and forth process to determine a suitable level of detail for the constructed models and evaluation forms. Although the investigation could not take every aspect into account, most barrier functions and elements before and after a MOB accident were identified, named and presented in figures. Although important barrier functions and elements in the phases leading up to a MOB accident were identified, most time and effort was used to investigate the phases succeeding a MOB accident. Due to its importance in MOB emergency response, it was decided to focus on the *rescue and recover* barrier function. Through ensuing detailed investigations, the MOB-crew was identified as the most important barrier element and *competence* as the most important performance influencing factor. Several indicators were developed and the following three was determined to be most suitable for monitoring the competence of the MOB-crew:

1. Fraction of MOB-personnel with valid certification.

2. Fraction of successful exercises.

3. Fraction of successful exercises conducted close to maximum allowed weather conditions.

Keep in mind that the above results are not necessarily valid for the chosen MOB scenario as a whole. It was decided to focus on the *rescue and recover* barrier function, and this is the function where the MOB-crew is the most important barrier element. Looking at the MOB scenario as a whole will probably yield different results (logically, probability reducing barrier functions and elements are most important in the MOB accident scenario as a whole).

All defined objectives in the case study were met with the exception of one; no indicators for operational barrier elements were found. As explained in the discussion above, identifying indicators for identified operational barrier elements proved difficult and was abandoned in favor of pursuing indicators for organizational barrier elements. The strict time limitations played a significant role in this prioritization. No indicators for barrier elements in the phases leading up to a MOB accident were identified. As stated, the focus was on the phases succeeding the accident.

An overall conclusion is that every operator needs to take care when choosing a set of barrier definitions to follow, because ultimately the chosen definitions will determine what is considered as barriers to be managed.

6.3 Recommendations for further work

This thesis contributes to bridge only a small gap in a complex area of research. As such there are plenty of opportunities left to investigate as possible extensions of the thesis.

One possibility is to investigate indicators for more than just the MOB-crew barrier element under the *rescue and recover* barrier function. The thesis explains the basic methodology to apply, so further investigations are only contingent upon available time and creativity. Since the focus of this thesis turned out to be mostly organizational elements, it could be of value to explicitly focus on the operational barrier elements (using the classification and definitions suggested by Øien et al. (2015)).

Another option is to generate test data and apply the suggested set of indicators to see whether or not they perform as intended (for example if the indicators possess the desired sensitivity). The next step could be to implement the indicators on an actual installation and gain experience data from using them on a regular basis to monitor MOB-crew competence.

A third possibility is to investigate how the choice of having both the primary and secondary MOB-boat on the SBV impacts barrier management. A comparison study of all three possibilities could be conducted ((1) both MOB-boats on the SBV, (2) one MOB-boat on the SBV and one on the PU, (3) both MOB-boats on the PU). There could be some significant differences between the three.

As established, the results from the case study can be generalized and applied for other scenarios. A study of challenges pertaining to this transfer to another scenario (like a major accident scenario) could be of value.

The last proposal for further work is to use the case study results to create a scored risk model. Based on risk considerations it is possible to weigh how much the failure of each barrier element will impact the performance of their barrier function, and as such create a numerical model to calculate how the status of a barrier impacts the overall risk picture. Extensive research have already been conducted on the development of such risk models, so important knowledge is easily found in the literature. An example is the approach developed and used in the risk barometer project (Paltrinieri et al., 2014 and IO center, 2014). Figure 6.1 shows a generalized scored risk model which could be adopted to this purpose.

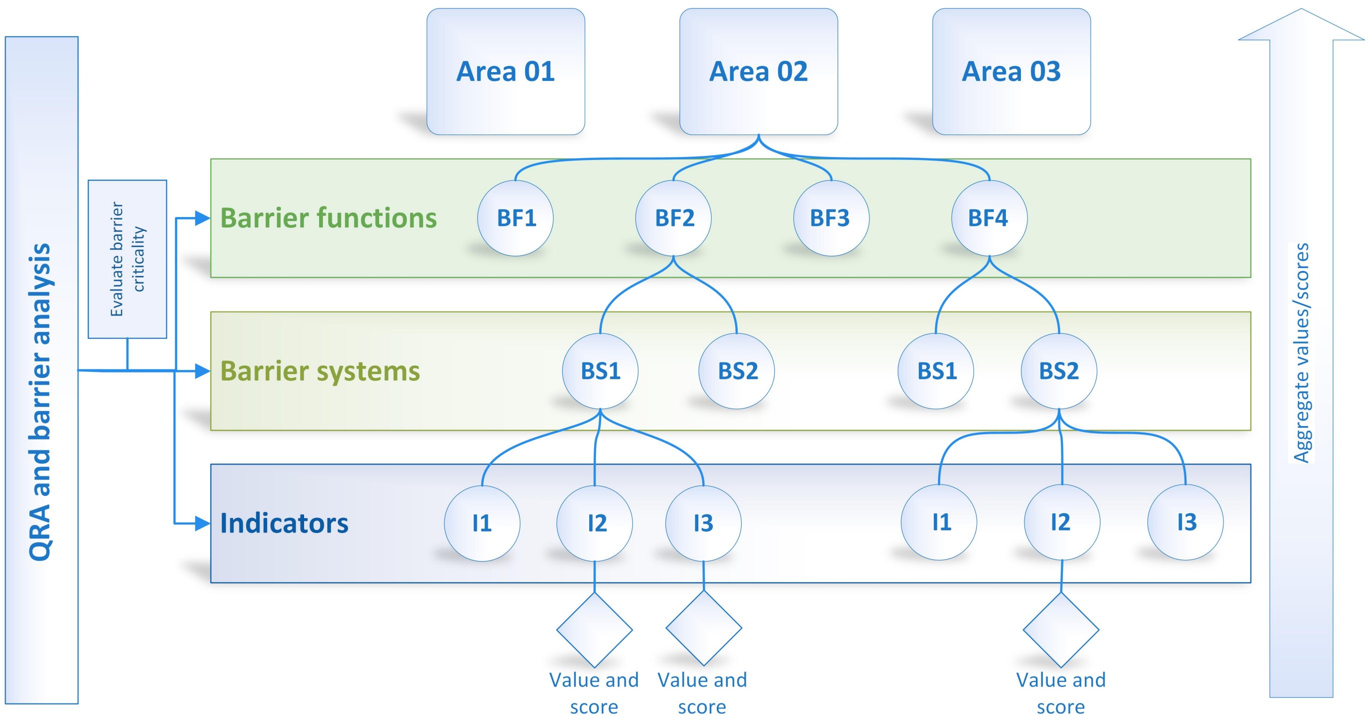

Figure 6.1: The risk barometer approach for scoring the status of barriers to determine their effect on the risk picture (adapted from Paltrinieri et al. (2014)).

Appendix A

Acronyms

BORA	Barrier and Operational Risk Analysis
CCR	Central control room
DC	Daughter craft
FRC	Fast rescue craft
LCR	Local control room
MOB	Man over board
MTO	Man, Technology, Organization
NOG	Norwegian Oil and Gas Association
ORIM	Organizational risk influence model
OTS	Operational Safety Condition (Norwegian acronym)
PIF	Performance influencing factor
PSA	Petroleum Safety Authority Norway
PSV	Platform supply vessel
PU	Production unit
QFD	Quality function deployment diagram
RISK OMT	Risk modeling - integration of organizational, human and technical factors
SBV	Stand-by vessel
SPAR-H	Human reliability analysis method
STEP	Sequential Timed Events Plotting

Appendix B

Safety guard duties during work over open sea

5.2.13 Duties for the safety guard during work over open sea The safety guard must…..		OK
General	Have received necessary training according to the guidelines in the company.	
	Be identified/marked so that it is clearly visible who have the guard function.	
	Have participated if SJA was performed/ have reviewed the SJA.	
Communication/ Warning	Have located the nearest manual fire call point/telephone.	
	Have established radio communication with CCR/Radio room/MOB-function and the work site.	
	Communication routine must be agreed between involved parties including information exchange at start, completion and interruptions/breaks in the work.	
	Communication shall be checked prior to start of the work.	
Emergency response/ preparations	Ensure that the MOB-function is informed and operational prior to start of the work.	
	Ensure that involved personnel are familiar with the escape routes.	
	Become familiar with the weather limitations for work above sea and the prevailing weather conditions.	
During the work	Not take active part in the work and always be present when work above sea is ongoing.	
	Be located at the permanent deck of the installation and have an unhindered view of the executing personnel.	
	Monitor the number of personnel involved in the work, be alert and sound the alarm should personnel fall overboard.	
	Monitor changes in weather conditions/visibility and light and stop the work if the preconditions and limitations for the work are exceeded.	
	Monitor the working situation and the surroundings so that the work can be stopped should a situation arise that calls for such action.	
Interruptions/breaks/ Completion of the work	Secure equipment/the work site.	
	Inform the area technician if safety systems have been isolated so that they can be reactivated.	
	Adhere to agreed communication routine.	
	Monitor the personnel until everyone has reported back on a safe location on the permanent deck of the installation.	
Actions if "man overboard"	Alert fellow workers, CCR /MOB –function and sound the alarm.	
	Throw out a life buoy.	
	Maintain visual contact with the person.	
	Secure equipment/the work site.	
Other alarm situations	Alert fellow workers and stop the work.	
	Secure equipment/the work site.	
	Muster according to the station bill.	
	Monitor the personnel until everyone has reported back on a safe location on the platform deck.	

Figure B.1: Safety guard duties suggested by NOG (2013b).

Appendix C

MOB musterlist on SBV

[redacted]

Standby Manual – Alden Standby manual

Muster List - MOB - Recovery with FRC

Doc.no: [redacted]
Issued: 2014-06-27
Revision: 0
Author: [redacted]
Approver: [redacted]
Page: 1 of 2

MUSTERLIST: MOB – Recovery with FRC

OOW: Sounds the alarm!

RANK	INSTRUCTION
Captain	Take command on bridge.
Chief Officer	Take command on deck/hospital.
2nd Officer	Assist Captain on bridge. Radio operator – send emergency call. Prepare checklists. Lookout on Bridge
Chief Eng.	Take command in Engine control room. Start up all necessary propulsion engines.
2nd engineer	Prepare FRC. Launch and recover FRC.
Steward	Prepare hospital and reception. Preparing blankets, stretchers and oxygen. Preparing the recovery room. Unlocking cabinets in hospital. Preparing defibrillator. Locating thermometer and sphygmomanometer. Meet up at the MOB station with stretcher and blankets.
AB 1	FRC crew.
AB 2	FRC crew.
AB 3	FRC crew.
Additional crew	Assists where necessary
Trainees	Assist on deck. Loose lashings, prepare FRC

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Figure C.1: MOB musterlist on SBV

Appendix D

Exercise log example on SBV

[redacted]

Forms and Checklists- RR - Rescue and Recovery Vessels

RR1 Rescue and Recovery Vessels Exercise Log

Doc.no: [redacted]
Issued:
Revision: 3
Author: [redacted]
Approver:
Page: 1 of 2

Vessel Name: [redacted] Location: [redacted] Master: [redacted]

Week: [redacted] Month: [redacted] Year: [redacted]

Day/Date	Start time	End time	Wind (dir & speed)	Swell (Significant)	Type of Exercise	Participants	Evaluation value	Comments
Monday, 16	18:30	19:00	SSE 5	5	Enclosed Space Entry and Rescue drill	A	9	Went through procedure for entering closed space. Mounted and tested lift for closed space.
Tuesday, 17	12:30	13:00	SE 4	5	Drill with Dacon scoop	A	8	Pick up dummy from water with Dacon scoop. Debriefing at bridge.
Wednesday ,18	10:25	11:25	S 3	3	DC training	M	8	DC on water, familiarisation, testing and manoeuvring
Thursday, 19	12:30	13:00	WSW 3	3	MOB drill	A	9	12:30 MOB Alarm, 12:31 Hospital ready, 12:32 FRC on water, 12:33 dummy onboard FRC, 12:35 FRC onboard own ship, 12:36 patient on the hospital. Debrief on bridge
Friday,20	18:30	19:00	NNE 7	4	Night search	A	9	Night search, searchlights, lookout, communication
Saturday, 21	12:30	13:00	NNE 5	4	Hospital drill	A	8	Treatment and transport of the person who has fallen and broke his leg and arm. Use of vacuum splint.
Sunday,22								

- The RR1 Exercise Log to be sent to the Operation Dep. at the end of each period when the vessel is in standby service
- First Aid Exercise or Safety drill to be held at least once per week
- Man overboard drill to be held at least once per week dependent on the weather conditions
- Fire drill/ Evacuation drill/ muster to be held at least once during the period
- If exercises are made impossible due to weather conditions, work operation etc., this must be noted in the Log/ Journal
- To be filed onboard for 24 months. 1 copy to Operation Dep.

Participants:

- A = All
- D = Deck Crew
- E = Engine Crew
- M = MOB/FRC/DC Crew

Evaluation value, between 1-10:

1= Unsuccessful

10= Most successful

Master's Signature:

Figure D.1: Exercise log example on SBV.

Appendix E

STEP - SAIPEM 7000 (2007) example

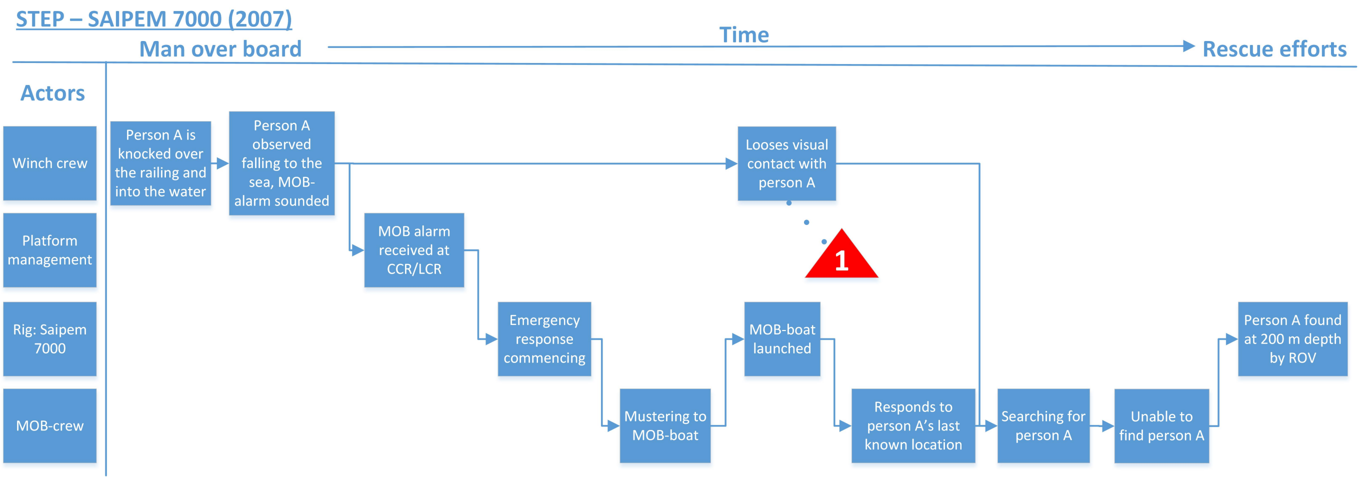

Figure E.1: A STEP analysis of a short time-period during the MOB emergency response.

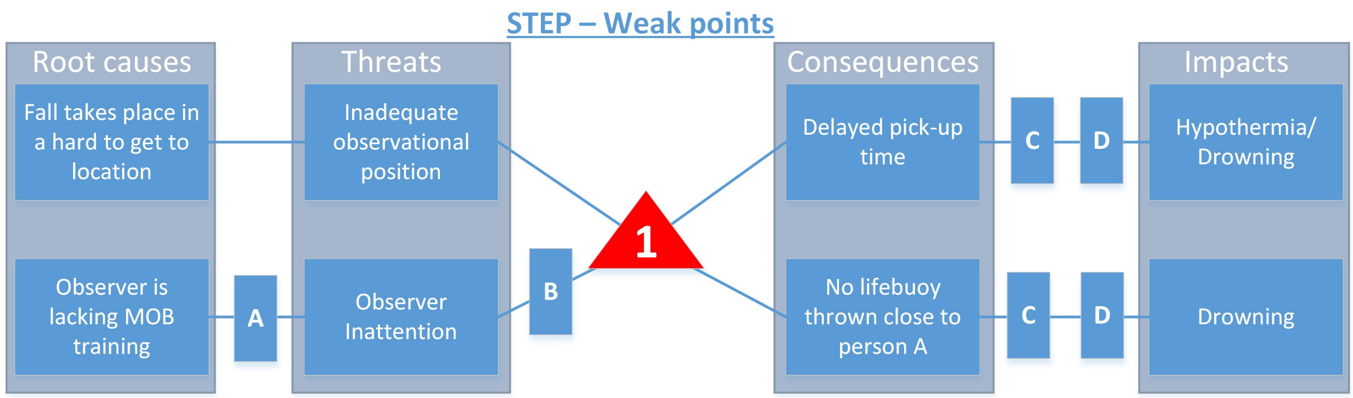

Figure E.2: Possible barrier functions for prevention and limitation of the "weak point": A - Provide sufficient training, B - Provide redundant observation, C - Provide bouyancy, D - Prevent exposure to the elements.

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Language Skills

- **Norwegian:** Native speaker
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Education

- **2013 - 2015** Norwegian University of Science and Technology; *Department of Production and Quality Engineering*

  Master of Science: Mechanical Engineering with specialization in RAMS

- **2010 - 2013** Østfold University College

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Experience

- **2014 - 2015** Dahles Auto Fredrikstad AS

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Hobbies and Other Activities

Participant in reference groups for courses at NTNU: TPK 5160, TPK 4135 and TPK 5170

Certificates:

- **2013** Short Range Certificate: VHF radio
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