NTNU – Trondheim
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Risk modelling of collision between supply ships and oil- and gas installations

Erik Fredheim Tvedt

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Supervisor: Jørn Vatn, IPK

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RAMS
Reliability, Availability,
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Risk modelling of collsions between supply ships and oil- and gas installations

A risk influence modelling framework

Erik Fredheim Tvedt

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MASTER THESIS
Department of Production and Quality Engineering
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Supervisor: Professor Jørn Vatn, IPK
Co-supervisors: Stein Hauge and Eivind Okstad, SINTEF Safety Research

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MASTER THESIS
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Risk modelling of collision between supply ships and oil- and gas installations

(Risikomodellering av kollisjoner mellom forsyningsfartøy og olje- og gassinstallasjoner)

Collisions between ships and oil-and gas installations are generally considered as a significant contribution to major accident risk in the industry. A wide range of methods have been published and are used in risk assessment related to ship transportation. The majority of these models focus on collision between installations and passing ships. These models are often driven by statistics, and not reflecting installation specific conditions, or conditions related to a particular operator of supply ships. The main objective of the work is to review and develop methods and models applicable for supply ships in a more explicit setting than many of the methods used in the industry today. Review of relevant incidents in the North Sea indicates events with a very high damage potential. Also the causal chains seem to be more complex than what is considered in existing models, at least what concerns quantification. Thus, development of new methods and models is required. The work to be undertaken shall build on work carried out in the project thesis by the candidate, where special emphasize shall be paid to:

1. Complete the literature from the project work whenever required.
2. Structuring the causal chains of collisions between field-related visiting vessels and offshore installations from investigation of incidents and other sources.
3. Identify and structure safety barriers relevant for relevant generic accident scenarios.
4. Identify risk influencing factors important to express the barrier failure probabilities.
5. Establish a risk model combining barrier failures, risk influencing factors and the state of risk indicators with necessary weights, strength of influences etc capturing the findings from the previous steps.
6. Test the model on one or more cases in collaboration with IO3-project where as far as possible the relevant model parameters are estimated and the state of risk influencing indicators assessed.

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

- An analysis of the work task's content with specific emphasis of the areas where new knowledge has to be gained.
- A description of the work packages that shall be performed. This description shall lead to a clear definition of the scope and extent of the total task to be performed.
- A time schedule for the project. The plan shall comprise a Gantt diagram with specification of the individual work packages, their scheduled start and end dates and a specification of project milestones.

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

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

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

The candidate shall follow the work regulations at the company's plant. The candidate may not intervene in the production process in any way. All orders for specific intervention of this kind should be channelled through company's plant management.

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

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

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

Deadline: 7 February 2014.

Copies of the final report are to be provided according to the regulations in the DAIM system.

Responsible supervisor:
Jørn Vatn
E-mail: jorn.vatn@ntnu.no
Phone: 41473730

Industrial contacts / Supervisors at Sintef:
Stein Hauge
E-mail: stein.hauge@sintef.no
Phone: 93018395

Eivind H. Okstad
E-mail: eivind.h.okstad@sintef.no
Phone: 93015869

DEPARTMENT OF PRODUCTION
AND QUALITY ENGINEERING

Per Schjølberg
Associate Professor/Head of Department

Jørn Vatn
Responsible Supervisor

Preface

This master thesis was written as the final part of the Master of Science programme in Reliability, Availability, Maintainability and Safety (RAMS) at the Norwegian University of Science and Technology (NTNU), Norway. It was written in collaboration with SINTEF Safety Reseach, and was carried out during the autumn semester of 2013.

The thesis is a development of a risk analysis framework for ship-platform collision risk. It is a continuation of the project thesis, that was a review of ship-platform collision models used in quantitative risk analyses.

Trondheim, 2014-02-09

Erik Fredheim Tvedt

Erik Fredheim Tvedt

Acknowledgment

I would first like to thank my supervisor, Professor Jørn Vatn at the department of Production and Quality Engineering (NTNU), for his help and guidance throughout the process of writing this report.

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Last, but not least, I would like to thank my girlfriend Ane Sofie Fremstedal. Her support, belief in me and helpful advices has been crucial to maintain a high spirit during the last few weeks of the thesis.

E.T.

Summary and Conclusions

This thesis is a framework for risk influence modelling of supply vessel-platform collisions, with the inclusion of central concepts from the Risk OMT model. The framework is a improvement from existing QRA frameworks in the sense that it has taken recent collisions into consideration, and enabled the opportunity to do risk influence modelling for the calculation of site specific risk. It can also be used as a tool for risk management, when the risk influences have been quantified. This model provides no quantifications, but it makes a good foundation for future work.

The thesis incorporates knowledge from recent, representative collisions on the Norwegian Continental Shelf (NCS), and considered the guidelines and official safety procedures. This has been used to make three generic collision scenarios are general enough to take all probable collisions into account and at the same time be specific enough to account for the chains of events in previous accidents.

These generic collision scenarios has been analysed with event tree analysis (ETA) and fault tree analysis (FTA) to identify and break down the operational barrier functions available to prevent collisions. A large set of risk influencing factors (RIFs) have been identified to be used to express the failure rate probabilities of the basic events found the FTA. These have been included from many different sources, to ensure that all significant RIFs are presented.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

From the Risk Assessment of Buoyancy Loss (RABL) project in 1980, vessels colliding into the platform were considered one of the three major risks for loss of buoyancy for offshore oil- and gas installations (Standing, 2003). Since then, there has been a large focus on avoiding collisions between the platforms and passing vessels. Monitoring and warning of all vessel activity in the proximity of oil- and gas installations from onshore surveillance stations have been successful measures. There have only been two collisions with passing vessel reported at the Norwegian Continental Shelf (NCS), a submarine in 1988 and a vessel in 1995 (Kvitrud, 2011).

However, risk of collisions between supply vessel and oil- and gas installations still have a major hazard potential. During the years of 1999 and 2000 there were 15 collisions each year (Kvitrud, 2011). Since then, the Norwegian Petroleum Safety Authority (PSA) have worked towards informing supply vessels to stop using the installations as navigational target for their autopilot navigation (Oltedal, 2012). Over the period 2001-2010 there have been a total of 26 reported collisions between supply vessels and offshore oil- and gas installations (Kvitrud, 2011). Of these accidents, six have had a major damage potential, exceeding the collision energy the installations were designed to handle. Luckily, there has been no loss of lives, even though the economic consequences have been large (Oltedal, 2012).

Reviews for the major accidents (Oltedal, 2012; Kvitrud, 2011) reveals that the accidents have different chains of events than what the quantitative risk analyses (QRAs) in use today take into account, when calculating the risks (Tvedt, 2013). The QRA methods are mainly derived from the RABL project, that was made for the purpose of estimating the risk of collisions with passing vessels (af Geijerstam and Svensson, 2008). This is a big weakness, as passing vessels-platform collisions are principally different from collisions between supply vessels and oil- and gas installations. One particular difference is that the vessels visiting the platform will be authorised by an offshore surveillance center, and will therefore not be warned if they sail on collision course towards the installation during their approach (ConocoPhillips, 2013). These issues emphasizes that the methods used to calculate the risk are not optimal. A new framework should be made, based on information about representative accidents and recent technological advancements.

1.2 Objectives

The main objectives of this thesis are

- Structure the causal chains of collisions between field-related visiting vessels and offshore installations.
- Identify and structure safety barriers for relevant generic accident scenarios.
- Identify risk influencing factors important for the expression of the failure rate probabilities.
- Make a risk analysis framework based on the findings of the previous steps and Risk OMT model.

1.3 Limitations

Risk modeling of collisions between supply ships and oil- and gas installations is a large field of study and several limitations have to be made. Most accidents happening are small collisions involving ships operating in the close proximity of the platform. Those collisions are principally different from those happing between vessels approaching the platform at high speed. Not only is the potential damage significantly lower, but as the vessels are controlled by a dynamic positioning (DP) system during this loading and unloading operation they will to a larger degree depend on technical navigation aids and will have less complex chain of events. The QRAs used to calculate the risks of these collisions are also of more recent origin and based on newer generic failure rates (Tvedt, 2013). The need for a new framework is therefore not present, so this thesis focuses on building a new framework for accidents not taken into consideration today.

As mentioned, this thesis aims to create a risk analysis framework using the principles of Risk OMT, but will not do the calculation process as there are lack of adequate data at the present time. For risk of collisions between offshore supply vessels and offshore installation there has been conducted several studies to identify risk influencing factors recently (Ali and Haugen, 2012; Dai et al., 2013), but there have been few attempts to quantify any influences. Proper estimation of both the influences and state of the risk influencing factors within the oil- and gas industry will require extensive amount of time and resources in form of expert judgements. Therefore, it has been decided that the focus of the thesis is limited to the making of the framework that can be used for risk influence modelling.

1.4 Structure of the Report

As the report aims to make a risk analysis framework based on the Risk OMT model, the reports will be structured as the steps in a risk assessment. Chapter 2 makes up the theoretical foundation with the introduction of relevant concepts used throughout the thesis. The chapter also provides a stepwise approach for a risk assessment using the risk influence modelling methodology. Chapter 3 shows an identification of safety critical tasks during the different phases of the supply vessel operations. This is connected to the review of the major collision incidents that happened from 2001-2010, which is presented in Chapter 4. The accident review forms the basis for generic collision scenarios made to cover all possible, relevant collisions between supply vessels and oil- and gas installations. Chapter 5 presents these generic collision scenarios. Chapter 6 and 7 provides a further analysis of one of the generic scenarios. These chapters shows the fault tree analyses of barrier functions in the collision scenario and identification of risk influencing factors, respectively. The last chapter provides a summary of the thesis, with a discussion, conclusions and recommendations for further work.

Chapter 2

Risk influence modelling

This chapter introduces the concept of risk influence modelling, and describes the more in-depth theory and terms used in modelling. The thesis uses the approach from risk influence modelling theory presented by Vatn (2012) and from the Risk OMT-papers by Vinnem et al. (2012) and Gran et al. (2012a) to create a risk assessment framework for vessel collisions with off-shore oil- and gas installations, and puts the Risk OMT theory in a historical context by shortly describing the methods leading up to its development. In the end of the chapter the approach used in the rest of the thesis is described and some of the challenges encountered during these steps.

2.1 Introduction

A standard risk model uses formal probabilistic methods like fault tree analysis and event tree analysis to capture the course of events in the various accident scenarios (Vatn, 2012). By using the formal logical structures of these methods, a risk model tries to include all causes and chains of events when estimating the risk. A weakness of such models is that they cannot take into account relations influencing the basic events. Risk influence modelling is then an extension of the primary risk model, with methods for assessing these relations. Thus, it aims to obtain a more realistic risk picture.

Vatn (2012) argued that there are many reasons to do risk influence modelling. One of the most important reasons is to get a more realistic risk picture taking "soft" factors into account. Ideally we want to include all factors that have a signifcant effect on the error probabilities in the formal model. For example the level of competence is assumed to influence the error probability of a critical task, but we cannot model this by for example fault tree analysis.

Another reason is to gain more insight into risk influencing conditions through the analysis (Vatn, 2012). Since making a risk influence model constitutes identifying risk influencing factors (RIF), it forces the analyst to look closer into the failure mechanisms and basic events of the model. From a risk management perspective, knowledge of these factors can also help eliminate certain risk factors completely.

A third reason is to better take into consideration the effect of risk reducing measures in the risk models. For example the risk of vessel collisions with offshore oil- and gas installations has received a lot of focus during the last ten years (Kvitrud, 2011), and several possible risk reducing measures have been suggested (Andersen, 2013). However, since the models used to estimate the risk contains generic failure probabilities based on old statistical data, it will not have an effect on the estimated risk (Tvedt, 2013). Linking these "soft" factors explicitly to the risk picture through risk influence modelling will enable the quantification of the effect of risk reducing measures. Then it is possible to obtain an installation specific risk.

Quantitative risk analyses (QRAs) are typically updated every five years (Vatn, 2012). But risk influence modelling can be a tool to achieve a "living" risk picture without updating the entire QRA. By establishing a framework with influencing factors, it is possible to track changes in the risk level through values of corresponding risk indicators.

2.2 Theory and terms used in risk influence modeling

2.2.1 Safety barriers

Safety barriers is vital in the petroleum industry, and in society in general, to protect humans and property from hazards and accident. However, the term safety barrier has been the cause of confusion, since it has been used in several contexts with different meanings. The understanding of the term safety barrier has been ranging from the classical understanding, the energy model shown in Figure 2.1 (Gibson, 1961; Haddon, 1980; Sklet, 2006), to Hollnagel (2004) defining modern principle of safety barriers as everything from protection against release of radioactive material to event reporting and safety policies. There are also several names used for safety barriers in the literature, with the same meaning: countermeasures, defence measures, lines of defence, layers of protection, safeguards, and safety critical systems (Sklet, 2006; Rausand, 2013).

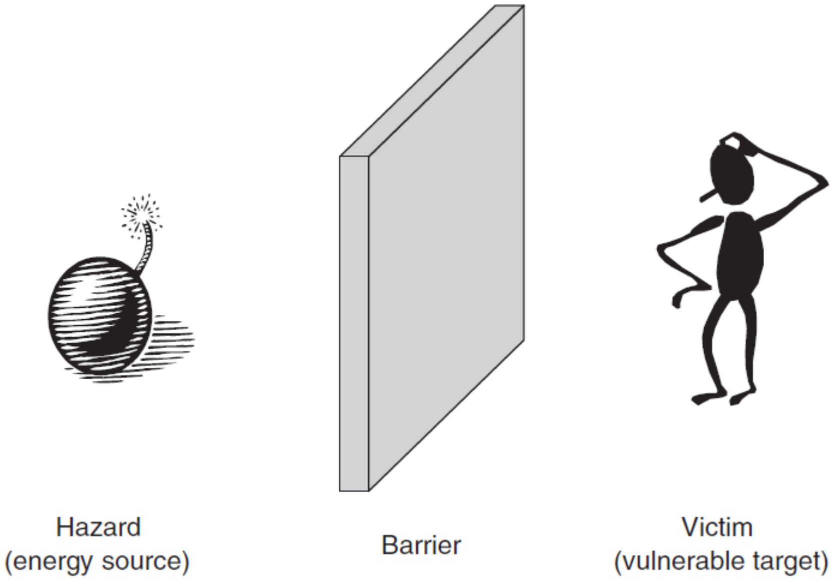


Figure 2.1: Classical understanding of safety barriers (Sklet, 2006).

To reduce confusion Sklet (2006) then proposes defintions for the terms related to the safety barrier concept; safety barrier, barrier function and barrier system. These definitions are similar to the terms the Petroleum Safety Authority PSA (2013), uses in the barrier management guideline, and are considered standard in the industry today.

☞ **Safety barrier**: Technical, operational and organisational elements which individually or collectively reduce opportunities for a specific error, hazard or accident to occur, or which limits its harm/drawbacks (PSA, 2013).

This definition makes safety barrier a very wide term and almost all measures to increase safety can then be interpreted as barriers, not considering the extent of their safety effect. A safety barrier can range from a single technical unit or human action, to a complex socio-technical system (Sklet, 2006). But the defintion also implies that organisational elements like competence building and safety culture can be considered safety barriers. However, having a clear distinction between safety barriers working directly to prevent accidents and safety barriers preventing accident more indirectly is very important when doing risk influence modelling.

☞ **Barrier function**: The job or role of the barrier. Examples include preventing leaks or ignition, reducing fireloads, ensuring acceptable evacuation and preventing hearing damage (PSA, 2013).

Barrier functions describe the purpose of safety barriers or what the safety barriers shall do in order to prevent, control, or mitigate undesired events or accidents (Sklet, 2006). A barrier function should have a direct and significant effect on the likelihood of an undesired incident, otherwise it should be defined as a risk influencing factor.

☞ **Barrier system**: A system that has been designed and implemented to perform one or more barrier functions (Sklet, 2006).

☞ **Barrier element**: Technical, operational or organisational measures or solutions that takes part in the realisation of a barrier function (PSA, 2013).

For modelling purposes, it is required to describe the measures needed to perform a barrier function. For a top-down approach this can be done by doing fault tree analysis (FTA) for a given barrier function. A barrier function consists of one or more barrier systems and these barrier systems often consists of several barrier elements. In a fault tree the barrier elements on the lowest levels are called basic events. The barrier system may also comprise redundant barrier elements where failure of one of them does not necessarily mean failure of the whole system (Sklet, 2006).

Barrier system can also be classified in several different ways. Sklet (2006) uses a distinction between *active* and *passive* barriers. Active barriers are dependent on the actions of an operator, a control system and/or some energy sources to perform their function. Passive barriers are integrated into the design of the workplace and do not require any human actions, energy sources, or information sources to perform their function. Figure 2.2 shows the classification of barriers in a detailed manner. One example of a barrier function performed to avoid vessel collisions with offshore oil- and gas installations is the monitoring of the vessel's approach to the platform. This is done by actively maintaining a continuous surveillance as there are no built-in passive barriers to do the monitoring. The barrier system then comprises the technical equipment, radar and automatic identification system (AIS), which is an automatic tracking system used on ships and by surveillance stations, and the human/operational part of human intervention with the technical equipment in addition to visual lookout in the sailing direction. A vessel that has both radar and AIS is considered to have redundancy in the technical monitoring equipment, and an incident where one of them has failed does not mean a failure of the system. However, the human/operational intervention is needed to have a successful monitoring.

2.2.2 Risk influencing factors

A risk influencing factor (RIF) may be defined as an aspect of a system or an activity that affects the risk level of this system/activity (Øien, 2001b). Since the influence of a RIF is indirect, we always assume that the RIFs work through parameters in a risk model (Vatn, 2013). For example, the performance of watchkeeping can be influenced by bad weather conditions, personnel

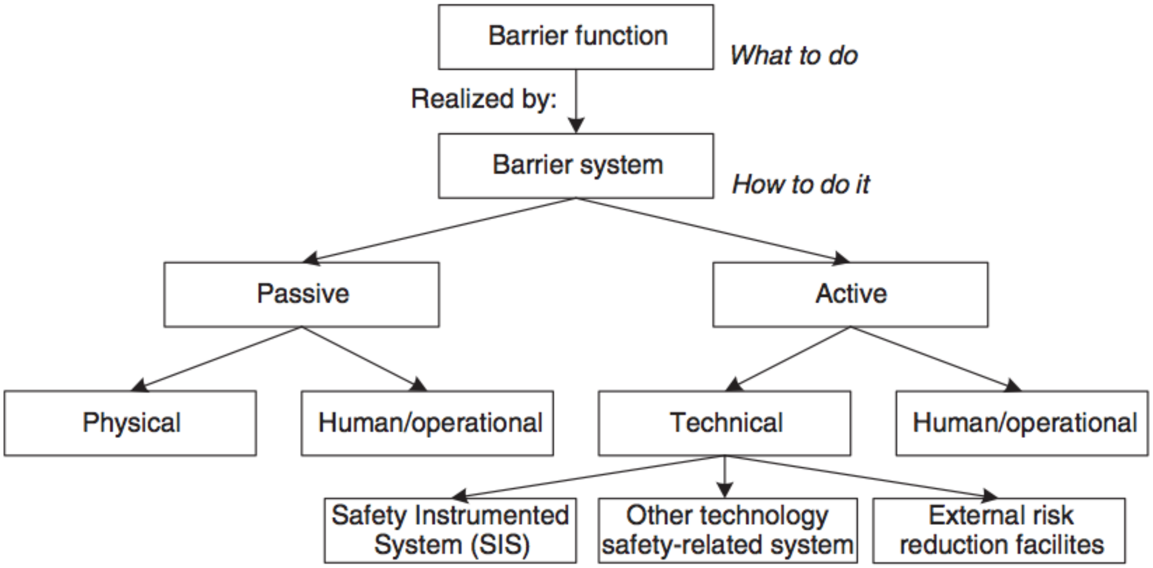


Figure 2.2: Classification of safety barriers (Sklet, 2006).

competence, workload, and so on (Dai et al., 2013). It may be efficient to first identify RIFs in specific categories, such as human characteristics, task specific factors, system characteristics, environment and organisational factors (Ali and Haugen, 2012; Dai et al., 2013).

A theory is that risk control can be achieved through control of the RIFs (Vinnem et al., 2012). This is, however, dependent on three conditions:

1. All relevant RIFs are identified. This means that all RIFs that have a significant impact on the outcome of a basic event will have to be included in the model.
2. The RIFs are "measurable". This must not be thought of as a quantifiable measure, but more of a relative score. I.e. competence is not quantified, but rather scored relative to average of the industry. It can still be a challenge for many RIFs, as especially organisational factors like safety culture can be hard to measure.
3. The relationship between the RIFs and the risk is known. This relates to the RIFs influence on the basic events in the model.

It is always assumed that the RIFs are affecting the risk at the bottom level, at the basic event level of a risk model. According to the safety barrier classification from the previous section this will be the technical, human/operational or physical barrier elements.

Related to the implementation of RIFs in the modelling are also the terms *weights* and *scores*. The weights are a measure of the importance of a RIF, how strong influence the RIF has on the probability of a failure. The weighting of the RIFs has to be set by expert judgements (Gran et al., 2012b). The scores are the "goodness" of the RIF compared to an industry average. The common method is to use a scale for the scores, where the middle point in the scale represents the industry average for that particular RIF.

2.3 Development of Risk OMT framework

Many different approaches to introduce human and/or organisational factors in risk analysis have been made (e.g., ORIM (Øien, 2001a) and WPAM (Davoudian et al., 1994)). This thesis focuses on the Risk OMT framework, and is therefore only describing the two methods the framework is based upon; BORA (Aven et al., 2006) and OTS (Sklet et al., 2010). Figure 2.3 shows the relations between these concepts.

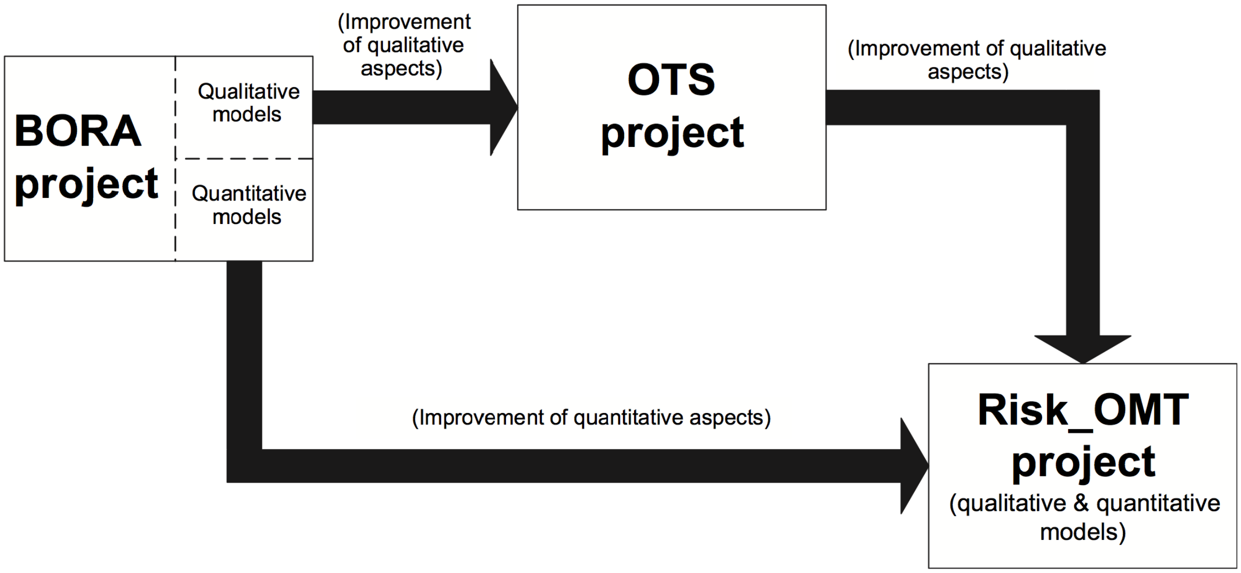


Figure 2.3: Relationship between BORA, OTS and Risk OMT (Gran et al., 2012a).

2.3.1 Barrier and Operational Risk Analysis

The Barrier and Operational Risk Analysis (BORA) project was a research project from 2003 to 2006. BORA focuses on analysing barriers in the operational phase of oil- and gas installations, particularly hydrocarbon release scenarios (Rausand, 2013; Aven et al., 2006). The method has also been used for analysing the risk of collisions between supply vessels and offshore installations (Ali and Haugen, 2012). The objective with the research project was to incorporate human, operational and organisational factors in qualitative and quantitative risk analyses, in addition to technical factors, to address the barrier situation in detail (Gran et al., 2012a). The BORA method consists of several steps (Aven et al., 2006). It starts with the development of a formal probabilistic model and the modelling of the performance of safety barriers. These steps are done through a barrier block diagram (BBD) and fault tree analysis (FTA). After that follows an assignment of generic input data and risk quantification to the initiating events and the basic events. The generic input can be both technical failure rates and human error probabilities. These values represent the industry average for the basic events and initiating events.

The next step is to identify the RIFs influencing the basic events through development of risk influence diagrams. Figure 2.4 shows an example of a risk influence diagram where communication, methodology, procedures for leak test, competence are RIFs that are influencing the probability of the basic event, failure to detect leak in the leak test. After the RIFs are identified they are scored on a scale from A to F, where A is the best and F the worst. These scores are a comparison to the industry average, which is graded C. The RIFs are weighted in a five point scale after their importance, and then given a relative weight so that the sum of the influences for a particular basic event will be 1. The scoring and weighting of the RIFs are used to adjust the generic input data and thereby recalculate the risk to get a site specific risk.

2.3.2 Operational Condition Safety

The Operational Condition Safety (OTS - Norwegian acronym) is a proactive method for monitoring of the status of human and organisational factors influencing the risk of major accidents on oil and gas installations (Sklet et al., 2010). It was a joint industry project in the research

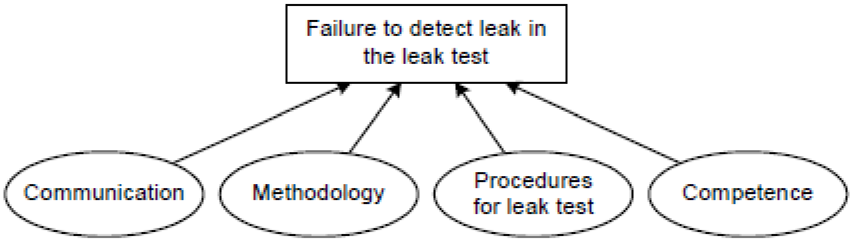


Figure 2.4: Example of risk influence digram (Aven et al., 2006)

field of risk management and from the oil- and gas industry. An OTS-verification is systematic and independent assessment of the status on several factors influencing the operational safety barriers. The assessment method comprises seven performance standards; work practice, competence, procedures and documentation, communication, workload and physical working environment, management and management of change. By conducting surveys and interviews the method aims to compare location specific practice to the set of standards. Then a qualitative description of the performance is given, in addition to grading on a scale from A-F, as mentioned in the previous section (Sklet et al., 2010).

2.4 Risk assessment using the Risk OMT framework

Risk modelling - integration of organisational, human and technical factors (Risk OMT) is a framework developed to provide new knowledge and tools for major hazard risk management for installations and plants, based on improved understanding of the influence of organisational, human and technical factors (Gran et al., 2012a). The project was under development from 2008 to 2011. The Risk OMT program is a further development of the methods presented in the BORA and OTS project, as seen in Figure 2.3.

There are two major changes in the Risk OMT model compared to the BORA model (Vatn, 2013). The first one is the different structuring of the RIFs. The BORA model combined the RIFs on the same level, as Figure 2.4 shows. All the RIFs have a direct influence on the failure probability of the basic event. In the Risk OMT model the RIFs are structured in two levels where the level "closest" to the basic event level represents factors having a direct influence on the failure probabilities (Gran et al., 2012a). Figure 2.5 shows this hierarchy. While the RIFs on the first level can be factors like competence, workload and time pressure, all RIFs on level two are related to management, for example competence management and safety culture. Only the RIFs on level one are affecting the basic events. However, the second level RIFs are considered to influence the basic events via the RIFs on level one. These may be regarded as means to reduce the uncertainty implied by observations of RIFs on level one (Gran et al., 2012a).

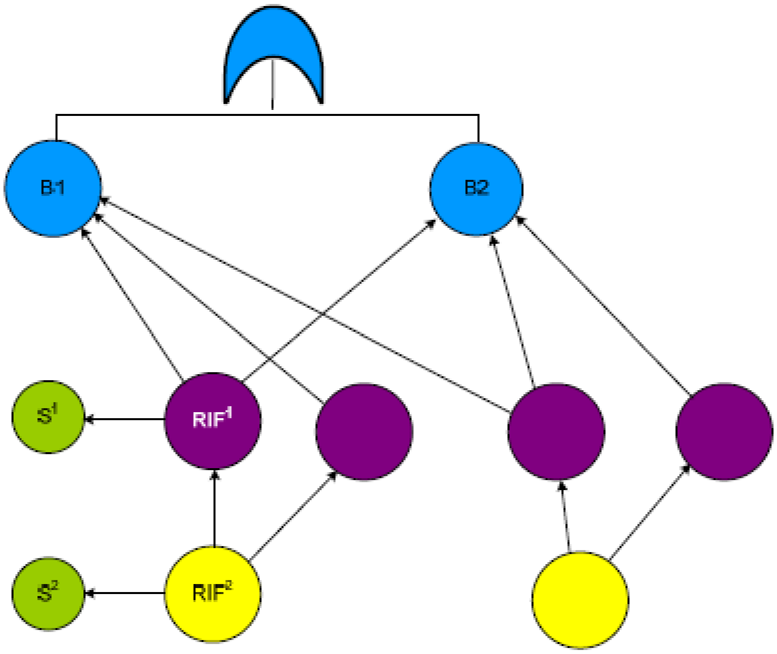


Figure 2.5: RIFs on two levels with scores and relation to basic events in a fault tree (Vatn, 2013).

Risk assessment is the process of assessing the risk picture. Essentially this means to identify relevant hazardous events of concern, to represent the corresponding values threatened in terms of a set of end consequences, and the uncertainty involved usually expressed by probabilities (Vatn, 2012).

The risk assessment starts with a description of the system being analysed. In this case, that is the supply vessel operation from the vessel starts planning the sailing to the installation, until it arrives at the installation. Chapter 3 shows a description of the supply vessel operations with guidelines and checklists for safe procedures. The next part of the initial assessment is the identification of relevant primary causes and underlying factors causing the collisions. This is done through a review of recent major collisions with respect to causal chains, seen in Chapter 4.

After this, the modelling can start. Here, a probabilistic model is used. A probabilistic model is a model that enables the risk analyst to apply the law of total probability in an efficient way when expressing uncertainty (Vatn, 2012). The modelling tools that are used are formal probabilistic risk analysis techniques like event tree analysis (ETA) and fault tree analysis (FTA). First, a few generic scenarios assumed to be representative for most accidents are made, and further described with the use of ETA. Figure 2.6 shows how this is done in Risk OMT. The scenario starts with an initiating event that marks the start of the scenario. Then, each event is described with a barrier function, and the branches represent the outcome (e.g., if the function has been successful or not). The barrier functions are broken down into barrier systems and barrier elements, before arriving at basic events at the bottom level. Assigned to the basic events will also be a RIF structure as discussed above, and shown in Figure 2.5.

Figure 2.7 shows how a fault tree is structured using the Risk OMT model. All human errors are broken down into *failures of omission* and *failures of execution* (Vatn, 2013). Failure of omission denotes whether or not the prescribed activity is carried out. Failures of execution are inadequate actions that may cause failures, and is the results of either *human errors* or *violations*. Human errors can be further broken down into *mistakes* and *slips and lapses*.

To do risk influence modelling all relevant RIFs need to be identified. For the Risk OMT framework a generic RIF model for execution and control activities was made, shown in Chapter 7.2. This needs to be combined with a set of RIFs specific for conditions and tasks onboard the supply vessels to create a RIF structure for the entire model.

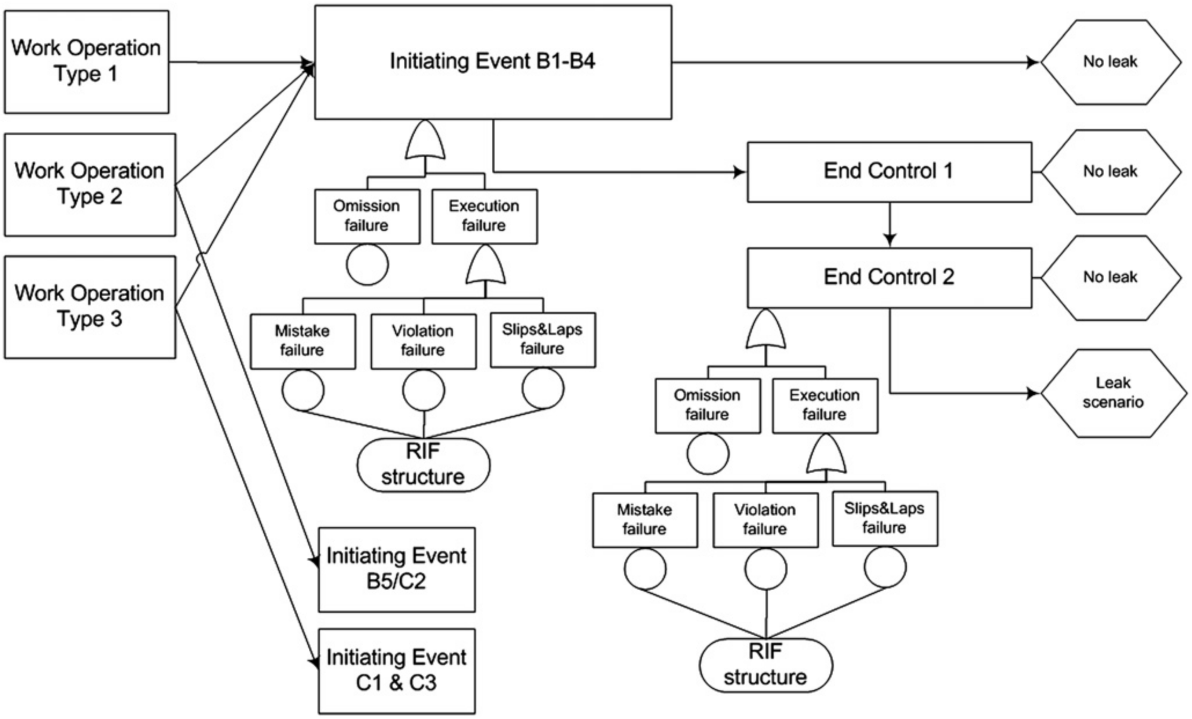


Figure 2.6: Modelling principle for leak scenarios in Risk OMT (Vinnem et al., 2012)

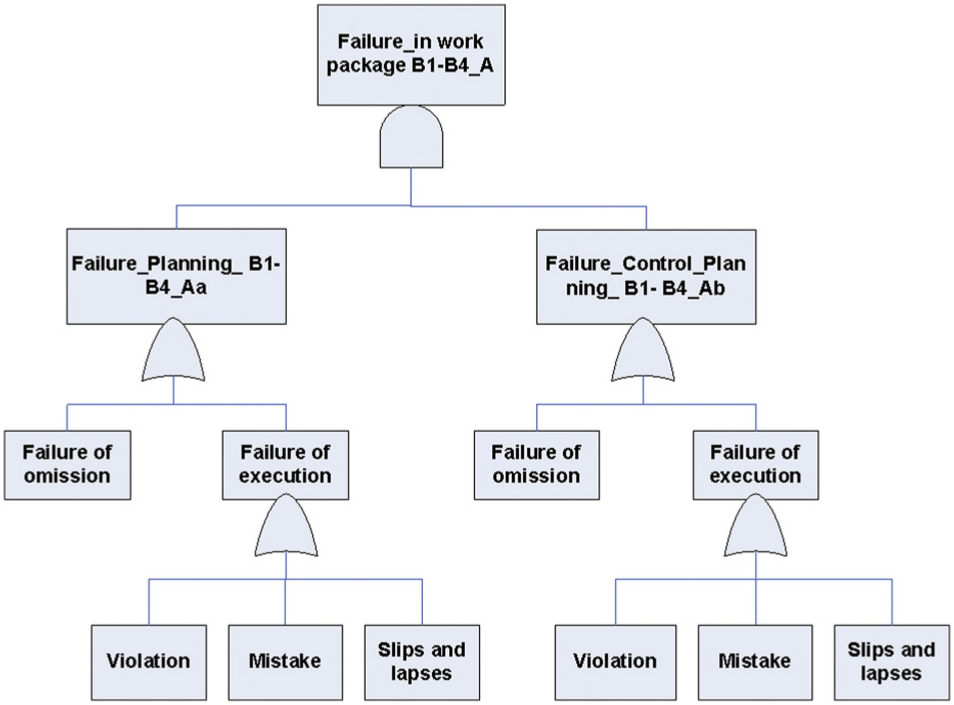


Figure 2.7: Example of a fault tree using Risk OMT (Vinnem et al., 2012)

Chapter 3

Supply vessel operations

This chapter introduces the procedures of the supply vessel operations, with both focus on guidelines for safe operations, and the operational handling of potential collisions. This provides a short background of the tasks that should be performed at each phase of the supply vessel operation. Deviations from any of these tasks can create dangerous situations, but in most cases a chain of events including many errors are causing the collisions. To give a better overview of safety-critical tasks, an examination of the observable activities associated with the execution of a required task or piece of work, also known as a task analysis (Rausand, 2013), is provided for each phase.

3.1 Overview

A supply vessel is designated to the provide supplies for offshore installations. The vessel loads it's supplies at an onshore base, and then it sails to one or more offshore platforms to unload cargo and load up return cargo before it sails back to the onshore base. Vessels in the Norwegian Continental Shelf use Dynamic Positioning (DP) system for the operations close to the platform, which is a computer-controlled system to automatically maintain the vessel's position or heading, considering the effects of wind and currents (Kongsvik et al., 2011). The DP system will not be turned on during the voyage to the platform, but is prepared during the approach outside a 500-metre safety zone around the installation (NWEA, 2009). When sailing to the platform the vessel will instead use autopilot to navigate to a predetermined destination close to the installation.

Since the vessel is sailing to the installation and thus will have a high probability of being on collision course with its destination, a safe and standardized set of procedures and industrial guidelines for the supply vessel operations have been made by North West European Area NWEA (2009). Together with a series of interviews conducted by Kongsvik et al. (2011) this is the main source of information in the presentation of the operations.

3.2 In port (voyage planning)

Before a supply vessel can leave the port, an extensive voyage plan must be undertaken to ensure the safety and cost-effectiveness of the operations. The planning phase will include a plan of the placement of cargo to reduce the time spent at the installation. Also, planning of the route must be done, both considering the weather conditions at the site and setting the correct "way-point" for the autopilot. Especially setting the "way-point" at a side of the installation, outside the 500-metre safety zone around the platform is important. Many accident have been caused by a "way-point" being set directly at the installation, and this is something the Petroleum Safety Authority (PSA) have focused on in the recent years (Kvitrud, 2011). To reduce the probability of technical failures during the sailing testing of technical equipment onboard should be done at a regular interval to detect and repair latent errors before departing from port. Figure 3.1 shows a hierarchical task analysis of the most important aspects of the planning phase.

3.3 Surveillance around the 500-metre safety zone

Around the offshore oil- and gas installation a 500-metre safety zone have been defined. This is a circular area with a 500 metre radius from the platform. The purpose of the zone is to control the traffic around the platform, and thus reduce the number of potential collisions. The traffic around the safety zone is monitored from an onshore surveillance center, or in some cases from an offshore control tower. The surveillance center is paying attention to the course of all vessel that have automatic identification system (AIS) onboard, and alarms will go off if they are sail-

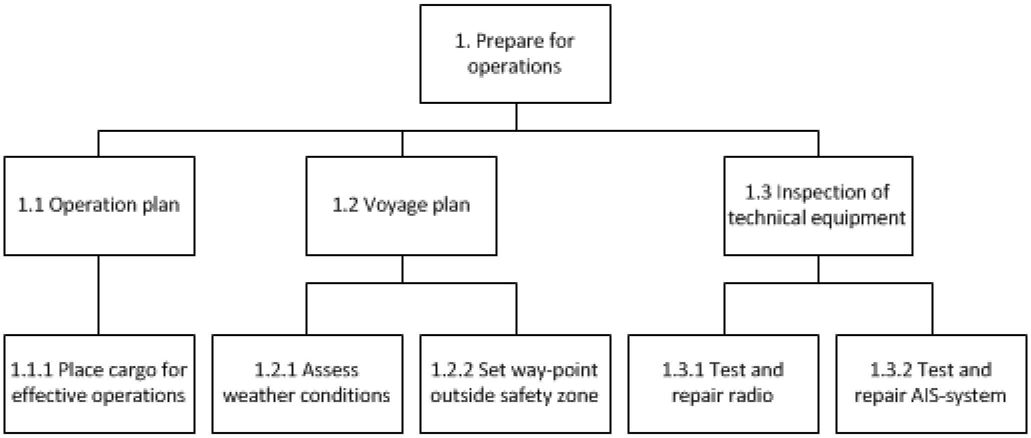


Figure 3.1: Hierarchical task analysis of the voyage planning.

ing directly towards an installation. This surveillance is mostly directed towards passing errant vessels and other irregular traffic, but supply vessels sailing directly towards the platform will also be contacted. However, supply vessels will get permission to enter the safety zone and thus be authorised for sailing close to the platform without any alarms going off (ConocoPhillips, 2013). There is also surveillance from a standby vessel at the installation, but Kongsvik et al. (2011) reports that this is not always used as a barrier. Figure 3.2 shows the tasks summarised in a hierarchical task analysis.

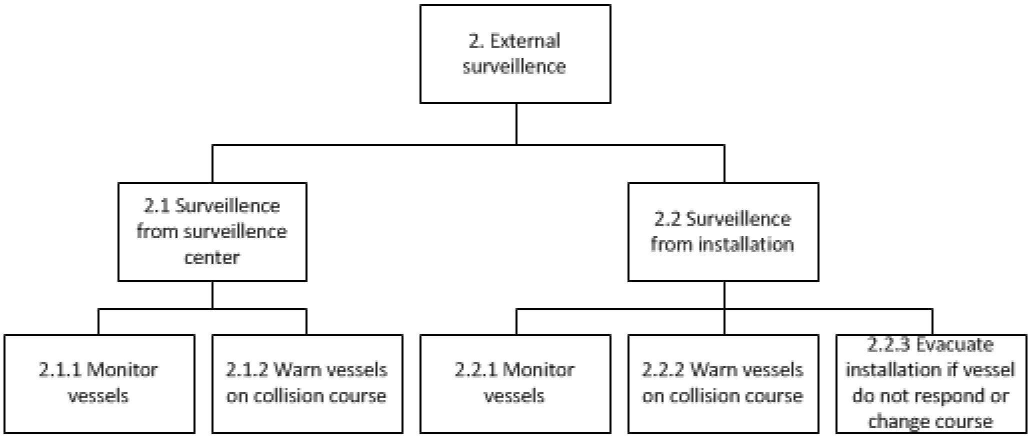


Figure 3.2: Hierarchical task analysis of external surveillance of the vessel.

3.4 Approaching safety zone

The supply vessel establishes communication with the surveillance center and installation approximately one hour before arrival Ali and Haugen (2012). Permission to enter the safety zone must be sought from the installation by the vessel, and permission cannot be granted until both vessel and installation have completed and passed the pre-arrival checklist (see Figure 3.4) . The checklist is prepared internally and includes checking for failures in technical equipment and clarifying responsibility onboard the vessel. After this the monitoring of a potential collision course is left to the crew onboard the vessel. This can be critical during the point of turning off the autopilot and changing direction towards the platform. Before entering the safety zone a number of safety assessments should be conducted by the vessel crew. They shall consider wind and waves at the destination to decide whether safe operations can be undertaken. This is often done through a risk assessment or a Job Safety Analysis (JSA). Clarifying roles and responsibility of the crew members on the bridge is also a part of the preparation before entering the safety zone. The most important tasks for the crew in the phase of approaching the safety zone is shown in the hierarchical task analysis in Figure 3.3

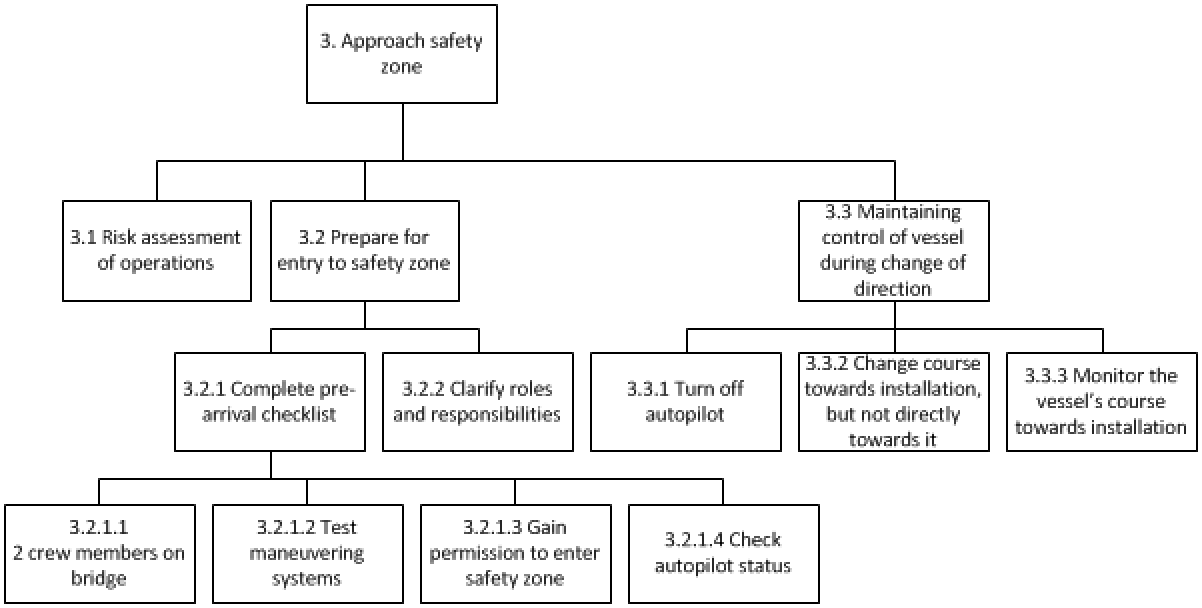


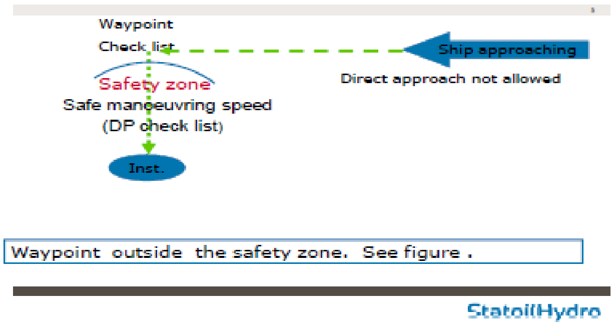
Figure 3.3: Hierarchical task analysis of the approach to the safety zone.

3.5 Pre-arrival checklist

The pre-arrival checklist is a form that should be filled out by responsible personnel onboard the incoming vessel before permission to enter the safety zone is given. The form contains 14 checks to be performed to ensure safe operations in the proximity of the platform. Figure 3.4 shows a version of a pre-arrival checklist made by NWEA (2009), but other companies may use other forms where more points are added to the list. The form includes checking if sea and weather conditions are acceptable for safe operations, bridge manned with two persons and engine room with at least one person, communication established, hot work finished, autopilot deactivated, maneuvering and emergency maneuvering systems tested and details of operation agreed with installation. If the operations is to be performed in DP-mode, a seperate DP-checklist must also be controlled and filled out.

3.6 Arrival at installation

Inside the safety zone, there must be two persons present at the bridge at all times for redundance in the navigation phase. Since the vessel should manually navigate inside the safety zone, one person should be on constant lookout and the other person responsible for the steering of the vessel. Before the ship is positioned by the installation to unload cargo, a clear agreement on how to proceed with the operation must be made between vessel and installation. The vessel must slow down and maneuver to a safe position at least 50 meters away from the installation. When the personnel in charge at the platform is confident that the intended operations can be carried out the vessel can move towards the operating position at speed less than 0.5 knots. Figure 3.5 shows a summary of the tasks related to arrival at the installation in a hierarchical task analysis.



Waypoint outside the safety zone. See figure .

Vessel		
Field installation		
Date/time	Date:	Time:

	CHECKS TO BE CARRIED OUT BEFORE ENTERING 500 M SAFETY ZONE	**Status Yes/No**		*Comments*
1	Sea/weather conditions acceptable for a safe operation			
2	Limitations due to sea/weather condition			
3	Safe direction of approach towards installation evaluated			
4	Bridge (2 man) and Engine room(1man) manned at all times inside 500m			
5	Communication established			
6	No hot work/smoking on deck within 500 m zone			
7	Auto Pilot off			
8	All manoeuvring and steering gear systems tested including changeover between control positions and manoeuvring modes.			
9	Emergency manoeuvring system tested			
10	Working side confirmed with installation – if weather side RA to be performed			
11	Load operations (cargo, bulk, fluid) confirmed with installation *(CHERRY PICKING is not permitted)			
12	Installation to confirm readiness for vessel arrival and operation (inclusive no overboard discharge)			
13	Manoeuvring mode during the operation to be agreed. If DP mode DP checklist to be used in addition.			
14	On-going and/or planned activities within 500 m zone confirmed between installation, vessel and ERRV (if in attendance)			
15	Permission for entering the safety zone obtained			Date: Time:

Figure 3.4: Pre-arrival checklist from NWEA (2009).

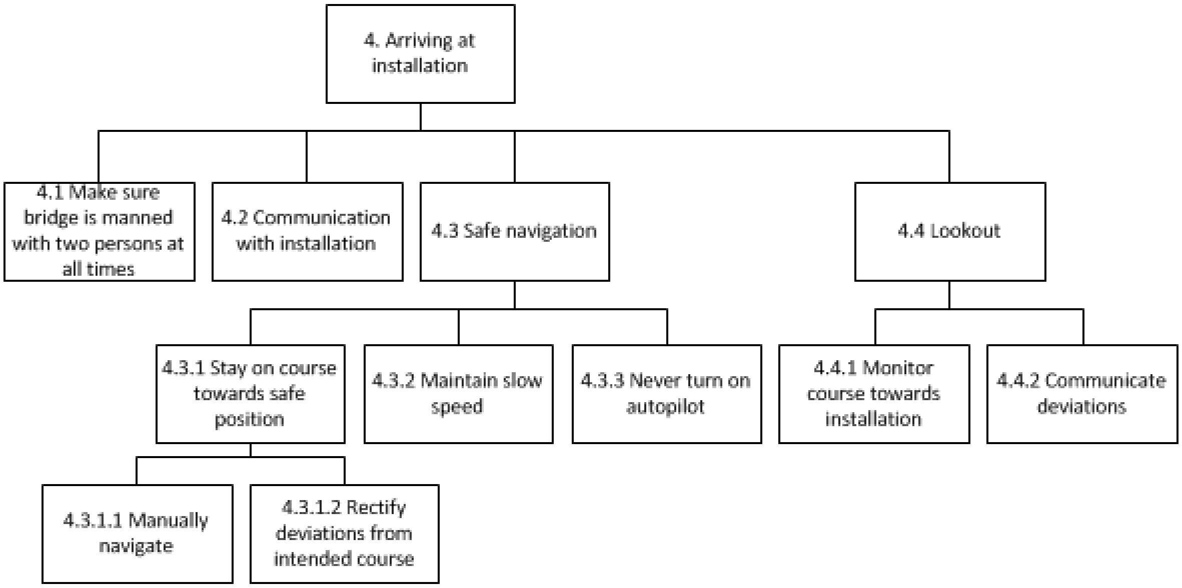


Figure 3.5: Hierarchical task analysis of the navigation inside the safety zone.

Chapter 4

Collision accidents in the period 2001-2010

There have been 26 collisions between platforms and ships on the Norwegian Continental Shelf (NCS) in the period 2001-2010 (Kvitrud, 2011). Most of these collisions have been small incidents causing minor impacts, and none of them have caused loss of lives or personal injuries. However, six of these collisions have been considered to have a very large hazard potential and had significant economic consequeces (Oltedal, 2012). Two of the accidents happened during operations close to the platform. In those cases it was mainly the big displacement of the vessel that caused the large damage potential. Since this thesis focus on the risk of collision when a vessel is approaching the installation, those accidents have been excluded. The following is a presentation of the four serious accidents that have happened during approach to the installations since 2001 as presented by (Kvitrud, 2011; Oltedal, 2012).

4.1 Classification of failure causes

In the literature, different terms have been used to classify the failures that directly and indirectly lead to an accident.Oltedal (2012) uses direct and underlying causes. Kvitrud (2011) uses the wider term, main causes, for all failures leading directly or indirectly to the collisions. Kongsvik et al. (2011) describes the causes as triggering cause and contributing cause. In this thesis the following two terms are used;

☞ **Primary cause**: A direct cause to the accident, without this the accident would not have happened. For a given accident there can be more than one direct cause. Typical primary causes can be "Set way-point to platform" or "Autopilot not switched off during approach".

☞ **Underlying factors**: Failures that did not directly cause the accident but rather influenced one of the primary causes. Typical underlying factors can be "500-metre safety zone checklist not completed" or "Lack of familiarity with emergency steering".

The term of primary cause is used in this chapter mostly, but it has a clear relation to other terms in the risk analysis framework. For most accidents the primary cause or at least one of the primary causes are related to the tasks defined when the operations are assessed. In this case it is the tasks in the hierarchical task analysis in Chapter 3. The reason that not all primary causes necessarily have a connection to the tasks described is that the tasks defined are measures to prevent situations where emergency preparedness is needed, and not covering all consequences of failures of a task. In a probabilistic model the primary causes are often failures of basic events of the barrier functions implemented to prevent the accidents, but given very specific barrier functions they can also be directly related to those.

By knowing how primary causes are related to the barrier functions and basic events and how RIFs influence the probabilities of failure of the basic events, it is easily seen from the definition of underlying factors that RIFs and underlying factors are similar. The difference between the underlying factors and the RIFs is that the underlying factors are failures that have happened and can be seen as an outcome of a RIF condition, whereas a RIF is defined as an aspect that affects the risk level of a system/activity (Øien, 2001b). For example if "not performing pre-arrival checklist" is a underlying factor, then "performing checklist" and "organisational safety culture" can be RIFs at level 1 and level 2, respectively. Knowing this, connecting the underlying factors to the primary causes in the accident review can then make the identification of RIFs in Chapter 7 easier. The connection is made in the tables throughout the accident review, where the underlying factor had an influence on the primary cause in the same row.

4.2 Far Symphony collision with West Venture Semi in 2004

The Far Symphony vessel was approaching the 500-metre safety zone around the installation at night during normal operation. As stated in standard procedures and guidelines the vessel was supposed to disengage the autopilot and switch over to manual steering. According to investigation report, this was not done. When the vessel then continued towards the installation, the officer on watch tried to reduce the speed. Since the autopilot overrides manual steering when it is turned on the vessel did not slow down from this maneuver, but rather increased it's speed. The crew was not aware of the fact that the autopilot was left on, and did not understand why the vessel did not respond as normal. A short time later the vessel hit the column of the semi with a speed of 3.7 m/s.

The identified primary causes of the collision in the investigation report were that the autopilot was not switched off, and defective error detection from the navigator. There were also several other underlying factors that influenced the primary causes. The 500-metre checklist was signed as completed, but this could not have been done correctly as this would have detected the autopilot status (Oltedal, 2012). In addition, it was conluded that lack of understanding of the autopilot led to the defective error detection. It should also be noted that the vessel being on collision course was not a result of waypoint set for the installation, but rather that wind and waves brought the ship off the intended course (Kvitrud, 2011).

Oltedal (2012) mentions that lack of system understanding, lack of familiarity with emergency steering, non-compliance with procedures and drifting operational practice as underlying factors. Kvitrud (2011) points out that the vessel was about three months old, and the crew had insufficient training and understanding of the vessel's maneuvering systems.

4.3 Ocean Carrier collision with the bridge at Ekofisk in 2005

In dense fog the vessel Ocean Carrier was approaching Ekofisk. The visibility was estimated at about 100-150 meters. 20 minutes before the accident the captain entered the bridge. Without any formal transfer of command there was confusion as to who was responsible for the navi-

Table 4.1: Accident causes of "Far Symphony" with related task numbers in brackets.

Accident causes - Far Symphony	
Primary causes	**Underlying factors**
Autpilot not switched off inside safety zone [3.3.1]	Not performing pre-arrival checklist [3.2.1]
	Non-compliance with procedures
Defective error detection	Lack of familiarity with emergency steering
	Lack of system understanding

gation. The captain thought the second navigator to be in command, but the second navigator assumed that the navigator had taken over the command. As a result of this confusion and the heavy fog, the dangerous situation was detected too late. When the captain saw the platform, he slowed down, but he could not avoid a collision. At a speed of about 3 m/s Ocean Carrier hit the bridge at Ekofisk. The incident had a very large damage potential, but the bridge suffered only minor damage (Kvitrud, 2011).

Oltedal (2012) reports inappropriate transfer of command and unmonitored approach as the primary causes for the collision, and not performing the 500-metre checklist as an underlying factor as this could have detected and prevented the other failures. Other underlying factors identified were communication failure, non compliance with procedures, attention to paperwork, unclear division of responsibilities and drifting operational practice. The investigation report by ConocoPhillips (2005) concludes the following causes, classified as main causes:

- Inadequate communication on the bridge due to changes in procedures at Ekofisk.
- Lack of communication at the handover of command on the bridge, roles and responsibilities.
- Weakness in navigation practices with bad visibility.
- Incomplete compliance with governing documents in relation to the safe zone.

Table 4.2: Accident causes of "Ocean Carrier" with related task numbers in brackets.

Accident causes - Ocean Carrier	
Primary cause	**Underlying factors**
Unmonitored approach [3.3.3] and [4.4.1]	Inappropriate transfer of command
	Non-compliance with procedures
	Not performing pre-arrival checklist [3.2.1]
	Communication failure
	Bad visibility

4.4 Bourbon Surf collision with Grane jacket in 2007

The collision took place during the approach to the installation. According to Oltedal (2012) the captain arrived at the bridge shortly before the incident, and did not formally take command of the vessel. He then commanded the second navigator to leave to prepare the vessel for operations at the installation. After that the captain also left the bridge for about one minute, leaving the approach unmonitored. When he returned to the bridge, the collision was inevitable. The vessel hit the installation at a speed of 4.0 m/s (Oltedal, 2012).

Norsk Hydro (2007) concludes that the main causes for the collision was:

- The master did not keep lookout at the bridge.
- The master misjudged the ship's speed and distance to the platform.
- The platform was used as a target for the "way-point" setting.
- The ship continued on autopilot directly to the platform after passing the 500-metre zone.
- A culture that not sufficiently emphasize compliance with procedures.

4.5 Big Orange XVIII collision with Ekofisk in 2009

Big Orange XVIII was approaching the installation when the captain received a phone call regarding entry to a 1000-metre zone around Ekofisk. When he answered the phone he left the bridge and switched from manual steering to autopilot, instead of leaving the steering control

Table 4.3: Accident causes of "Bourbon Surf" with related task numbers in brackets.

Accident causes - Bourbon Surf	
Primary causes	**Underlying factors**
Unmonitored approach [3.3.3] and [4.4.1]	Inappropriate transfer of command
	Unclear roles and responsibilities [3.2.2]
	Non compliance with procedures
Platform set as "way-point" [1.2.2]	

to the second navigator (Oltedal, 2012). The vessel then entered the 500-metre safety zone with permission, but even though the pre-entry checklist was signed as completed the autopilot was still turned on. When trying to maneuver the ship, the steering was overridden by the autopilot, but neither the captain nor the second navigator identified why the vessel did not respond. The vessel managed to avoid colliding with Ekofisk 2/4-X and Ekofisk 2/4-C, and passed under the bridge between these platforms. It also avoided colliding with the jack-up flotel COSLRigmar, but ultimately collided with the unmanned water injection platform Ekofisk 2/4-W (Kvitrud, 2011). At the time of impact Big Orange XVIII had a speed of 4.5-4.8 m/s.

The main causes of the accident according to the investigation report by Leonhardsen et al. (2009) were:

- The captain takes "manual steering/local control" but the system is on autopilot.
- The captain left the steering position and went in to the “old” radio room to take a telephone call.
- The captain did not use the "emergency push buttons" for emergency steering.
- The control panel had been updated without autopilot alarms etc.
- The procedure for familiarization and vessel specific training was not followed.
- The 2nd officer observed the situation without taking an active role.

Oltedal (2012) points to the autopilot not being switched off as the main cause of the collision, with defective error detection and response as well as not completing the 500-metre checklist correctly as contributing factors.

Table 4.4: Accident causes of "Big Orange XVIII" with related task numbers in brackets.

Accident causes - Big Orange	
Primary causes	**Underlying factors**
Autpilot not switched off inside safety zone [4.3.3]	Not performing pre-arrival checklist [3.2.1]
	Non-compliance with procedures
Defective error detection	Lack of familiarity with emergency steering
	Lack of system understanding
	Unclear roles and responsibilities [3.2.2]

4.6 Summary of accident causes

4.6.1 Human errors versus technical failures

As is seen from the reported accidents the most common causes of collision is human error. Kongsvik et al. (2011) reports that as many as three of four incidents in the last ten years had human error as their primary cause, and also that the human errors dominated the identified contributing factors. Oltedal (2012) also reports that between 75% and 96% of all marine casualities are explained by some form of human error. This finding is reflected in the results of the accident review above, where all the primary causes are of related to failures made by the crew in the approach to the platform.

Another finding by (Kongsvik et al., 2011), which is not seen from the accident review is that seven of nine incidents with a vessel on collision course that did not lead to a collision had technical failures of safety critical equipment as it's primary cause. With the requirement of testing equipment before the sailing to the installation starts, it can be argued that many of the technical failures also are related to human error on some level. One possible conclusion from the combination of these findings is that human intervenes in situations where the technology fails, but since human intervention is the last line of defence against accident it is most often seen as the primary cause of collisions.

4.6.2 Primary causes of accidents

These accidents may not necessarily be representative for all the accidents that can happen, if there would have been more data we might have seen collisions that were caused by failures of technical equipment or other human failures related to the procedures when approaching installations. This needs to be considered to include barriers for all failures when a collision risk model is made.

With this precaution in mind, it can be observed that most of the failures is happening when the vessel is approaching the safety zone. Another conclusion is that all of them should have been avoided by following the procedures and revealing status of technical equipment through completing the checklist. A summary and a short description of the most important causal factors are:

Autopilot not switched off inside safety zone:
This failure is seen as a primary cause of collision in the accidents of "Far Symphony" and "Big Orange XVIII". Turning off the autopilot before entering the safety zone is a part of the procedures, and one point in the pre-arrival checklist is to specifically check the autopilot status. After that it shall not be turned on again for any reason, before leaving the installation. If this failure is not detected and dealt with it will, given the vessel is on collision course, lead to an impact.

Platform set as "way-point":
In the accident of "Bourbon Surf" this was seen as a primary cause of collision. The failure indicate that the procedures in the planning phase were not followed. There is no monitoring from any external part when the ship is approaching the safety zone. This makes changing the target position after the vessel has been authorized for traffic close to platform a potential hazard.

Unmonitored approach:
The lookout is an essential part of discovering that the vessel is on collision course with the platform. This can be done by paying attention to the radar, but also by visual lookout in the direction the ship is heading. In the accident reports this is reported to be the result of absence

of crew ("Bourbon Surf") or bad visibility ("Ocean Carrier"). According to the guidelines from (NWEA, 2009), there should be two persons manning the bridge during approach, and one of them shall be keeping watch continuously.

Defective error detection:
This failure was the primary cause for the accidents of "Far Symphony" and "Big Orange XVIII". During these accidents it was closely related to the autopilot status. A defective error detection is a wide term and can be applied to many situations where the crew did not understand the errors or dangers. It can be the result of lack of knowledge of equipment or lack of experience with emergency situations. This can also result in a lack of/wrong emergency response.

4.6.3 Underlying factors of accidents

Investigation reports and articles based on reports of collisions between supply vessel and oil- and gas installations points to several underlying factors that have contributed to the accidents. All of them can be regarded as outcome of RIFs, either having a direct influence or an indirect influence as organisational factors. The underlying factors can also be general conditions influencing many of the basic events (i.e., compliance with procedures, completing checklist) , or they can be a more specific condition influencing only one particular basic event (i.e., bad visibility).

Not performing the pre-arrival checklist:
The checklist was not completed properly in any of the accidents mentioned above. In the case of "Bourbon Surf" it is unclear if completion of the checklist would have prevented the accident (Oltedal, 2012). This underlying factor does not lead to any accidents, but in most cases the checklist can be a good tool to check if the crew has everything under control before approaching the platform. Thus, completing the checklist properly will prevent many potentially dangerous incidents. Related RIFs can be "performing checklist" and "organisational safety culture".

Non-compliance with procedures:

Following the procedures is important for the safety, but this failure is very wide and basically not telling us anything of what went wrong. If a vessel is colliding with a platform, there will always be a breach of the procedures at some level. Oltedal (2012) addresses this as an underlying factor in all the major supply vessel collision accidents. Related RIFs can be "adherence to procedures" and "organisational safety culture".

Lack of familiarity with emergency steering:

Familiarity with emergency steering is seen to be important in the cases where the potential accident is detected and need to be prevented from happening. Lack of familiarity can lead to mistakes in the stressful situation where the navigator has limited time to react. Lack of familiarity with emergency steering can also point to organisational deficiencies with regards to competence building. Related RIFs can be "competence", "familiarity" and "competence management".

Lack of system understanding:

Lack of system understanding is listed as an underlying factor related to the detection of the autopilot status, but this can also be a factor for the watchkeeper when using the radar or AIS. Lack of system understanding can point to organisational deficiencies, in the same way as lack of familiarity with emergency steering. Related RIFs can be "competence", "familiarity" and "competence management".

Inappropriate transfer of command:

Formal change of command on the bridge is a way to remove confusion as to whom is in charge, and inappropriate transfer of command causes unclear roles and responsibilities which in turn can lead to important tasks (e.g. monitoring, steering) being left unattended (Oltedal, 2012). Related RIFs can be "adherence to procedures" and "organisational safety culture".

Communication failure:

Communication failure has here been seen in relation to the bridge resource management, where this underlying factor can lead to confusion on the bridge in the same way as the inappropriate transfer of command. According to (NWEA, 2009), good communication between vessel and installation/surveillance center is important, and lack of proper communatication can prevent 3rd party from warning the vessel given a straight course towards the installation (Ali and Haugen, 2012). Related RIFs can be "communication" and "general management".

Bad visibility:

During an approach to the platform in dense fog or other weather conditions that reduce the visibility, the vessel cannot rely on visual lookout. Operating the radar and AIS equipment will then be a more important task and should have dedicated personnel. Bad visibility is a constant variable that cannot be improved or avoided, but as mentioned in the previous chapter it should be planned and accounted for before the vessel leaves port. A related RIF can be "visibility".

Chapter 5

Generic collision scenarios

It is seen from the accidents that there are many similarities in these accidents when it comes to the primary causes, but when the whole chain of events and the underlying factors are considered, there are many differences. To use the formal probabilistic risk analysis techniques, the information available must first be structured. This is done by creating generic collision scenarios that can explain the reviewed accidents, but still general enough to assume that it also can explain future collisions that can happen. Making one scenario that are able to take all specific failures into account and at the same time be general enough to cover all incidents that can happen, is a difficult, if not impossible, task. Besides the difficulty, there are also other reasons why the model should be split into several collision scenarios. First of all, many of the hazardous situations start at different times. It is not neccessary to include aspects of the operations happening before a possible collision scenario is initiated, if they are not relevant to the accident scenario. From a quantitative risk analysis perspective, the probabilities of failure are not independent of where a vessel is situated; even though many of the basic events and barriers are the same in the accidents. Examples of this can be that the monitoring the position of the vessel have a higher probability of failing on open sea than close to a platform because of extra awareness from crew and visual detection possibilities. The purpose of this chapter is to introduce a few generic collision scenarios that are covering all failures that have a significant probability of causing a collision.

5.1 Considering the safety barriers from the literature regarding vessel-platform collisions

As mentioned it is important to not get blinded by a few registered incidents and think that those are representative for all possible accidents that can happen. There are other material written on the subject, even though these studies often had another agenda to address (e.g., Kongsvik et al. (2011) work towards identifying safety barriers for barrier management and af Geijerstam and Svensson (2008) research on important factors to prevent collisions with passing vessels). In these articles there are at least some information that can be transfered to the process of finding generic collision scenarios.

Kongsvik et al. (2011) follows the very wide definition of safety barriers introduced in Chapter 2.2.1 in the effort to identify barriers that can prevent collisions between supply vessels and offshore oil- and gas installations. These barriers are seen in Table 5.1. The barriers were categorized in phases of the operation, and were identified mostly from interview with experts about what they felt were the important factors to prevent collisions. This resulted in a mixture of barrier systems (e.g. DP-system), barrier functions (e.g. surveillance from installation) and risk influencing factors (e.g. staff qualified personell in machine room) all defined as barriers.

Ali and Haugen (2012) uses the BORA approach to make a collision risk model. Barriers are included based on information from the risk estimation models of COLLIDE and CRASH, but also uses information from recent collisions. Figure 5.1 shows the barrier block diagram from this model.

5.2 Challenges making generic scenarios and event trees

Challenges regarding identifying representative scenarios for the collisions are briefly mentioned in the start of the chapter. It is often a challenge to find a chain of events that will cover all failures that can lead to an accident, but in this case it is particularly challenging as there are lack of passive barriers. As Table 5.1 shows, there are many operational barriers to ensure safety in-

Table 5.1: Barriers in offshore supply vessel traffic (adapted from (Kongsvik et al., 2011))

Phase	**Base activities**	**Sailing**	**Entering safety zone**	**Departure from installation**
Barriers	Develop a good sailing plan	Navigation with waypoint outside safety zone	Use navigator on bridge and having good role clarification	Establish safe distance from installation before switching from DP to manual navigation
	Develop a good loading plan	Surveillance from marine surveillance center	Review the 500-metre safety zone checklist pre-arrival	
	Assess weather conditions before sailing	Surveillance from standby vessel	Navigation during arrival at the installation	
	Check weight of cargo	Surveillance from installation	Function test of thrusters	
		Route coordination during sailing	Establish communication with installation	
		Communication with installation before arrival	Assess weather conditions	

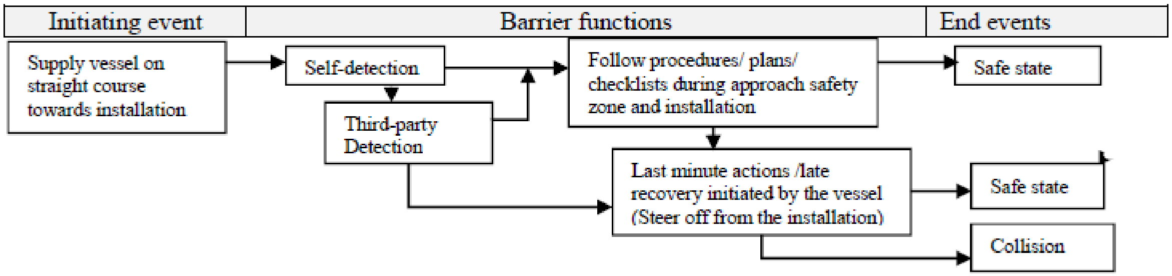


Figure 5.1: Barrier block diagram for offshore supply vessel on collision course event (Ali and Haugen, 2012).

stead. As a result, the scenarios is focused on the operations taking place to prevent a collision given that the vessel is on collision course with the platform.

Another large challenge is indepence. Indepence between the barrier functions are not easy to obtain, and the principle of independence may also reduce the efficiency and flexibility of the system (Rausand, 2013). For the event trees presented in Figures 5.3, 5.4 and 5.5, especially the problem with the same components being present in several of the barrier functions are faced. Crew on bridge being absent, or physically uncapable of performing the tasks required is one of the largest contributors to failure of all the operational barrier functions (af Geijerstam and Svensson, 2008). This could be handled by splitting the event tree into several branches, categorised by the exact cause/causes of the barrier function failure. The drawback is that this would have created many branches that require a separate set of failure probabilities and degree of influence from RIFs, and thus require more input to the quantitative assessments.

5.3 Overview of the generic collision scenarios

To give a general idea of the difference between the generic collision scenarios, Figure 5.2 shows how they are connected. The supply vessel operation start with planning of the voyage where the "way-point" is set. A "way-point" set directly towards the installation is the starting point of a potential accident, since the vessel will then be on collision course until a preventive action is taken from the crew. This is scenario 3. If the "way-point" has been set outside the safety zone, or if scenario 3 have been averted, the vessel will approach the installation as normal and be authorised for sailing close to installation without any alarms being set off. Approaching the safety zone the vessel should then turn off the autopilot and proceed to a safe location 50 metres at the side of the installation waiting for a signal that the loading/unloading procedure can be undertaken. Deviations from these procedures can happen with a new autopilot "way-point" being set to installation instead causing the vessel to be on a collision course with the platform with no outside monitoring, or manually steering the vessel directly towards the platform. These two navigaton errors marks the initiating events of scenario 2 and scenario 1, respectively. Influenced by the barrier block diagram in Figure 5.1, a possibility of last minute actions to steer away from platform has been included as the last line of defence in each of the scenarios.

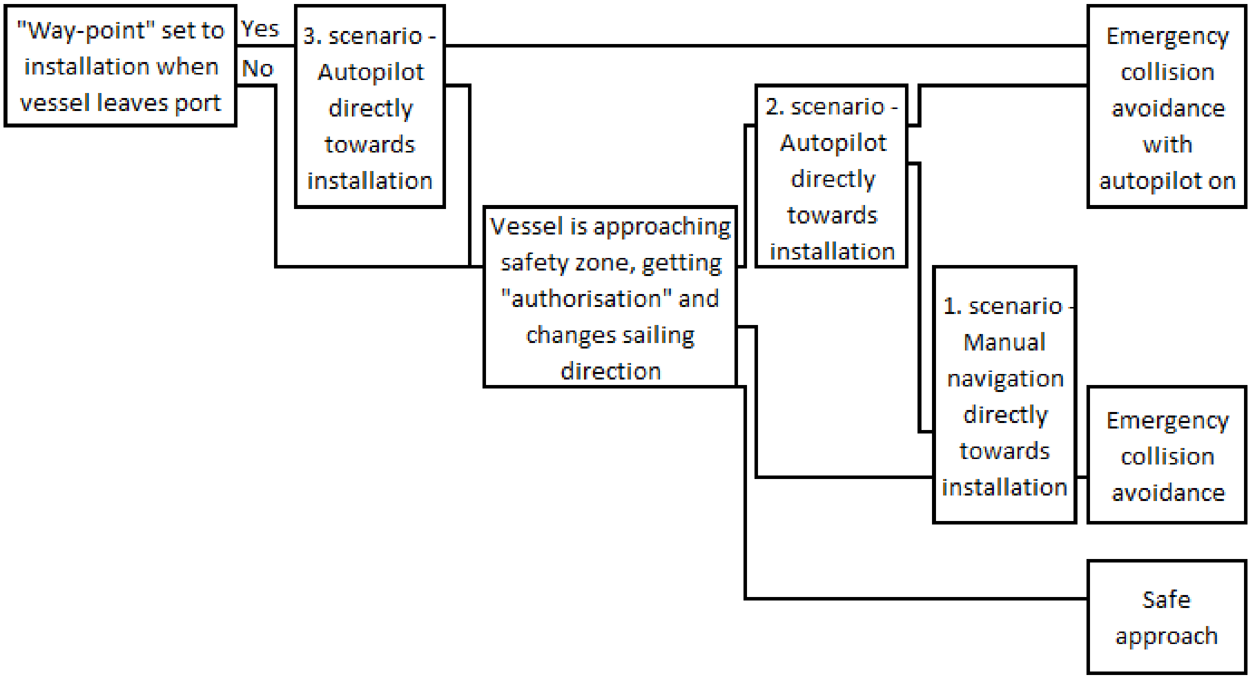


Figure 5.2: Overview of scenarios that can lead to a collision

5.4 Scenario 1: On collision course manually navigating directly towards the installation close to the safety zone

From the accident review in the last chapter it can be seen that all incidents have been initiated close to the platform. Approaching the safety zone vessels are required to turn off their autopilot.

Since the correct "way-point" for the autopilot are at least 500 metres away from the platform, the navigator must manually change the vessel's direction and safely navigate to a distance of 50 m from the installation and wait for clearance to start the loading/unloading operations. During this procedure and subsequent sailing phase the vessel navigates manually and can easily find itself on collision course with the platform. In the scenario, this serves as the initiating event. Event tree for this scenarios can be seen in Figure 5.3.

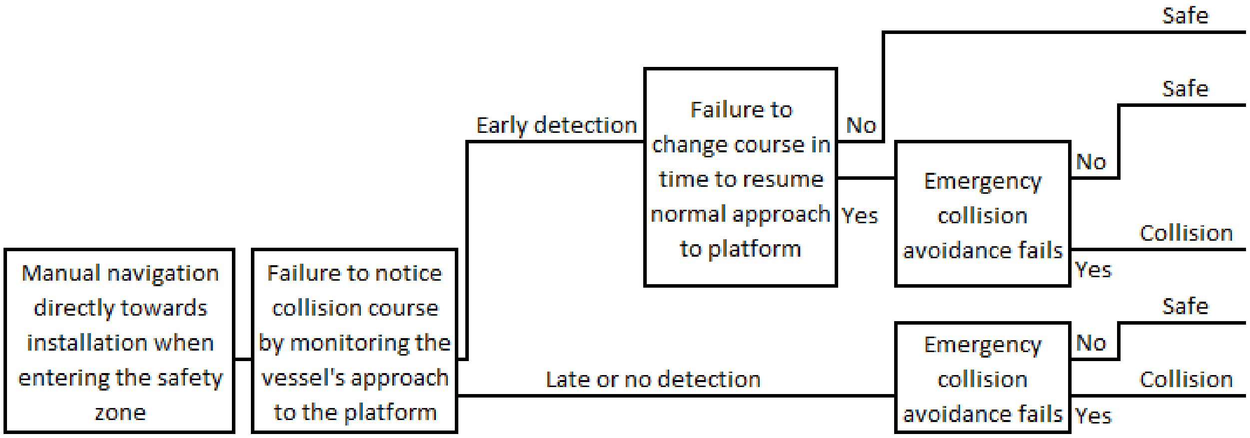


Figure 5.3: Event tree for vessels on collision course using manual navigation during approach to installation

From the point of the iniating event to an eventual impact the crew onboard has an opportunity to detect the situation by successfully monitoring the vessel's approach to the platform both visually and by use of technical equipment. A navigator has to be present for this barrier function to be effective. This is a continous process, which is ongoing from the point of the initiating event to an eventual impact. It is not easy to say how long time a crew member on lookout has to detect the collision course as this is highly dependent on the speed and the distance from the point where the initiating event starts. Since this is a continous process, the event tree could have split up into a large amount of branches to specify the amount of time available for changing the vessel's direction. To simplify, distinction between early detection and late/no detection is made here. Splitting into these two branches are done because early detection can give the navigator an opporunity to normalise the situation instead of just turning away from the platform. Vessel are authorised for sailing close to the platform, so there is no outside detection of collision course (ConocoPhillips, 2013).

If the monitoring of the approach to the platform is successful an officer will typically try to change the course manually to continue the intended operation. If this maneuver fails there will still be an opportunity to turn away from the platform at the last minute.

For late/no detection it will in most cases still be enough time to avoid a collision given that there is visibility towards the platform. No detection is assumed to only be a possibility if there are no personnel present, since there will be possible to visually spot the platform before the collision even in bad weather collisions. This is taken into account in the fault tree analysis.

5.5 Scenario 2: On collision course navigating with autopilot directly towards installation close to the safety zone

The second scenario is quite similar to the previous, but with an added element as the autopilot is still turned on. This is a clear violation of the guidelines and checklist by (NWEA, 2009). The autopilot status is, as the monitoring of the approach, a continous process. This process happens simultaneously with the monitoring, so there is nothing other that estetichal reasons why this is placed before the monitoring in Figure 5.4. The upper part of the event tree is equal to the one in Figure 5.3.

However, as the Risk OMT will be much focused on the human failures of operation it makes sense to include this part of the scenario here in addition to having it as a separate scenario. Given that the autopilot is left on during approach even though the checklist has been completed suggests that adherence to procedure is not optimal, and that will have an effect on other failure probabilities.

As the autopilot left on during both the accidents of Far Symphony (Chapter 4.1) and Big Orange (Chapter 4.4), this can be assumed to be a significant contribution to major collision accident. The autopilot is here assumed to be recently turned on, since a vessel on collision course far away from platform would have been detected by an onshore monitoring station (Kongsvik et al., 2011; Ali and Haugen, 2012), and thus dealt with earlier. That would also have triggered the initiating event earlier, which is considered in the scenario described in the next section.

The failure to turn off the autopilot status before a potential collision is reported by the officer on lookout will complicate the process of normalising the vessel's direction and emergency collision avoidance, as this will include switching from autopilot to manual navigation.

The rest of the event is qualitatively the same as the scenario in Chapter 5.4, and is therefore not repeated here.

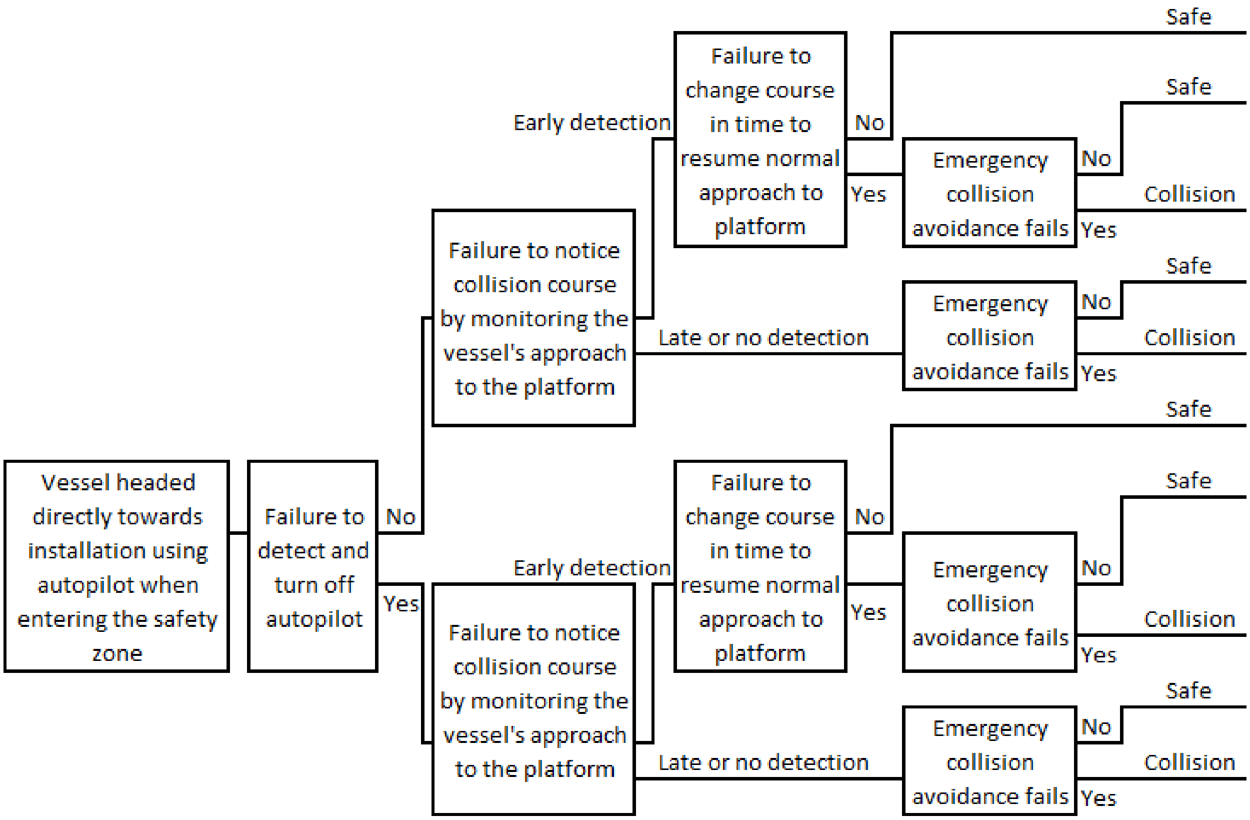


Figure 5.4: Event tree for vessels on collision course with autopilot on during approach to installation

5.6 Scenario 3: Vessels on collision course with installation as a result of "way-point" set directly to installation

After the extensive focus to make crew set way-point to the side of the installation, the number of ships on collision course with offshore oil- and gas platforms per platform have decreased steadily since 2002. According to (Kvitrud, 2011), the annual number of vessels on collision course is less than 0.5 per installation per year.

This scenario cover the chain of events for collisions considered in many QRA models, as seen in (Tvedt, 2013). The incidents in this scenario are starting far away from the platform, with the vessel on collision course as the initiating event. The premise of this potential accident is that if the crew does not take any action over a long period of time a collision will certainly occur.

The method for calculating risk of supply vessel colliding with oil- and gas installations multiplies three factors considered to be the cause of collisions; failure to prevent being on collision course, failure to self-detect that vessel is on collision course and failure of detection by third-party. Adding the last minute actions/late recovery discussed by (Ali and Haugen, 2012), gives the event tree in Figure 5.5.

Compared to the accidents investigated in the last 10 years, this does not fit most of the incidents, and can be seen as a major simplification. However, since oil companies have taken the step to introduce constant monitoring from an onshore station (e.g., Statoil Maritime Control centre at Sandsli (Kvitrud, 2011)) it is hard to argue against this being a possible scenario.

The model reviewed by (Tvedt, 2013) considered that a vessel being on collision course will happen if, and only if, the vessel does not set "way-point" outside the 500-metre safety zone at the side of the installation. This means that from this model a vessel will not crash if it sets a "way-point" according to standard procedures. If a way-point has not been set correctly, and no action is taken from the ship, a collision is highly likely to occur. There have been much focus on set-

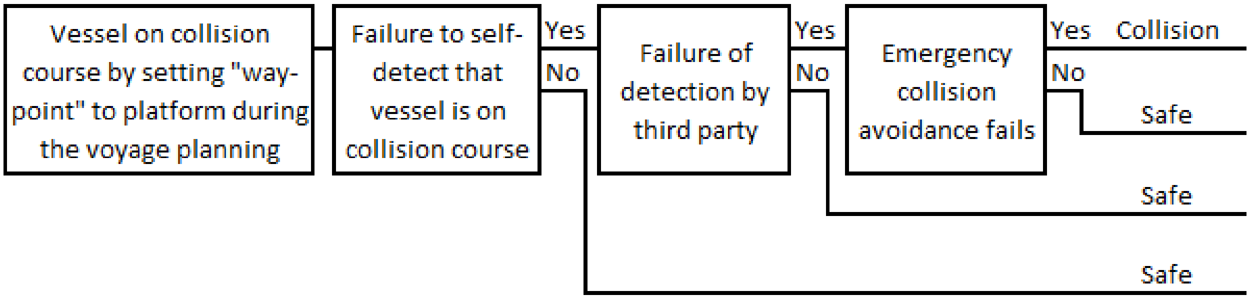


Figure 5.5: Event tree for vessels on collision course with installation far away from installation

ting correct "way-point" in the last 10-15 years, and the result have been a major reduction in vessels on collision course. Kvitrud (2011) reports a reduction factor of four since 2002.

The navigator or captain of the vessel should be able to detect that it is sailing on direct collision course with the installation. This can be done by radar or AIS during the voyage. When the ship is getting closer to the installation detection by lookout will also be possible, unless bad weather is reducing the visual range to a distance where it is too late to change course.

Unlike in the other scenarios there is also continuous surveillance either from an onshore base, or offshore at a surveillance tower. They follow the ships passing and visiting installations, and an alarm will go off if a vessel is on collision course longer than a few minutes inside a certain distance of the platform (ConocoPhillips, 2013). The platform itself also often have surveillance of nearby vessels, through a standby vessel in close proximity of the platform. This can be used to signal the vessel with light and sound if no contact can be made through radio communication. The failure of detection by third party does not necessarily means that the surveillance center did not detect the vessel on collision course. It also includes the failure of warning the ship and making it change course, thus making it dependent on the reason behind the failure of self-detection by vessel.

The last minute emergency collision avoidance have been covered in section 5.4, and is based on the possibility of crew members recovering from the conditions that made the failure of the previous barrier functions happen (e.g., absence from bridge, being asleep, attention to other tasks). All of these barriers must fail for a collision to occur, otherwise the vessel (and platform) is safe for now.

Chapter 6

Analysis of barrier functions

Further analysis of the barrier functions is shown here. The barrier functions are explained and broken down into basic events by fault tree analysis. The failures of human intervention is divided into failure of execution and failure of omission, as explained in Chapter 2.4. Risk OMT broke the failure of execution further down into mistakes, violation and slips and lapses, but this is not done here. It can be discussed whether or not this is a smart choice. The reason for choosing not to split failure of execution into three subgroups, is related to the lack of complexity related to the tasks. Thus, can the added level of complexity in the calculations of the human failures be seen as a complication rather than a help. From the accidents, the human failures is not in the execution of the necessary action, but rather to detect and understand the dangerous situations in time to react to them.

This chapter presents fault tree analyses made for scenario 1; *On collision course manually navigating directly towards the installation close to the safety zone.* Similar fault tree analysis have been done for the other scenarios, and the complete set of fault trees can be seen in appendix a.

6.1 Challenges

Some challenges regarding independence were discussed in Chapter 5.2. The same problems apply here, as there are common cause failures for the basic events in the fault trees. According to (Vinnem et al., 2012) there are two feasible ways to include the common cause effects in the modelling. The first alternative is to model the common causes effects explicitly through creating new basic events in the fault trees. The other alternative is to introduce the common cause failure in the processing of minimal cut sets later. Then the possible dependencies must be described for various classes of basic events, and common cause terms added when the minimal cut set contribution are calculated. It is still hard to solve this challenge entirely, but to some degree the challenge has been dealt with by including the absence of personnel as a basic event. Then absence of personnel is for example not seen as a failure cause for visual lookout or operational error in the fault tree of monitoring the vessel's approach to the platform.

6.2 Scenario 1

6.2.1 Failure to notice collision course by monitoring the vessel's approach to the platform

If all guidelines have been followed (e.g., communication with the platform, speed restrictions) and there is good visibility, the monitoring is really just a formality as the crew are aware of the installation visually long before they reach it. Problems can happen if there is dense fog, problems with the equipment or irregularites following the guidelines and checklist. The fault tree in Figure 6.1 is an adaptation of a fault tree developed by (Ali and Haugen, 2012) for self-detection on collision course.

For the top-event to occur there must be a failure in both the visual lookout and navigational detection systems, or "no officer present at the bridge" (P1). Failure of visual lookout is happening either with a "failure of omission" (lookout not performed, P2) or "failure of execution" (insufficient lookout, P3). For most vessels, an AIS system complements the marine radar as method for collision avoidance, and both of them have to fail for the barrier system to fail (Ali and Haugen, 2012). The subsystems for the equipment include "technical failure" (P4, P7), and the operational errors; "failure of omission" (P5, P8) and "failure of execution" (P6, P9).

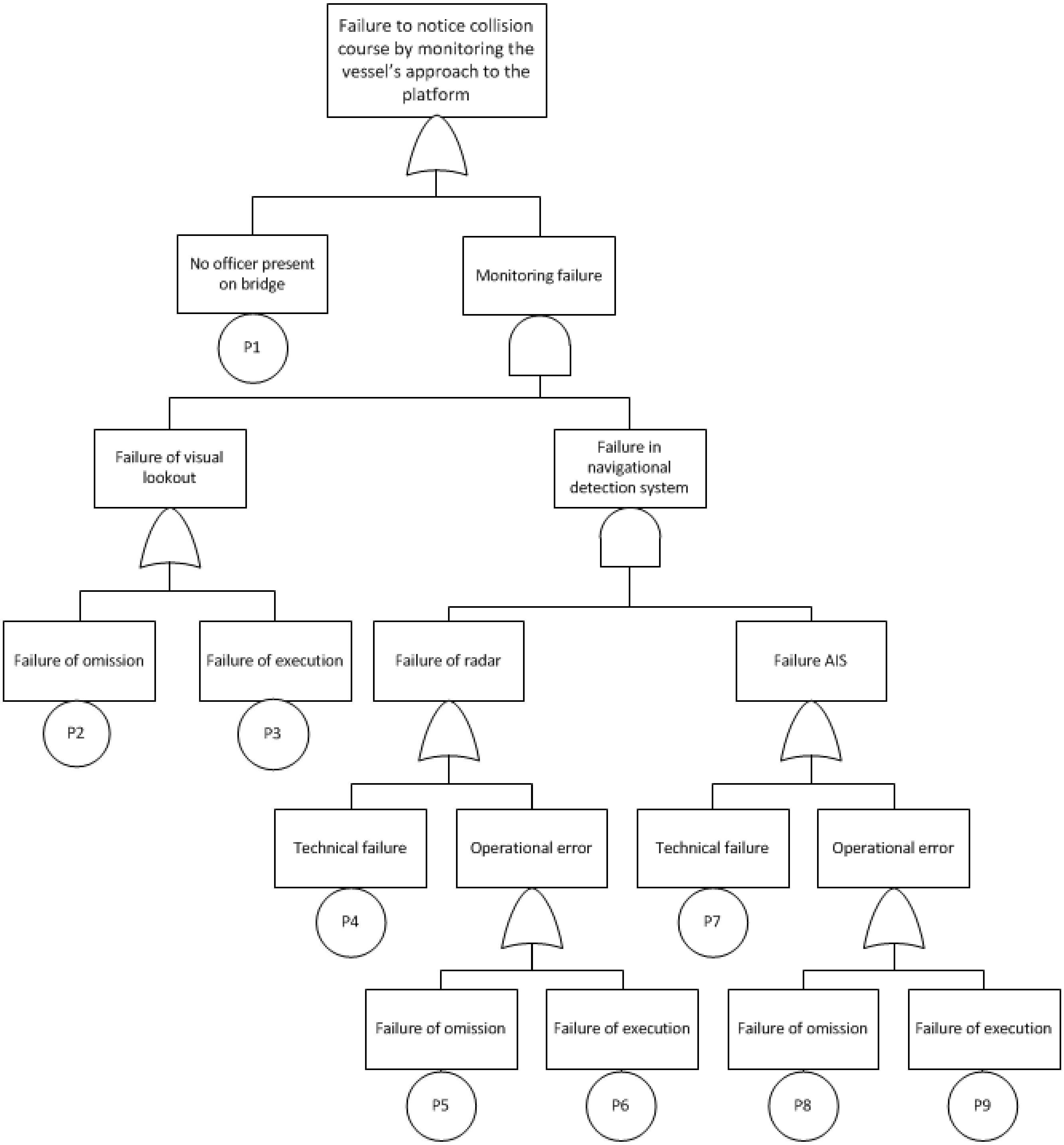


Figure 6.1: Fault tree for the failure to notice collision course by monitoring the vessel's approach to the platform (partly adapted from Ali and Haugen (2012)).

6.2.2 Failure to change course in time to resume normal approach to platform

An assumption for this is that the officer on the bridge will only take corrective action if a collision course is detected, otherwise the vessel will continue straight forward. Early detection will give the officer an opportunity to correct the course in time to resume normal approach and perform the operations by the installation as planned. Figure 6.2 shows the fault tree. The checklist states that there should be two persons available on the bridge for redundancy performing the tasks (NWEA, 2009), but both the navigator and the watchkeeper should be able to perform a corrective action. And since a the collision course with the platform has just been detected, it is considered unlikely that there are no personnel present.

The failure to take a suitable corrective action can happen either because of "technical failure navigation of the vessel" (P1) or human failure related to the steering. The human failure can be categorised as a "failure of execution" (not successful manouver, P2) or "failure of omission" (no action taken, P3).

6.2.3 Emergency collision avoidance fails

For the failure of this top event, the status of the watchkeeping must be taken into account. Thus, for the barrier function of emergency collision avoidance there are two distinct fault trees. The first is given that the collision course is detected, shown in Figure 6.3. This fault tree is fairly simple as it only considers the failure to take a corrective action. As mentioned in the section above, a failure can happen either because of "technical failure related to navigation of vessel" (P1) or human failure related to the steering (P2, P3).

The fault tree for situations where collision course has not been detected is shown in Figure 6.4. This is for situations where the early monitoring have failed, but as the vessel is getting closer to the platform even distracted personnel should have the ability to detect the platform visually. Since there are only OR-gates in this fault tree, all five basic events will lead to failure

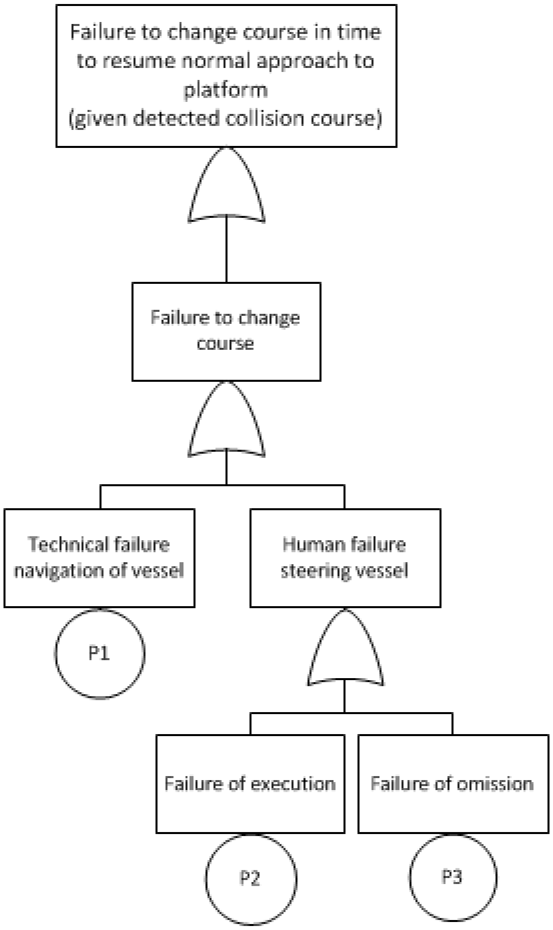


Figure 6.2: Fault tree for failure to change course in time to resume normal approach to platform.

of the barrier function. These are; "technical failure ralted to navigation of vessel" (P1), "failure of execution" (P2), "failure of omission" (P3), "navigator not present" (P4) and "inadequate detection" (P5).

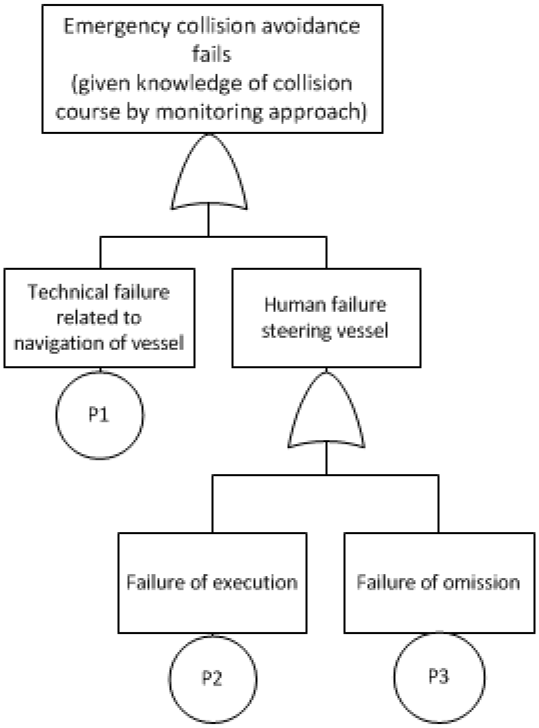


Figure 6.3: Fault tree for failure of emergency collision avoidance given detected collision course.

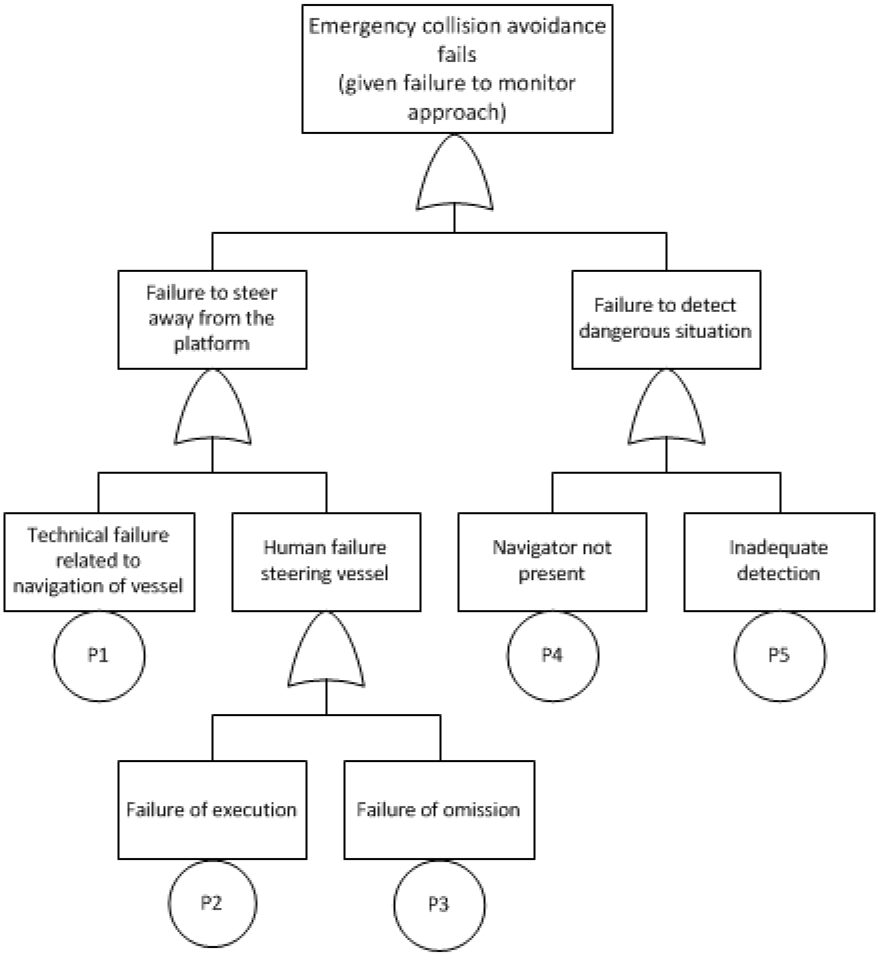


Figure 6.4: Fault tree for failure of emergency collision avoidance given failure to monitor approach

Chapter 7

Risk influencing factors

The term of RIF was introduced and thoroughly explained in general in Chapter 2.2.2 . This chapter discusses RIFs identified in previous studies of ship collisions, and presents the generic RIF models from the Risk OMT framework. These part are combined to form the list of RIFs for the basic events of the scenario 1; *On collision course manually navigating towards installation*.

7.1 Situation specific RIFs identified in the literature

Several articles have been written, in which attempts to identify and structure relevant RIFs have been done. A common problem with the transferability of the findings is that everybody have been operating with different definitions for barrier functions, barrier elements, basic events and risk influencing factors. In the Risk OMT framework there was introduced two levels of the RIFs where the second level influenced the basic events through the RIF in the first level, but this is not done in any of the studies reviewed.

af Geijerstam and Svensson (2008) lists four primary reasons four a collisions; intentional failure, technical problems, lack of awareness and handling error. The intentional failure has not been considered in this thesis, but the other four primary reasons is corresponding to technical failures, failure to monitor approach to platform and human failures, respectively. Further interviews with experts from different part of the industry were conducted to identify and quantify factors that influenced these primary reasons. The causes behind the failure to monitor approach are substance abuse, being asleep, illness, distractions and absence from bridge. These conditions were examined further to identify influencing factors, thus creating a hierarchy of failure causes and risk influencing factors. The human handling errors are broken down in the same detailed manner.

Dai et al. (2013) analyses the risk of collision between service vessels and offshore wind turbines, where risk influencing factors in relation to watchkeeping failure, failure of taking corrective action to avoid collision and failure og navigational detection system were listed.

Ali and Haugen (2012) identifies risk influencing factors according to the BORA model. The RIFs were put into four categories; Human, system, task and environment. The environmental category included psyical environment and organisational factors. The list of risk influencing factors is mostly based on this identification, but is also trying to incorporate the information from the other sources. The category of environment will be split up to fit into Risk OMT, so that the organizational factors will be used as an extra category.

7.2 Generic RIFs from Risk OMT framework

The Risk OMT framework includes two RIF models; one for planning activities and one for execution and control activities (Vinnem et al., 2012). The two models, seen in Figures 7.1 and 7.2, are considered to be generic for the *failure of execution* basic events. This generic model is not automatically applicable to all basic events. Some of the RIFs are relevant for all, while others only apply to a few (Vinnem et al., 2012). The generic RIFs on level 2 respresent different aspects of management that are influencing the RIFs on level 1 (Gran et al., 2012b). All the RIFs on level 1, have a corresponding RIF on a management level. This can be regarded as means to reduce uncertainty implied by the obsevations of RIFs on level 1.

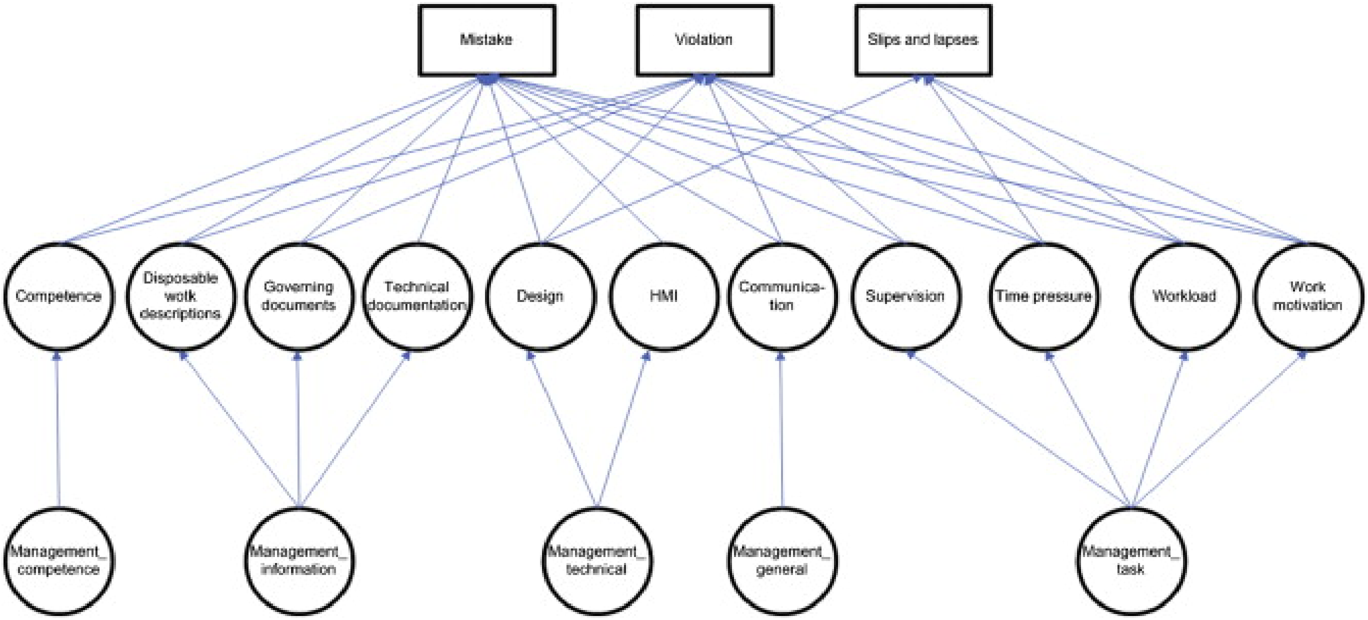


Figure 7.1: Generic RIF model for execution and control activities (Vinnem et al., 2012)

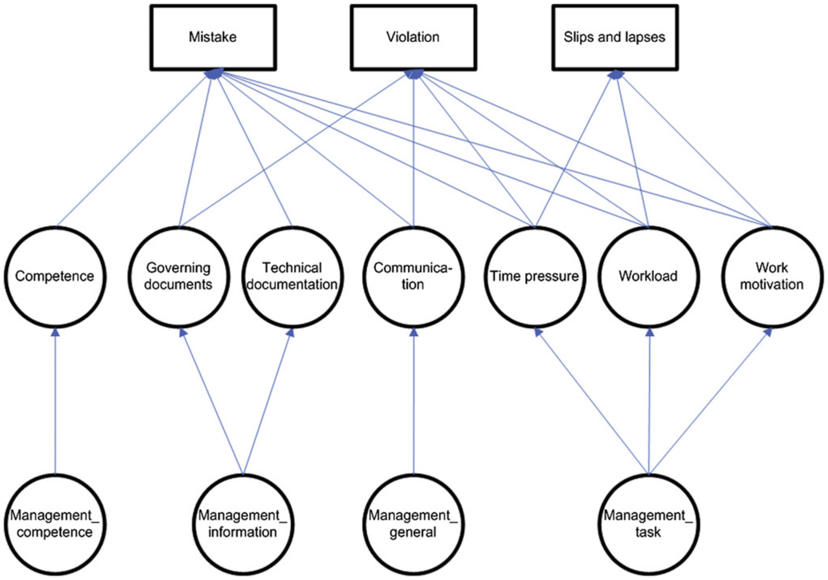


Figure 7.2: Generic RIF model for planning activities (Vinnem et al., 2012)

7.3 Challenges

Challenges both regarding identifying the risk influencing factors, but also regarding discussing the relevance of risk influencing factors mentioned in the literature. As briefly mentioned in

Chapter 4, a clear separation between underlying factors and RIFs must be made. The underlying factors are often specific breaches of procedures that makes accidents possible, while RIFs are constant measurable factors that influence the risk. For example the factors; being asleep, illness and absence from bridge identified by (af Geijerstam and Svensson, 2008) as underlying factors causing a failure of monitoring approach, are not directly transferable as a RIF. These factors are not "measurable", and are conditions that either causes the monitoring to fail, or they have no effect. In this example being asleep can be the result of "workload" or "watch system" RIFs, illness can be resulting from "health management", absence from the bridge can be the result of "competence" or "organisational safety culture". Finding RIFs that can capture the essence of the underlying factors and ensure transferability of findings from the literature is a challenge in this chapter.

Another challenge is include the risk influencing factors at the right place. This framework is developed based on information from recent accidents, with an unique probabilistic risk model. Thus, RIFs have not been identified previously for all the basic events. A consequence is that some of the RIF identification is left up to personal judgement, based on information presented in previous chapters.

7.4 RIFs for the basic events in the barrier function "Monitoring the vessel's approach to the platform"

No officer present on the bridge (P1):
The presence of officer/officers on bridge is placed as a basic event to include common cause failures in the model. Dai et al. (2013) and Ali and Haugen (2012) consider this to be a RIF and not a basic event. Figure 7.3 shows a risk influence diagram with a hierarchical layout of the RIFs.

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[1] (af Geijerstam and Svensson, 2008)
[2] (Dai et al., 2013)
[3] (Ali and Haugen, 2012)
[4] Generic RIF from (Vinnem et al., 2012)
[5] RIF based on the accident review

Level 1: Competence[1] , reliance on technical equipment[1], layout of the bridge[1], watch system[1], communication[4], workload[4], work motivation[4], checklist performance[5].

Level 2: Competence management[4], organisational safety culture[15], technical management[4], general management[4], task management[4].

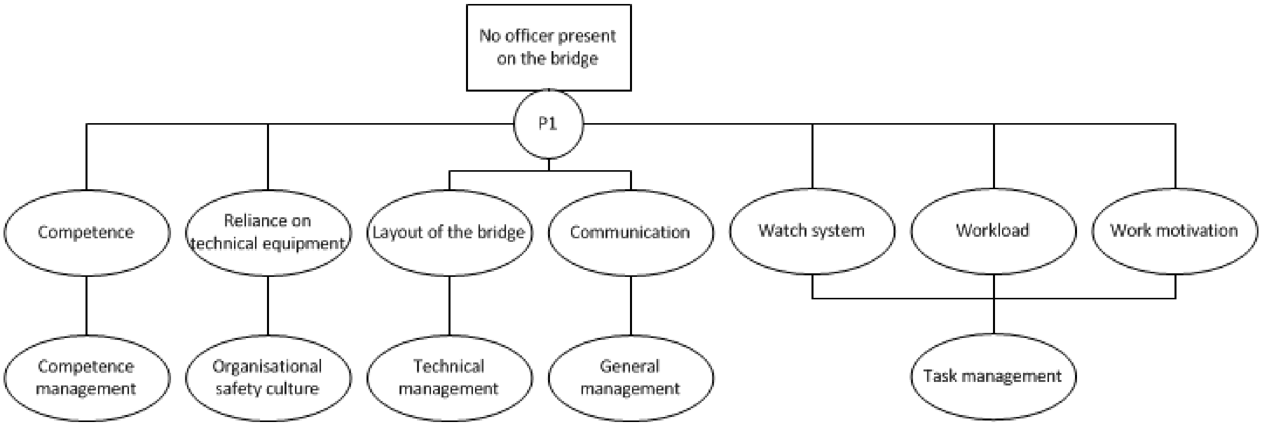

Figure 7.3: Risk influence diagram for the basic event "No officer present on the bridge".

Failure of omission - visual lookout (P2):

Level 1: Workload[13], time distribution[1], bridge procedures[23], reliance on technical equipment[1], bridge design[13], health[23], communication[5], clear roles and responsibilities[5].

Level 2: Task management[4], organisational safety culture[1], technical management[4], health management, general management[4].

Failure of execution - visual lookout (P3):

Level 1: Competence[1234], visibility[5], watch system[13], workload/stress[134], work/time pressure[14], bridge procedures[3], communication[4], work motivation[4], health[23].

Level 2: Competence management[4], task management[4], organisational safety culture[1], general

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[1] (af Geijerstam and Svensson, 2008)

[2] (Dai et al., 2013)

[3] (Ali and Haugen, 2012)

[4] Generic RIF from (Vinnem et al., 2012)

[5] RIF based on the accident review

management[4], health management[5].

Technical failure - Radar (P4):

Level 1: Equipment design[23], technical condition[23], maintenance of equipment[123], reliability of equipment[23], human-machine interface[23], system feedback[23], checklist performance[5].

Level 2: Technical management[4], maintenance management[5], organisational safety culture[5].

Failure of omission - radar (P5):

Level 1: Competence[12], workload/stress[23], bridge manning[3], bridge procedures[5], clear roles and responsibilities[5], communication[5].

Level 2: Competence management[4], health management[5], task management[4], organisational safety culture[5], general management[4].

Failure of execution - radar (P6):

Level 1: Competence[1234], decision making abilities[23], familiarity with equipment[23], communication[234], judgement abilities[23], design of equipment[4], human-machine interface[4], supervision[4], time pressure[4], workload[4], work motivation[4].

Level 2: Management procedures[23], competence management[4], technical management[4], general management[4], task management[4].

Technical failure - AIS (P7):

Level 1: Equipment design[23], technical condition[23], maintenance of equipment[123], reliability of equipment[23], human-machine interface[23], system feedback[23], checklist performance[5].

Level 2: Technical management[4], maintenance management[5], organisational safety culture[5].

Failure of omission - AIS (P8):

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[1] (af Geijerstam and Svensson, 2008)

[2] (Dai et al., 2013)

[3] (Ali and Haugen, 2012)

[4] Generic RIF from (Vinnem et al., 2012)

[5] RIF based on the accident review

Level 1: Competence[1][2], workload/stress[2][3], bridge manning[3], bridge procedures[5], clear roles and responsibilities[5], communication[5].
Level 2: Competence management[4], health management[5], task management[4], organisational safety culture[5], general management[4].

Failure of execution - AIS (P9):
Level 1: Competence[1][2][3][4], decision making abilities[2][3], familiarity with equipment[2][3], communication[2][3][4], judgement abilities[2][3], design of equipment[4], human-machine interface[4], supervision[4], time pressure[4], workload[4], work motivation[4].
Level 2: Management procedures[2][3], competence management[4], technical management[4], general management[4], task management[4].

7.5 RIFs for the basic events in the barrier function "Change of course in time to resume normal approach to platform"

Technical failure related to navigation of vessel (P1):
Level 1: Technical condition[2][3], maintenance of equipment[1], checklist performance[5].
Level 2: Maintenance management[5], organisation safety culture[5].

Failure of execution - steering (P2):
Level 1: Competence[1][2][3][5], familiarity with equipment[1][5], work pressure[1], insufficient training[2], time pressure[2][3], workload/stress[2][3].
Level 2: Organisational safety culture[1][2][3], competence management[5].

Failure of omission - steering (P3):

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[1] (af Geijerstam and Svensson, 2008)
[2] (Dai et al., 2013)
[3] (Ali and Haugen, 2012)
[4] Generic RIF from (Vinnem et al., 2012)
[5] RIF based on the accident review

Level 1: Competence[5], reliance on technical equipment[1], communication[1], manning[2], workload/stress[2,3], wishful thinking[5].

Level 2: Competence management[4], organisational safety culture[1,2,3], task management[4], general management[4].

7.6 RIFs in for the basic events in the barrier function "Emergency collision avoidance"

Technical failure related to navigation of vessel (P1):

Level 1: Technical condition[2,3], maintenance of equipment[1], checklist performance[5].

Level 2: Maintenance management[5], organisation safety culture[5].

Failure of execution - emergency collision avoidance (P2):

Level 1: Competence[1,2,3,5], familiarity with equipment[1,5], work pressure[1], insufficient training[2], time pressure[2,3], workload/stress[2,3].

Level 2: Organisational safety culture[1,2,3], competence management[5].

Failure of omission - emergency collision avoidance (P3):

Level 1: Competence[5], reliance on technical equipment[1], communication[1], manning[2], workload/stress[2,3], wishful thinking[5].

Level 2: Competence management[4], organisational safety culture[1,2,3], task management[4], general management[4].

Navigator not present (P4):

Level 1: Competence[1] , reliance on technical equipment[1], layout of the bridge[1], watch system[1], communication[4], workload[4], work motivation[4], checklist performance[5].

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[1] (af Geijerstam and Svensson, 2008)

[2] (Dai et al., 2013)

[3] (Ali and Haugen, 2012)

[4] Generic RIF from (Vinnem et al., 2012)

[5] RIF based on the accident review

Level 2: Competence management[4], organisational safety culture[1,5], technical management[4], general management[4], task management[4].

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[1] (af Geijerstam and Svensson, 2008)

[2] (Dai et al., 2013)

[3] (Ali and Haugen, 2012)

[4] Generic RIF from (Vinnem et al., 2012)

[5] RIF based on the accident review

Chapter 8

Summary

8.1 Summary and discussion

The intention of this thesis has been to make a framework that can be used for quantitative risk analysis of supply vessel-platform collisions. Through preliminary review of accident reports and barrier identification studies, it was clear that there were not many traditional passive barriers implemented in the operations to prevent such collisions. In fact, it was made clear that most accident were caused by erroneous involvement from the crew onboard the vessels during the phase of approaching to the platform. The aim was therefore set to make the new framework based on the Risk OMT model, which could to a larger degree take human involvement into account in the risk analyses.

To form the basis for the framework tasks involved in the supply vessel operations were analysed, as well as detailed review of representative accidents with major damage potential over the last ten years. The accidents were principally different from each other, but there were some common factors among the primary causes of collisions. The accident reports especially highlighted the failure of two critical errors that had happened in at least two of the investigated accidents;

- Leaving the autopilot on during the approach to the installation.
- Lack of monitoring of the vessel's course towards the installation.

The framework was then divided into three generic collision scenarios. One point of this split was to be able to make a framwork that is specific enough to be able to represent the collisions that have already taken place, but at the same time be as general as possible to account for all probable incidents in the future. Another point was to be able to correctly include the risk influencing factors for a given human operation, the relevant setting must be taken into account. For example can time pressure be a risk influencing factor for the action of rectifying a vessel's collision course when the vessel is in the proximity of the platform, but not be relevant at a location far away from the platform. Personnel being present on the bridge to detect a collision course can also be seen to have a higher probability of failing one hour before the arrival to the platform, than when the vessel is entering the safety zone. The three scenarios comprises; manual navigation directly towards installation when the vessel is entering the safety zone, autopilot navigation directly towards the installation when the vessel is entering the safety zone, and autopilot navigation towards the installation with "way-point" set directly to installation during the voyage planning.

In each of the scenarios there a number of operational barrier functions included. The barrier functions are variations of the two basic measures to avoid a collision. Detecting the danger, and taking action. To account for all possible failure causes, these barrier functions were broken down into separate basic events in fault trees. The deal with common cause problems, extra basic events are included (i.e., absence from bridge). To each basic event there are assigned a number of risk influencing factors. These were both risk influencing factors influencing the basic events directly and organisational factors influencing them indirectly.

The framework is a improvement from existing QRA frameworks in the sense that it has taken recent collisions into consideration, and enabled the opportunity to do risk influence modelling for the calculation of site specific risk. It can also be used as a tool for risk management, when the risk influences have been quantified. This model provides no quantifications, but it makes a good foundation for future work.

The collision risk model developed has several advantages compared to existing risk analysis models:

1. It incorporates knowledge from recent, representative collisions on the Norwegian Continental Shelf (NCS).
2. The model considers the guidelines and official safety procedures.
3. It has considers the difference of the collision types, and therefore includes three different scenarios to take all probable collisions into account.
4. The model considers the dependence between the different barrier functions and basic events, and split the scenarios in to several branches to account for more failure causes.
5. It includes RIFs from many sources to provide a large amount of relevant risk influencing factors.

8.2 Conclusions

To make the conclusions a look at the intended objectives for this master thesis is done:

- **Structure the causal chains of collisions between field-related visiting vessels and offshore installations.**
  Through the Chapters 3 and 4 the information that set the basis for identification of generic scenarios with structured chains of events in the collisions were presented. The generic collision scenarios were split in three, and described in Chapter 5.

- **Identify and structure safety barriers for relevant generic accident scenarios.**
  The safety barriers or barrier functions were identified and presented in Chapter 5, and then further broken down and analysed in Chapter 6.

- **Identify risk influencing factors important for the expression of the failure rate probabilities.**
  A combination of generic RIFs from the Risk OMT model and ship-platform collision specific RIFs were discussed and presented in Chapter 7.

- **Make a risk analysis framework based on the findings of the previous steps and Risk OMT model.**

  Through solving the previous steps and including elements from the Risk OMT model a risk analysis framework has been made.

8.3 Recommendations for Further work

To be able to use this framework as a tool in quantitative risk analyses, the following areas need further investigation:

1. Retieving basic event and initiating event probabilitites. Since this is a new framework, these are not available at the present time. Some of the basic event probabilities can be taken from or adjusted from existing QRA analyses, while others will require expert judgements or statistical data. Human reliability analyses can also be a source of information for human error probabilities. Surveillance stations are tracking the number of vessels on collision course each year, and this can be valuable to determine the initiating event probabilities.

2. Expert review of the RIFs. The risk influencing factors listed in this thesis are based on many sources of information, with different perspectives on which RIFs should be considered important. An expert review of the RIFs suggested can be a good way to make sure that the RIFs suggested are relevant, and that all significant RIFs have been included.

3. Quantification of rifs. The RIFs listed in Chapter 7 are all "measurable", but no quantification has been made. Scoring and weighting the RIFs are a challenging taks. There are several sources of information that can be used. Expert judgements, statistical data, human reliability analysis and studies not reviewed here.

4. Calculations. The calculations are a very challenging task considering the amount of basic events, and the even bigger amount of risk influencing factors. The basic concepts of doing calculations in Risk OMT is shown by (Vinnem et al., 2012), (Gran et al., 2012b) and (Vatn, 2013), but it is still considered a massive, time consuming challenge.

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Appendix A

Acronyms

AIS	Automatic Identification System
BBD	Barrier block diagram
BE	Basic event
BORA	Barrier and operational risk analysis
ETA	Event tree analysis
FTA	Fault tree analysis
HMI	Human-machine interface
IE	Initiating event
NWEA	North West European Area
NCS	Norwegian continental shelf
OTS	Norwegian: Operasjonell tilstand sikkerhet (Operational condition safety)
PIF	Performance influencing factor
PSA	Petroleum safety authority, Norway
PSF	Performance shaping factor
QRA	Quantitative risk analysis
RID	Risk influencing diagram
RIF	Risk influencing factor
Risk OMT	Risk modelling - integration of organisational, human and technical factors (Norwegian acronym)

Appendix B

Fault trees for scenario 2

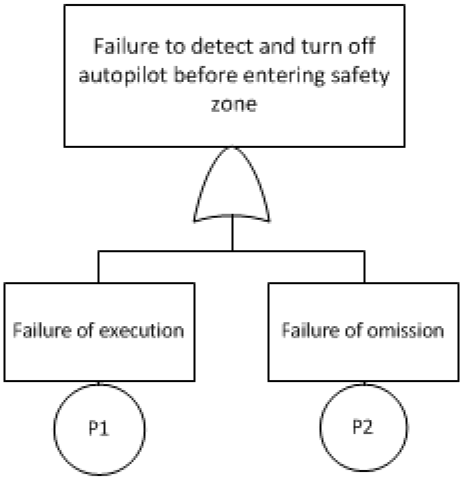

Figure B.1: Fault tree for the failure to detect and turn off autopilot before entering the safety zone.

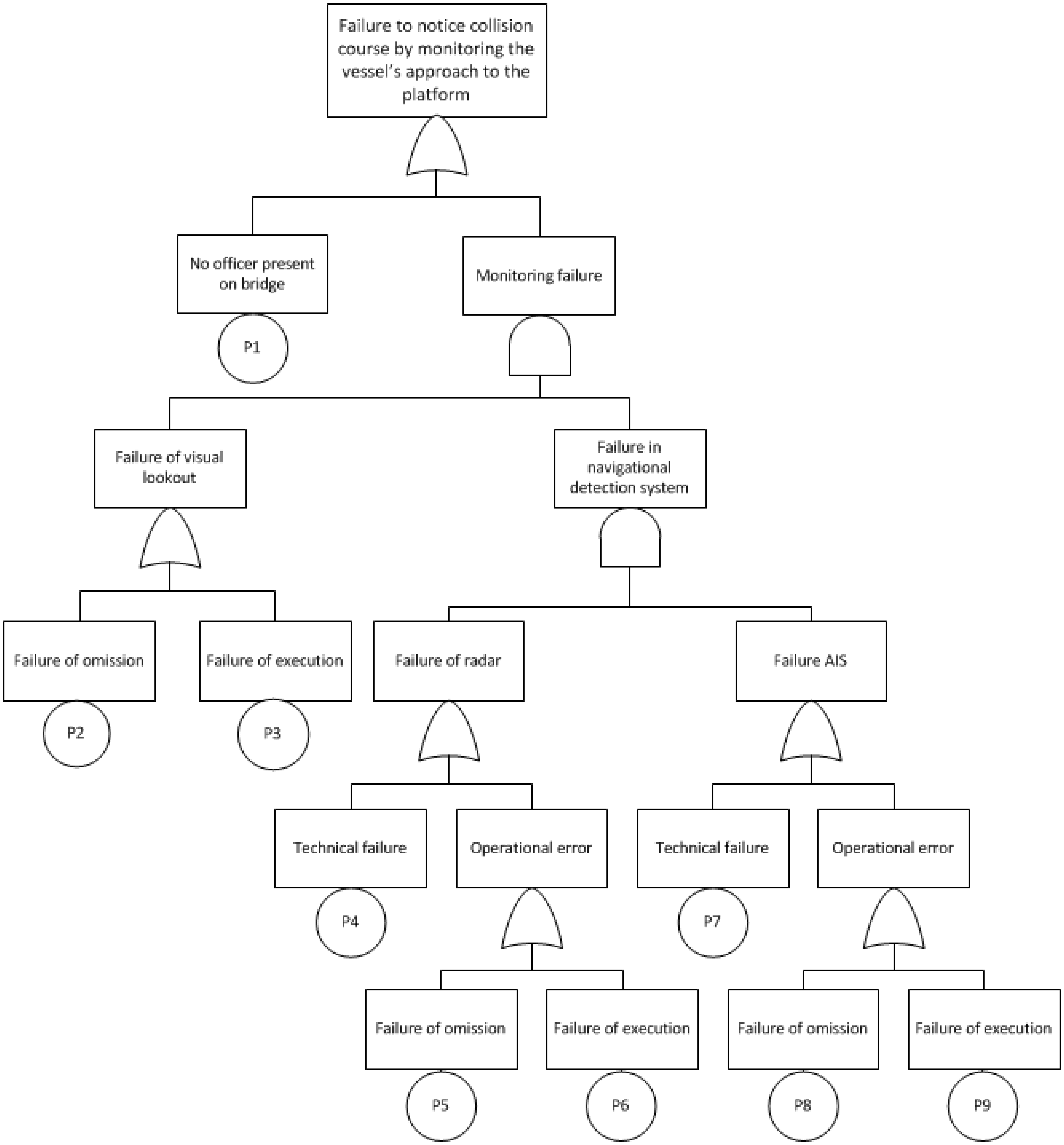

Figure B.2: Fault tree for the failure to notice collision course by monitoring the vessel's approach to the platform.

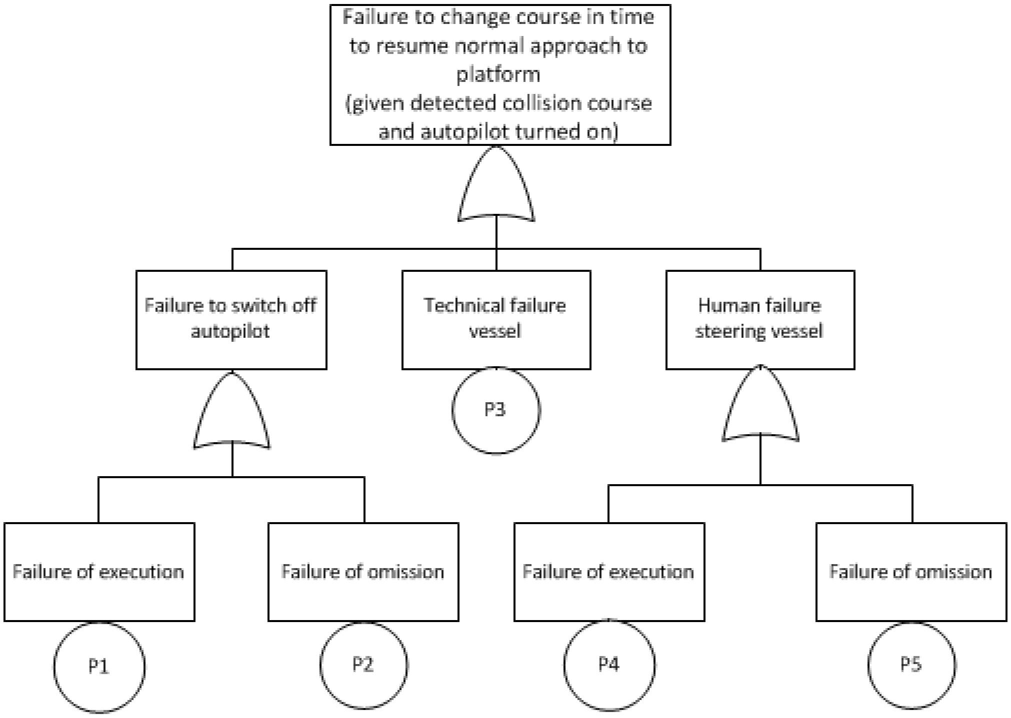

Figure B.3: Fault tree for the failure to change course in time to resume normal approach to the platform.

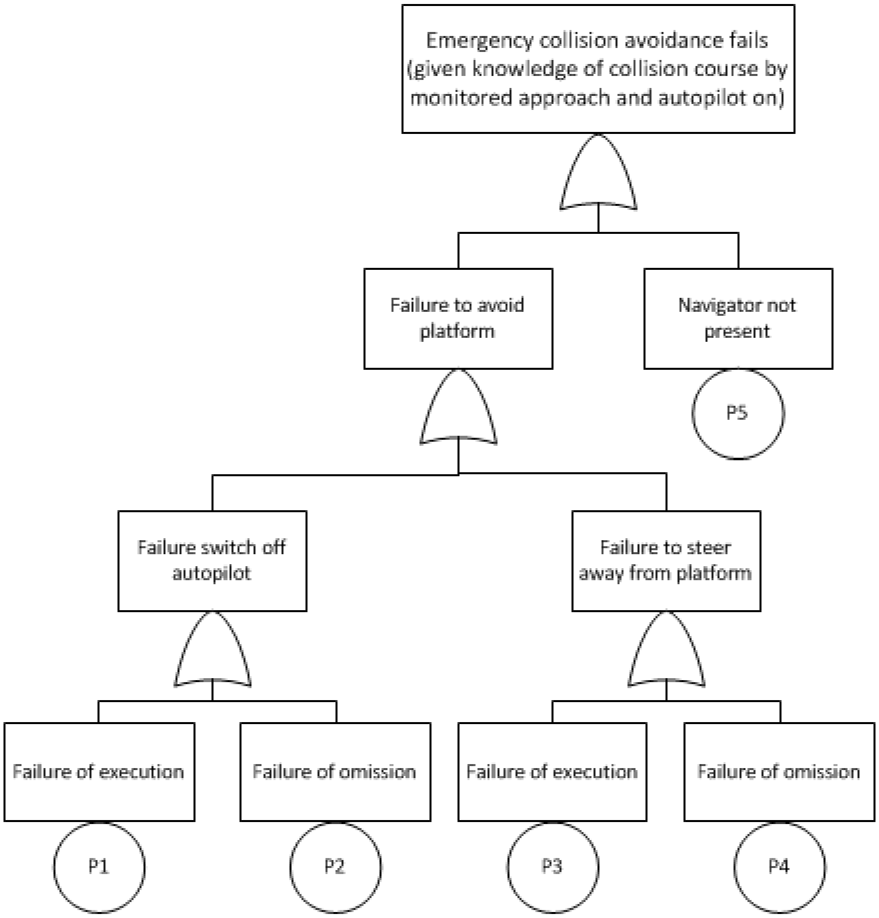

Figure B.4: Fault tree for the failure of emergency collision avoidance given knowledge of collision course, but autopilot left turned on.

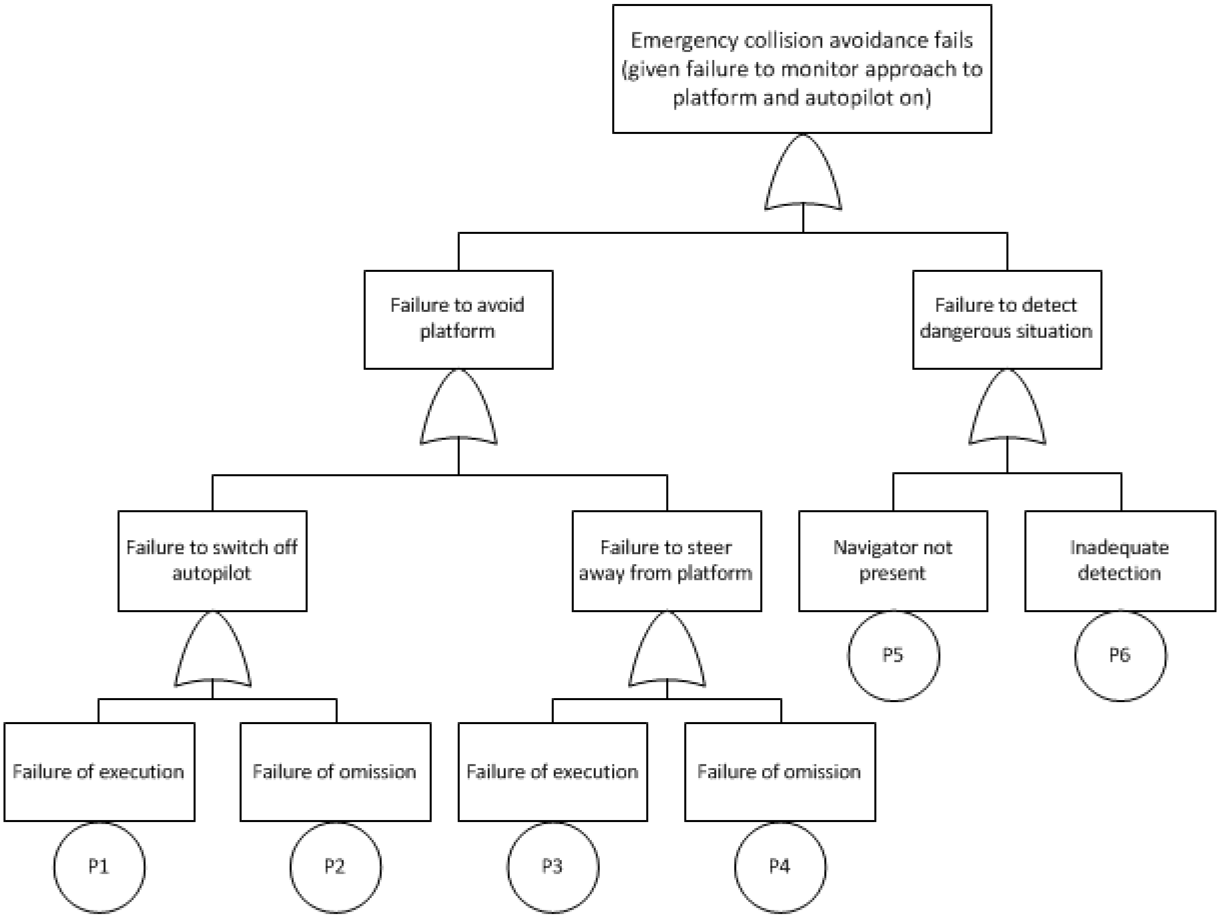

Figure B.5: Fault tree for the failure of emergency collision avoidance given failure to monitor the approach to the platform and autopilot left turned on.

Appendix C

Fault trees for scenario 3

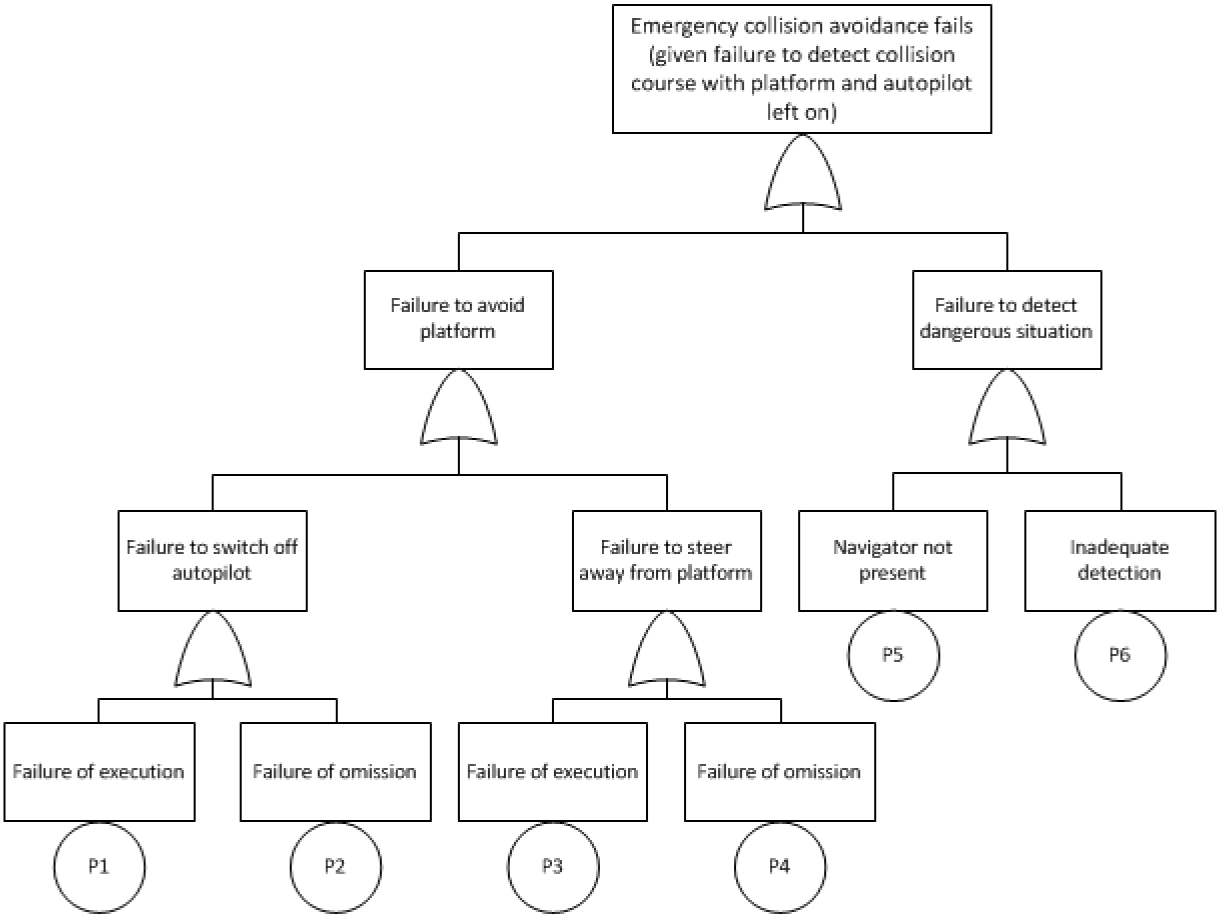

Figure C.1: Fault tree for the failure of emergency collision avoidance given failure to detect collision course early.

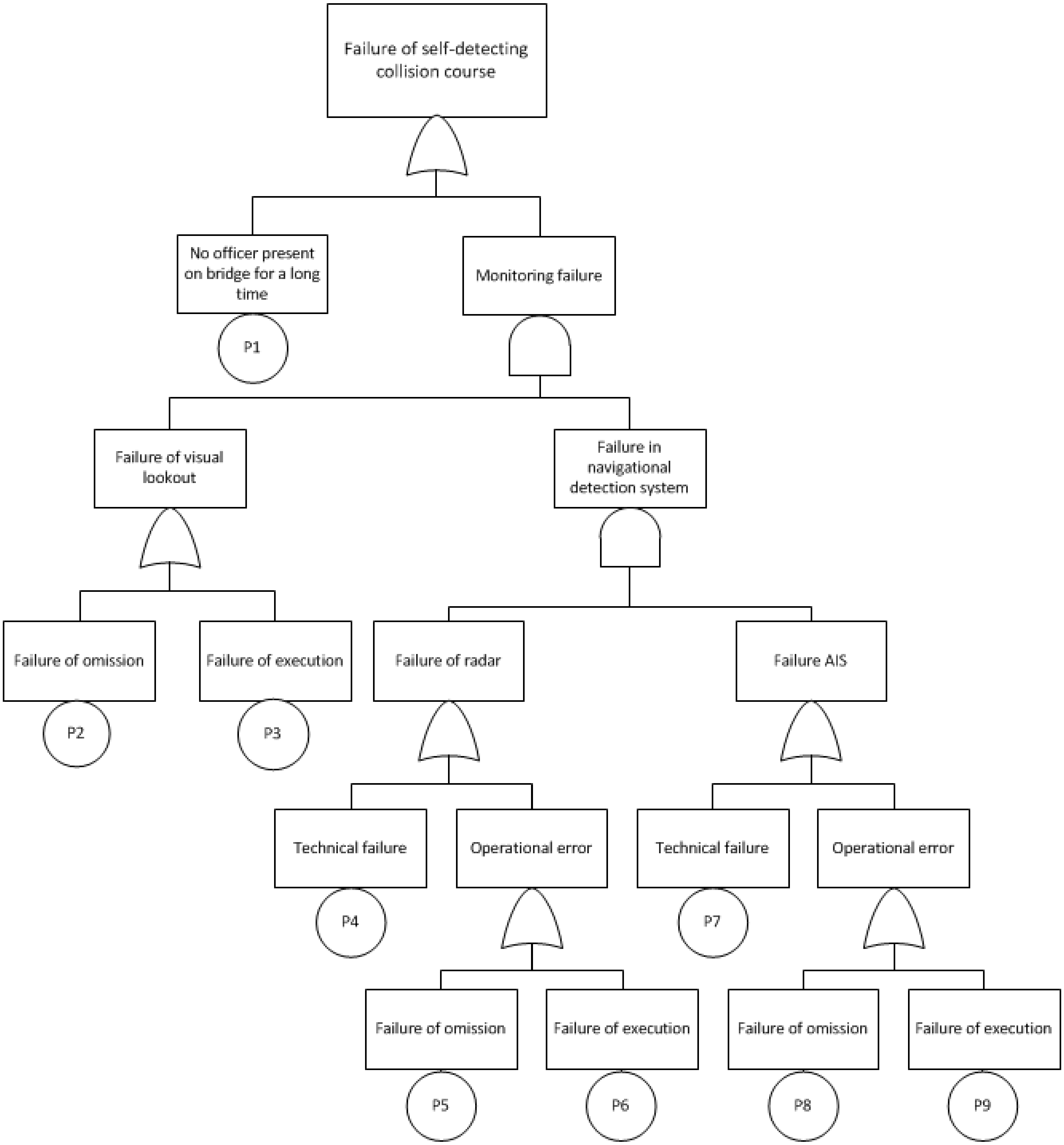

Figure C.2: Fault tree for the failure of self-detecting the collision course.

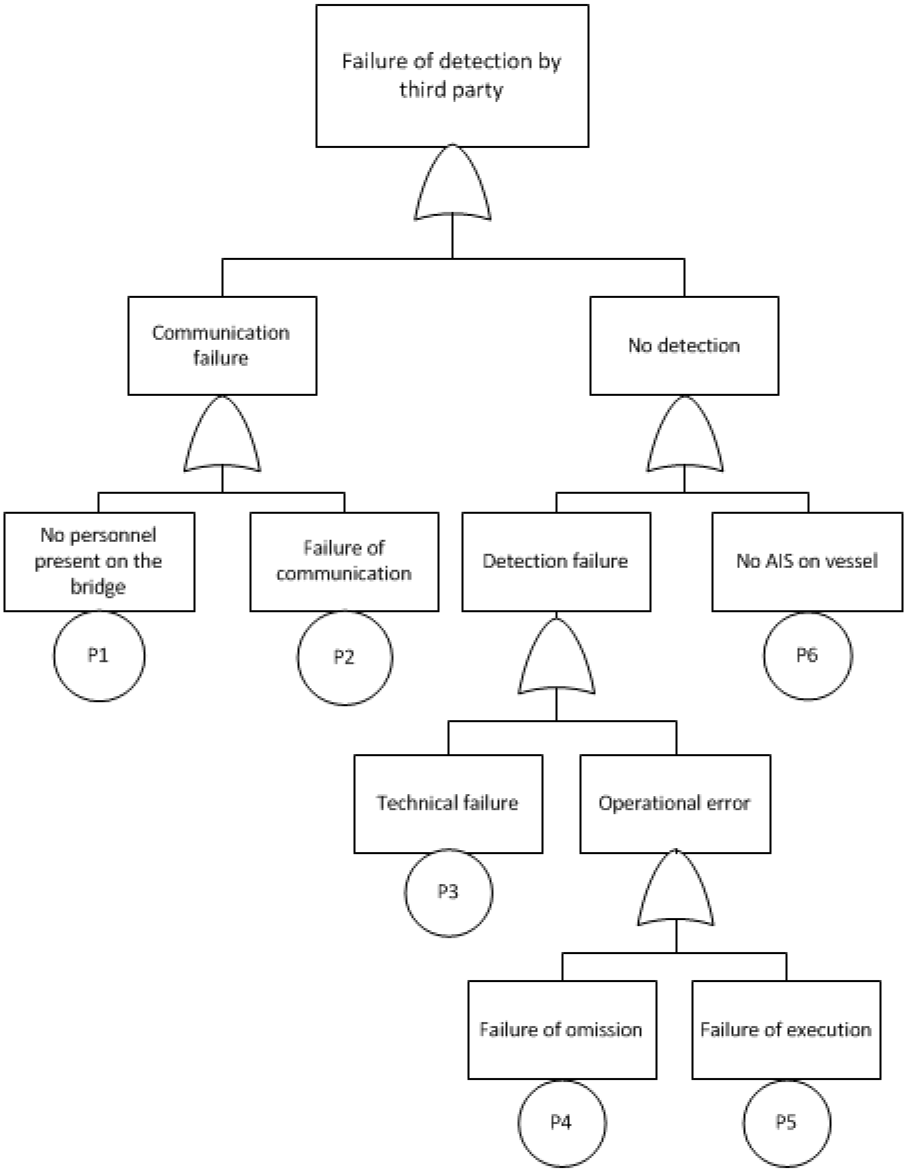

Figure C.3: Fault tree for the failure of detection by a third party.

Curriculum Vitae

Name:	**Erik Tvedt**
Gender:	Male
Date of birth:	1. July 1985
Address:	Stasjonsveien 21D, 0730 Oslo
Nationality:	Norwegian
Email (1):	erikfred@stud.ntnu.no
Email (2):	eftvedt@gmail.com
Telephone:	+47 45020842

Education

2012 -	t.d	**Reliability, Availability, Maintainability and Safety (MSc)** *Field of study: Risk analysis* *Project thesis: "Review of ship-platform collision risk models"*	NTNU, Trondheim
2011 -	2012	**Statistics (MSc)** *Unfinished due to change of study*	NTNU, Trondheim
2006 -	2011	**Mathematical sciences (BSc)** *Field of study: Statistics*	NTNU, Trondheim
2005 -	2006	**Mathematical sciences** *One-year programme*	NTNU, Trondheim
2001 -	2004	**High school** *Specialization: Mathematics, Physics, IT*	Åsane Gymnas, Bergen

Work experience

2013		**Summer job** *Review of ship collision methodology, consultant work on floatel collision analysis*	DNV, Risk Management Solutions, Oslo
2010 -	2013	**Shop assistant** *Part time job, closing responsibility weekends*	Rema 1000 Tiller, Trondheim
2009 -	2010	**Shop assistant** *Part time job*	På-plass bemanning, Trondheim
2007 -	2008	**Shop assistant** *Holiday job*	Rema 1000 Ulset Bergen
2004 -	2005	**Compulsory military service** *Second in command and depot manager*	CBRN Company, Engineer battalion, Skjold
2000 -	2001	**Summer job**	Bergen tax office, Bergen

Computer Skills

Advanced user of general IT-tools

R	*advanded knowledge*
Java	*advanded knowledge*
Microsoft Office	*advanded knowledge*
Matlab	*advanded knowledge*
MINITAB	*advanded knowledge*
LaTex	*advanded knowledge*
Visual Basic	*basic knowledge*
SQL	*basic knowledge*

Language skills

Norwegian	*native language*
English	*advanced level written and oral*
German	*basic level written and oral*