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After the risk assessment was performed, the frequency data used in the fault tree analysis was changed according to correction factors and safety factors. Based on this one could see that the changes in the frequency have a large effect on which risk control option that was found to be cost-beneficial and whether or not the calculated risk was above or below the intolerable risk limit.

Three formal safety reports from IMO were studied to see how uncertainty in frequency related to underreporting is dealt with in real risk assessments. There were found little or no mentioning of underreporting in the reports, and uncertainty in data was overall little dealt with.

Three approaches to correct for underreporting were suggested; correction factors, expert opinions and safety factors.

Keyword:

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Underreporting of maritime accidents – how it affects risk assessments and suggestions for correction

Master thesis spring 2011

Ellen Kristine Ombler
June 9, 2011

Preface

This report is written during the spring 2011 and is written as a master thesis at the Norwegian University of Science and Technology (NTNU) in Trondheim, at the department of marine technology. The report examines how underreporting of maritime accidents affect the results of a risk assessment.

The report is written by Ellen Kristine Ombler, MSc student, and the work has mainly taken place at Det Norske Veritas' offices at Høvik. The report is a part of the research project FARGE coordinated by Det Norske Veritas (DNV). The opinions expressed in this report do not represent the view of DNV or NTNU, but is solely the opinions of the author.

This report would not have been the same without the help from several contributors. First of all, I would like to thank all those at DNV that was willing to give me information and answer my questions, especially Peter Hoffmann and Martin Hassel in Safetec for providing useful information. In addition, I would like to thank Håvard Gåseidnes at the Norwegian Maritime Directorate for making sure that the two days spent in Haugesund was invaluable and chief pilot Rune Haukland for giving me a practical view of the collision risk by letting me accompany on a pilot mission in the Oslofjord. In the end, I would like to give a special thanks to my supervisor Professor Bjørn Egil Asbjørnslett for giving me knowledge, guidance and motivation during the work with this thesis and my study at NTNU.

Høvik, June 2011

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Ellen Kristine Ombler

Abstract

In this report it is looked at how underreporting of maritime accidents affects the results of a risk assessment, from the frequency analysis to the decision-making process. As a basis, a risk model is made and the accident scenario is a ship-to-ship collision in the Oslofjord area. The risk model is based on two other models; the F-risk model from the Norwegian Maritime Directorate, concerning ferry risk in Norway and the MARCS model from Det Norske Veritas.

First the risk of a collision in the Oslofjord was calculated by the use of a fault tree and an event tree. The result was compared with historical accident data reported to the Norwegian Maritime Directorates database. After the risk was established, several risk control options was suggested and three of them was included in a cost-benefit assessment. Discussion regarding the use of expert opinions and risk acceptance criteria was also included.

After the risk assessment was performed, the frequency data used in the fault tree analysis was changed according to correction factors and safety factors. The correction factors were in accordance with a degree of underreporting of 30 and 40 %.

Based on this one could see that the changes in the frequency have a large effect on which risk control option that was found to be cost-beneficial and whether or not the calculated risk was above or below the intolerable risk limit.

Three formal safety reports from IMO were studied to see how uncertainty in frequency related to underreporting is dealt with in real risk assessments. There were found little or no mentioning of underreporting in the reports, and uncertainty in data was overall little dealt with.

Three approaches to correct for underreporting were suggested; correction factors, expert opinions and safety factors. None of the approaches was found to be a perfect solution. A combination of a conservative approach and some use of expert opinions where this is needed were found to be the best solution. Correction factors for underreporting cannot be established before the degree of underreporting is known. Therefore it should be focused on how to find the degree of underreporting related to maritime accidents. The road transport sector has come up with suggestions for correction factors related to unreported accident and collaboration between the different transport sectors could be beneficial.

It is also mentioned that uncertainty related to underreporting is only one of many uncertainties when looking at a risk assessment. Uncertainty in general is an important aspect and should be dealt with. Sensitivity analyses should be a part of risk assessment reports.

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Definitions and Abbreviations

ALARP - As Low As Reasonable Practicable
CBA - Cost-Benefit Assessment
FSA - Formal Safety Assessment
GCAF - Gross Cost of Averting a Fatality
HSE - Health and Safety Executive (UK)
IMO - International Maritime Organization
LNG - Liquid Natural Gas
NCAF - Net Cost of Averting a Fatality
PEC - Pilot Exemption Certificate
PLL - Potential Loss of Life, the statistical number of persons within a given group which is killed due to a specific accident each year
RCO - Risk control option, also referred to as risk reducing measure
RoPax - Ro/ro-passenger vessel (ro/ro stands for roll-on/roll-off)

1 Introduction

1.1 Background

During an average day, many decisions are made. Some are only small ones that do not have a large effect, but from time to time the decision will have consequences that can last for a long time. Some only affects one person, whilst others can have consequences in all parts of the world. Either way it is important to be sure that the decision which is made is correct, but how can one be sure?

For all decision-making processes, accurate data or information and a transparency in the basis are two aspects that are of vital importance. In this thesis the focus will be on the background for decision-making for risk reducing measures in relation with maritime accidents.

The risk can never be zero, it will always be some probability that an unwanted event will happen and one can never remove all the consequences. Before decisions regarding risk reducing measures can be made, a risk assessment must be performed. Here statistical data, often in combination with expert judgements, are used to find the frequency of a given accident scenario or unwanted event. The frequency is then used to find the probability of each consequence. After the risk is established, it is time to find risk reducing measures and do a cost benefit analysis to find if the relevant measures are worth implementing. Many parameters are necessary before one can make a decision. Each parameter has some uncertainty and it is easy to understand that this uncertainty will have an effect on the final decision.

This thesis will discuss how uncertainty in data, especially related to underreporting of accidents, will affect the decision-making process and how one can be sure to make a sound decision regarding risk reducing measures.

1.2 Objectives

Often historical data is used to find the frequency of the relevant accident scenario and if the frequency is too low, the result from the risk assessment will be too optimistic. The risk assessment is often the basis for the decision regarding risk reducing measures and if the basis is not accurate, this will affect the decision-making.

After the work with this thesis, the following goals shall be achieved:

- Understand how underreporting of accidents affect the risk assessment results
- Come up with suggestions for how to correct for underreporting related to expert judgments and correction factors

In addition, a better insight in the different steps of a risk assessment shall be attained.

1.3 Structure

This thesis is divided into two parts where the first part (chapter 2-6) contains information about the risk assessment process and the second part (chapter 7-10) includes suggestions and discussions for how to correct for underreporting of maritime accidents.

In the first part, the main focus is on the construction of a collision model. The collision model is based on other risk models which are briefly described in chapter 2 and then the collision risk model is created and explained in chapter 3. The collision risk is calculated in chapter 3. Chapter 4 contains a description of the use of expert opinions in the risk assessment process, both quantitatively and qualitatively. The next step in the risk assessment is discussion regarding risk control options (chapter 5) followed by the final step, a cost-benefit assessment (chapter 6).

The second part starts with a discussion and quantification on how the result is affected by a change in the data (chapter 7). The next chapter (chapter 8) contains a brief summary of how uncertainty is dealt with in three different FSA reports. Based on this, three different approaches on how to correct for underreporting is suggested and introduced in chapter 9. Chapter 10 discuss the findings.

In the end, a final conclusion and suggestions for further work is included.

The report is written in such a way that it is assumed that the reader have some knowledge about risk assessment.

1.4 Limitations

The limitations in this thesis are both related to the extent of the risk model and the input data. Every step of the risk assessment, including fault tree and event tree analysis, risk control options and cost-benefit assessment are subject to simplification and assumptions. This has affected the final result when it comes to collision risk, but it is assumed that it is valid to show how underreporting affects the risk assessment, which is the purpose of this study.

The input data in the frequency and consequence part of the analysis is based on both relevant literature and assumptions. The data used in the cost-benefit assessment is only based on assumptions.

Due to time limitations, only three formal safety assessment (FSA) reports from IMO have been studied and the focus has been on the risk model created in this study. This does not necessarily give a correct picture of how uncertainty in data is dealt with in FSA reports and more reports should be studied.

Many aspects in this thesis, such as risk acceptance criteria and the use of expert opinions, are subject to much discussion. This has not been focused on in this thesis, but has been mentioned and discussed briefly.

2 Statistical risk model - general

Statistical databases are often used as input data to risk models. The quality of the model and the quality of the data is therefore of vital importance to get a god result from the risk analysis. Risk analyses are used as a background for decision-making when it for instance comes to implementations of new regulations concerning safety at sea and establishing risk acceptance criterions.

In this study two risk models will be looked into; the F-risk (Ferry risk) model from Norwegian Maritime Directorate (NMD) and the MARCS (Marine Accident Risk Calculation System) model from Det Norske Veritas (DNV) as part of the research project SAFECO (Safety of Shipping in Coastal Waters). Based on these two models, a simplified risk model for collision in the Oslofjord area will be made. This model will be the basis for the study on how the quality of data affects the results.

Often grounding accidents are also analysed in studies with collision accidents, but in this study only collision is included. Many of the same causal factors can be found for these two accident scenarios. (Mcrea, 2009) It is assumed that the more severe the accident is, the higher is the possibility for it being reported and therefore, that the data is more accurate. Both collision and grounding can have severe consequences. Due to speed restrictions in the Oslofjord, the consequences for grounding are often not so severe. For many of the grounding incidents, the vessel is able to get off by own means. These incidents are assumed to seldom be reported. For a ship-to-ship collision, more parties are involved and the probability that this will be reported is therefore assumed to be higher. In the summer, the Oslofjord have a high traffic density with vessel types varying from small leisure vessels to large cruise ships. A collision accident between these two vessel types can have serious consequences. Both grounding and collision accidents can lead to environmental damages due to oil spills. Environmental consequences have been much more focused on the last years, and accidents which have such consequences are assumed to have a higher degree of reporting than those where oil spills are not a possible outcome. In addition, grounding accidents are more common than ship-to-ship collisions and therefore more data exists for grounding scenarios. Based on this and the environmental consequence, it can be argued that this study should both include grounding and collision scenarios. This study does not have the purpose of finding the collision risk in the Oslofjord, but to discuss the problems relating to uncertainty in data. The reason why only ship-to-ship collision scenarios are included in this study is because it is assumed that one accident scenario is sufficient to create a risk model which will serve as a basis for discussion regarding uncertainty in data. This is also the reason why not collision with quay-accidents are included. The reason why collision and not grounding is chosen is because it is assumed that it is easier to find data for ship-to-ship collisions than for grounding accidents due to the possible severe consequences.

2.1 F-risk

F-risk is a risk model for domestic ferry traffic in Norway. The first part of the project was carried out between December 1995 and December 1996 by SINTEF and several collaborators. The main purpose of the project was to find which factors that had the highest influence on the risk level for domestic ferry transport. (Hokstad, et al., Risikoanalyse for innenriks fergetransport, 1997) Risk influencing factors was established and divided into four groups, in addition to frequency influencing and consequence influencing factors. The four groups are still today as follows:

1. Fairway/external conditions

2. The ferry
3. The ferry traffic
4. Operational measures (the ship owner)

Six main accident types were included:

1. Collision
2. Grounding
3. Loss of stability due to other causes
4. Fire
5. Dangerous cargo accident
6. Personal injury due to other causes

To calculate the risk for a given ferry route, an average total risk for the domestic ferries was found based on statistical data. This was then multiplied with several correction factors where the values are established for each route. These correction factors were based on risk indicators which were quantified based on questionnaires from the relevant ship owners. Reports of the risk for domestic ferry traffic have been published annually since 2005 and can be found on NMD's website, www.sjofartsdir.no.

2.1.1 Frequency

Historical data, mainly from NMD, were used to establish the frequency for the different accident scenarios. Frequencies for high consequence accidents were found based on estimations since no historical data exists for Norway. For each ferry route, the collision risk was calculated by adding up the number of crossing and meeting vessels. The numbers were found based on a questionnaire answered by the ferry companies.

When it comes to ferry traffic, it is assumed that the degree of reporting is quite good, especially when it comes to collision and grounding. This is because there are almost always passengers on board which will notice if something happens and the company and the captain wish to report it before the passengers alarm the media. In F-risk, ferry routes in all parts of Norway are included and therefore it is large variations in for instance weather conditions and fairway characteristics.

2.1.2 Consequence

Consequence classes were established and the frequencies found from historical data were distributed among the different classes. For the final risk calculation, some of these frequencies were adjusted. The final risk was defined as number of fatalities per year.

2.2 MARCS

The information in this chapter is based on (Dahle, Fowler, Hauso, & Kristoffersen, 1997). MARCS was developed as a part of the SAFECO project (Safety of shipping in coastal waters) in 1997. Based on analysis of accident causes, five accident scenarios were categorized and were modelled separately.

1. Intership collision
2. Powered grounding
3. Drift grounding
4. Ship structural failure
5. Fire and explosion on-board ship

Below is a block diagram showing the structure of MARCS. As can be seen by the block diagram, a wide range of data is needed to get the most out of MARCS.

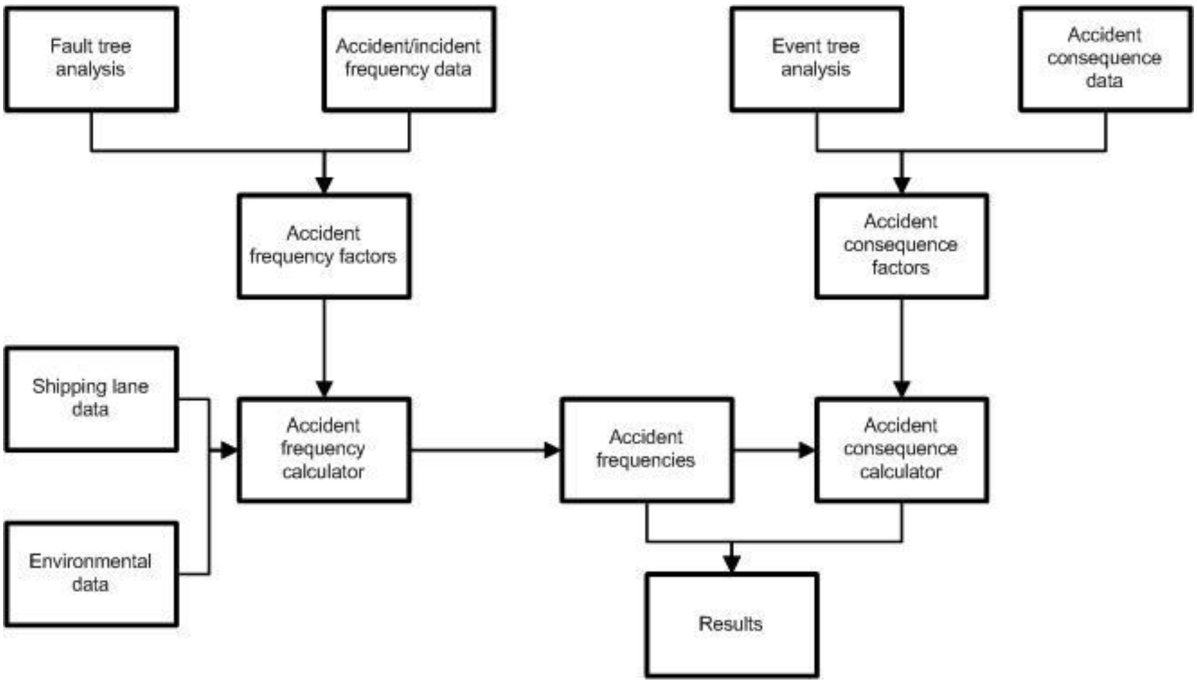


Figure 2-1 MARCS block diagram Source: (Dahle, Fowler, Hauso, & Kristoffersen, 1997)

2.2.1 Frequency

The frequency for each accident is calculated by the following terms:

$$\begin{aligned}&Accidents\ per\ area\ per\ year\\&\qquad = Number\ of\ critical\ situations\ per\ area\ per\ year\\&\qquad \times probability\ of\ an\ accident\ per\ critical\ situation\end{aligned}$$

The definition for a critical situation is depended to each accident type. The number of critical situations is derived from data that describes the environment, for instance traffic data. For the probability of the collision and grounding scenarios, fault tree analysis is used. The input data for the fault trees have been found based on both statistical data and expert judgements. For the fault tree analyses, technical, human and organizational factors in addition to external factors were included.

For the study concerning the Oslofjord area, historical data was collected from the database of Norwegian Maritime Directorate (NMD) as input to the fault tree and to compare with the results from MARCS.

2.2.2 Consequence

In the MARCS model, two scenarios is included in the consequence model

1. Oil spill due to accidents with crude oil tankers
2. Fatalities within the vessels crew and passengers

The focus in (Dahle, Fowler, Hauso, & Kristoffersen, 1997) is on the frequency part, and there is therefore little information regarding the consequence analysis.

3 Collision risk model

To best see the effect underreporting have on the final result in a risk assessment, a risk model will be made and will be the basis for a simplified risk assessment concerning collision risk in the Oslofjord area. By describing each step of the risk assessment, it is assumed that it is easier to understand how a small change in the data affect the final result and make a discussion regarding this topic. The first part of this thesis will therefore concentrate on the creation of the risk model and discussion regarding the effects will be focused on later.

In chapter 2, two risk models are described. One of them is only used for domestic ferry traffic, while the other one have a more general approach when it comes to vessel types and area. Based on these two models, a simplified model for the collision risk in the Oslofjord area will be created.

Since the subject in this study is on how underreporting of accidents affect risk assessment, the main focus will be on the frequency part, but consequence analysis will also be included. The consequences are often divided into consequence classes, like in F-risk. The frequency affects how the accidents/incidents are distributed for each consequence class. Further, the results from the calculations of frequency and consequence give the basis for cost-benefit-assessments.

3.1 Purpose of the risk assessment

The purpose of this study is not to make a complete picture of the collision risk in the Oslofjord. The two risk models mentioned above are based on a large quantity of data in addition to expert opinion. The data is used as input in a computer programmed model and the output is the calculated risk. In this study, the risk model will be much simplified and it will be possible to do all the calculations without the use of computer models. This means that the level of details will be largely reduced. As mentioned, the main purpose of this thesis is to examine to what degree underreporting of accidents affect risk assessments and the accident causes for collision will therefore not be focused on.

3.2 Frequencies

In this study, three main methods used to calculate the frequency of a given accident scenario will be looked at. The first method is a traffic-based method where traffic density and fairway characteristics are of importance, but does not include historical data. The other method is a fault tree analysis where the top event is collision and the basic events and their input data are found based on literature, statistics and/or expert opinions. The third one is to only use historical data of reported accidents to find the frequency. Both F-risk and MARCS have used fault tree analysis and historical data. According to Andreas Falck, DNV Senior Principal Engineer, it is often an even larger problem to find the correct data for the exposure than to find the correct data for the historical number of accidents. In addition, it is important to make sure that the data that is used is relevant for the area which is analysed. (Falck, 2011). Below is a brief description of the three methods which are mentioned above.

3.2.1 Traffic-based model/collision model

Traffic-based models do not look specifically at the causes for an accident. Often only the frequency is calculated. Information about traffic-density and the surroundings, which are included in a traffic-based model, give a better description of the relevant fairway. Where fault tree analysis can find causes which are general for a collision accident, a collision model can find the frequency for one specific fairway. In addition, with the use of a collision model one can differ between crossing and head-on collisions.

3.2.2 Fault tree analysis

A fault tree can either be used to identify which factors or components that cause an unwanted event or it can be used to find the frequency of the unwanted event. The difference between these two approaches is that in the first one the frequency of the top event is given and in the second one the frequency of the basic events are given. Uncertainty in data is relevant for both approaches. For the first one, inaccurate data for the top event frequency may lead to wrong results regarding which basic events which are most relevant. If the data for the basic events are inaccurate, this may lead to incorrect frequency of the top event. This frequency is further used in the risk analysis and will therefore influence the further calculations. Fault tree analysis is a common method to use in risk analysis and both MARCS and F-risk is based on this. Fault tree analysis will be an important part of this study.

3.2.3 Historical data

Historical accident data can be used to verify the results from a traffic-based model or fault tree analysis, or it can serve as a basis for the frequency analysis. When using historical data, it is important to be aware of who/what the source is. For this study, the Norwegian Maritime Directorate's database is assumed to be the best. Number of reported ship-to-ship collisions in the Oslofjord is limited. To get the most out of historical data, variation in for instance vessel type, flag states and age of vessels is preferred. It is therefore chosen not to use historical data alone to find the frequency, but in combination with the other methods.

Another method that is applicable to find the frequency of an unwanted event is Bayesian Belief Network. It will not be created such a network in this study. An example of a Bayesian network for ship-to-ship collisions can be found in (Friis-Hansen, Ravn, & Engberg, 2009).

3.3 Traffic-based model/collision model

There exist many collision models with different formulas used to calculate the frequency. In (Nyman, 2009), seven collision models are described briefly. The use of AIS data is an important factor in all the models mentioned. For this study, the limitations in information regarding the traffic in the Oslofjord will give limitations to the model. This study will therefore not concentrate on creating corrects models regarding the collision risk in the Oslofjord, both when it comes to collision model and fault tree. Discussion regarding the different approaches will be the main focus area.

To find the frequency of a collision accident for a given fairway, two parameters are needed. First, the probability of a collision given that the vessel is on collision course and second, information regarding the traffic. In (Dahle & Hassel, 2011), these two are calculated separately, but in (Kristiansen, 2005) another approach is given. In (Dahle & Hassel, 2011), no explanation of the probability of a collision is given, and therefore the focus in this study will be on the equations given in (Kristiansen, 2005), Equation 1 and Equation 2.

The probability of an accident is in (Kristiansen, 2005) given as the probability of loss of control multiplied with the probability of impact. This means that even if the vessel has lost control, it may not cause a collision. The probability of loss of control is related to the vessel itself, whilst the probability of impact is related to both the fairway and the vessel. In (Kristiansen, 2005) a proposition for a mean value for the probability of loss of control is given, which can be used for all fairways.

As mentioned, there are two types of collisions, head-on and crossing. These two collision types require different equations for calculating the probability of impact. For head-on collisions the probability of impact given that the control is lost is given in (Kristiansen, 2005) as a function of the speed (v) and beam (B) for each vessel, the width (W) and distance (D) of fairway and the arrival frequency of meeting ships (N_m). The difference for crossing collisions is that both length (L) and beam of both vessels are included and width and distance of the fairway is not included.

Head-on collision:

$$P_i = \frac{(B_1 + B_2)}{W} \cdot \frac{(v_1 + v_2)}{v_1 \cdot v_2} \cdot D \cdot N_{m1} \qquad \text{Equation 1}$$

Crossing collisions:

$$P_i = \frac{N_{m1}}{v_2} \cdot (B_1 + L_2) + \frac{N_{m1}}{v_1} (B_2 + L_1) \qquad \text{Equation 2}$$

For the crossing scenario, it is assumed that the vessel will have an angle of 90 degrees at the time of the impact. This is also the assumption in (Dahle, Fowler, Hauso, & Kristoffersen, 1997). Equation 2 implies that the probability for the following two scenarios is added together:

1. The crossing vessel hits the subject vessel
2. The subject vessel hits the crossing vessel

To find the frequency of meeting and crossing vessels, MARCS and F-risk have used to different approaches. In MARCS, the number of meeting and crossing vessels is based on a definition of critical situation. In the study by (Thevik, Sørgård, & Fowler), the following definition is used specifically for the Oslofjord:

For collisions, the critical situation is defined as when two ships come to close quarters; passing within half a nautical mile of each other (encounter situation).

The numbers are found from traffic data (AIS data).

In F-risk, the numbers are the number of “dangerous” crossing and meeting vessels and the numbers are given by the different ferry companies. A “dangerous” vessel is a defined as a vessel which can cause leakage damage which results in water break-through on the vessel.

As can be seen from the equations above, the frequency of meeting and crossing vessels, Nm, affects the probability of impact linearly. It is therefore of great importance that these numbers are correct. To find accurate data, both the approaches used in MARCS and F-risk are dependent on that the definition of dangerous situation/vessel is clearly stated. Especially F-risk is vulnerable to different interpretation of the definition regarding “dangerous” vessel since the “counting” is done by humans. In addition, since the number of meeting and crossing vessels is given by the ferry companies, one cannot be sure that these numbers are accurate. The numbers given may both be more and less than the actual numbers. In (Nyman, 2009), inaccuracy in AIS data is discussed. It is recommended that methods which can check the quality of the AIS-data and correct for errors and inaccuracy should be used. The method used in MARCS is therefore also subject to uncertainty.

Another aspect with the meeting frequency is that it is large variations in time of day and time of year. During the summer, the traffic density in the Oslofjord is largely increased compared to the winter. Especially leisure vessels with boatmen with little experience can cause dangerous situations. These large variations in traffic density, vessel types and experience for those who steer the vessels, cause problems when trying to calculate the probability of an accident during a whole year.

Due to the lack of data regarding the traffic in the Oslofjord, the probability of collision will not be calculated in this study based on a traffic-based model. Both the studies from (Thevik, Sørgård, & Fowler) and (Dahle & Hassel, 2011) have come up with a result for the collision risk. It is important to notice that in the study from (Dahle & Hassel, 2011) only the inner part of the Oslofjord was included and since the length of the fairway affects the probability of a collision it will not show the same results as (Thevik, Sørgård, & Fowler). The longer the fairway is, the higher the probability is for collision. Therefore the study from (Thevik, Sørgård, & Fowler) has a higher probability for collisions than the study from (Dahle & Hassel, 2011).

The vessel types that are included in the study by (Thevik, Sørgård, & Fowler) are tankers, bulk carriers, general cargo vessels and ferries. In the study by (Dahle & Hassel, 2011), the main subdivisions are passenger vessels, cargo vessels and tankers. The included vessel types are therefore approximately the same in both studies, and it is assumed that the numbers are comparable for the purpose of this study.

Below are the results from the two studies which show the total collisions ratio per year. These data will be further discussed later in chapter 3.5.1.

Table 3-1 Summary of frequencies for collisions in the Oslofjord area based on traffic-based models

(Dahle & Hassel, 2011)	0.69 collisions per year
(Thevik, Sørgård, & Fowler)	2 collisions per year

3.4 Fault tree analysis

For identifying the risk influencing factors and find the input data for the fault tree, both F-risk and MARCS will be used as a basis in addition to other relevant literature. With the use of fault tree, the input data can be varied for the different basic events. For instance, it is supposed that the data for human errors have a larger degree of uncertainty than the data for technical errors. This can be taken into consideration in a fault tree analysis.

According to (Friis-Hansen, Ravn, & Engberg, 2009), the causes of grounding and collision accidents can be summarized into four main groups.

1. *Due to failure in manoeuvring, including inaccurate positioning and poor lookout.*
2. *Due to incapacitation of personnel such as doze, drunkenness engaged in other tasks and sudden illness. Doze has been identified as one of the main causes for grounding.*
3. *Due to technical problems with engine, steering gear, or navigational instruments.*

4. *Due to environmental causes, such as visibility, wind, or waves.*

For collision, these causes can relate to either the subject vessel or for the crossing or meeting vessel.

In (Ombler & Skollevold, 2010) the fault tree below can be found. The fault tree has a low degree of details due to lack of input data at the time the study was performed.

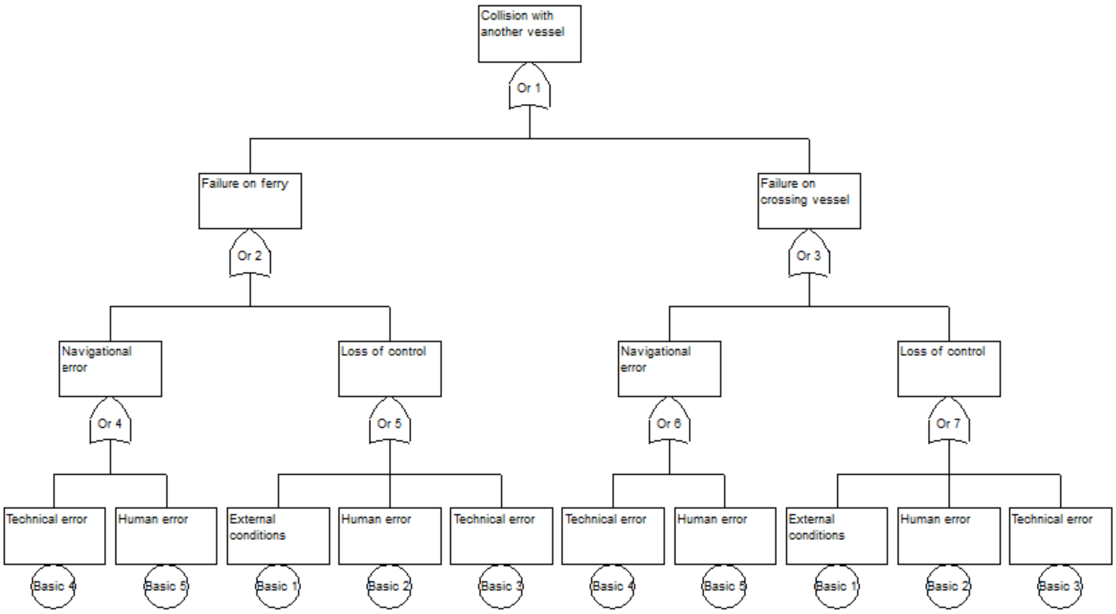


Figure 3-1 Fault tree model found in (Ombler & Skollevold, 2010)

(Due to poor interaction between the fault tree program CARA and MS Word, the quality is poor. The fault tree can be found as the lower part of the fault tree in Appendix A – Complete fault tree used in the fault tree analysis)

The four groups mentioned above from (Friis-Hansen, Ravn, & Engberg, 2009) are all included in the fault tree from (Ombler & Skollevold, 2010).

Below are the top levels of the causal tree used in F-risk which were used to establish the causes of each accident scenario. It is important to notice that this is not a fault tree containing gates, but a diagram showing the relation between the different causes for a collision scenario.

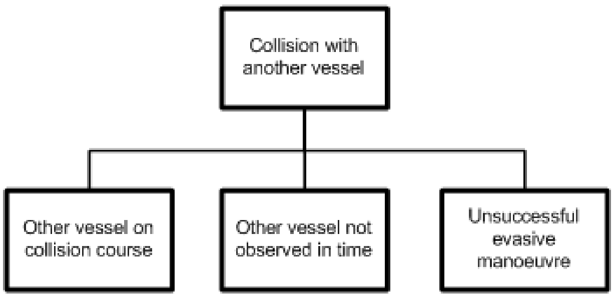


Figure 3-2 Causal tree used in the F-risk model
Source: (Hokstad, et al., Risikoanalyse for innenriks fergestransport, Del 2, Vedlegg, 1997)

This shows an important aspect with collision models; even if two vessels are on collision course they can avoid collision by carry out the correct actions. This is not included in the fault tree from (Ombler & Skollevold, 2010)

In the fault tree in the MARCS model, Figure 3-3, it is divided into failure on “other” ship and failure on “own” ship, like in (Ombler & Skollevold, 2010). The figure below shows only the first levels and is only a small part of the complete fault tree which can be found in (Dahle, Fowler, Hauso, & Kristoffersen, 1997). The complete fault tree contains both technical and human errors, external conditions such as weather and organisational factors. It is worth noticing that the top event in the fault tree from MARCS is “collision whilst on dangerous course”, while in F-risk the top event is “collision with another vessel”. This means that in MARCS it is already assumed that the vessel is on collision course. This can also be seen in the formula which is used for calculating the probability of a collision, where the term “critical situation” is important.

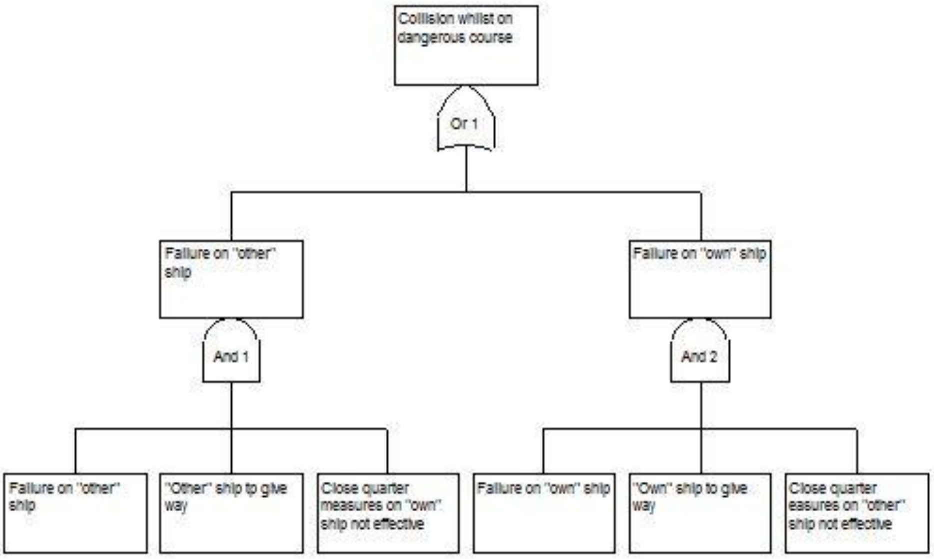


Figure 3-3 Fault tree from MARCS Source: (Dahle, Fowler, Hauso, & Kristoffersen, 1997)

As a final example of a fault tree for a collision scenario, the top level of the fault tree from the study from (Antão & Soares, 2006) is shown.

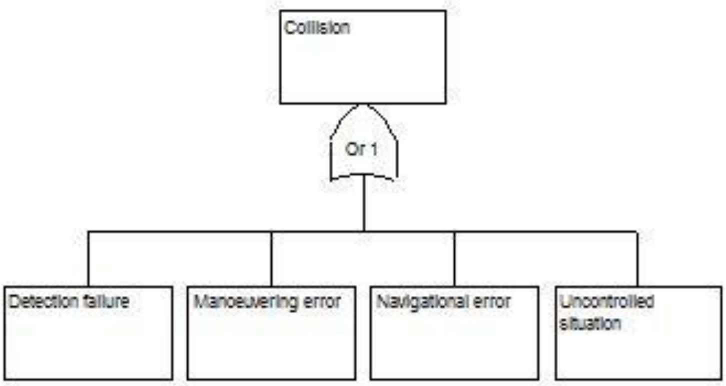


Figure 3-4 Fault tree from (Antão & Soares, 2006)

Collision is in (Antão & Soares, 2006) defined as “a ship striking or being struck by any self-propelled ship whilst at sea…” This fault tree does not differ between the two vessels involved in the collision. The purpose of the study by (Antão & Soares, 2006) is to find the minimal cut sets and this influence the construction of the fault tree. It is assumed that the same basic events are valid for both vessels involved. Therefore, by including both vessels, the result would be two copies of the listed fault tree, as seen in the fault tree used by MARCS in (Dahle, Fowler, Hauso, & Kristoffersen, 1997).

It is worth noticing that for all the fault tree examples mentioned in this study, only two vessels are involved in the ship-to-ship collision and they do not take into account collision with a group of vessels. In (Nyman, 2009) this is said to be a weakness with MARCS, and hence with the other models, since it may underestimate the frequency of collision. This will however not be taken into account in this thesis.

To create the optimal fault tree for a given study, the level of detail is important. A problem is to find a good combination between a detailed level in the fault tree and availability of input data. Since the purpose of this thesis is not to find all the basic events or to find the accurate data, the level of detail will be limited. However, to be able to properly describe the collision scenario, a certain degree of basic events must be included.

The basis for the fault tree in this study will be the four main groups listed in (Friis-Hansen, Ravn, & Engberg, 2009) and the four fault trees which are mentioned above.

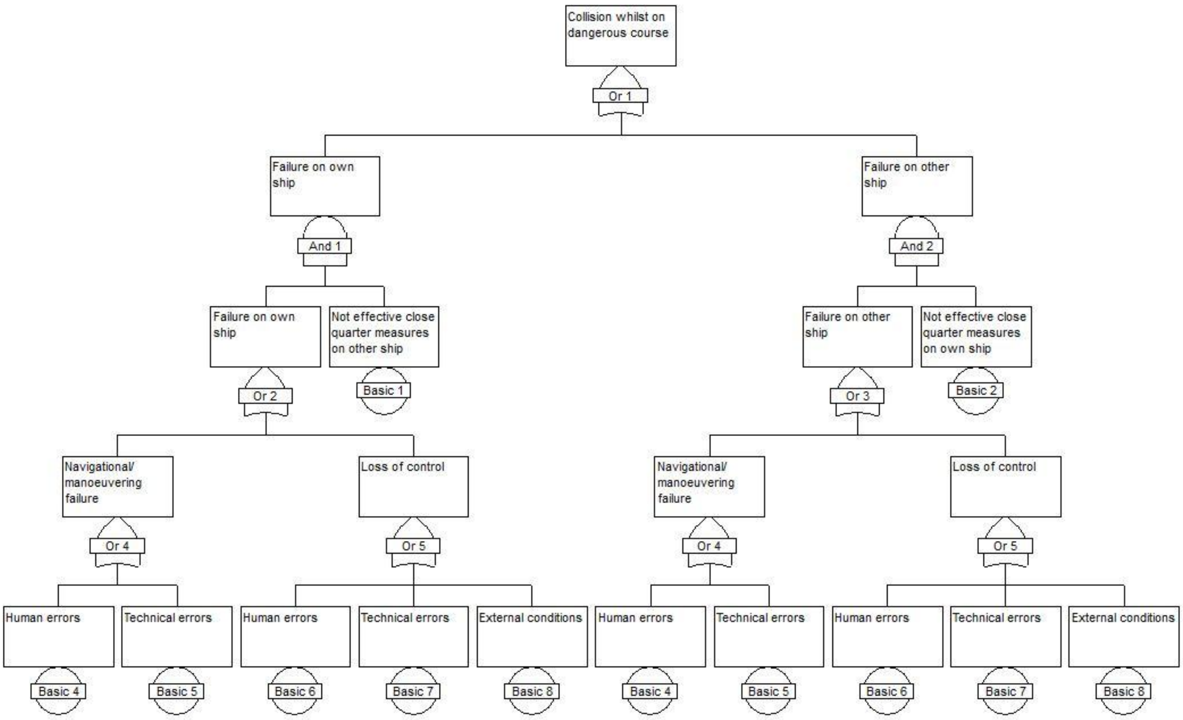


Figure 3-5 The fault tree which is used in this thesis A larger and clearer picture can be found in Appendix A.

The first two levels of the fault tree are based on the fault tree in (Dahle, Fowler, Hauso, & Kristoffersen, 1997). Notice that both *failure on own ship* and n*ot effective close quarter measures on other ship* must be present to get a failure on own ship. The two below levels are from the fault tree found in (Ombler & Skollevold, 2010).

3.4.1 Fault tree input data

There are several sources for the fault tree input data. For instance accident statistics, expert judgements, literature and local data can be used. However, there is a known fact that these data can be hard to obtain and that assumptions must often be made. Since the purpose of this study is not to find the accurate risk of collision in the Oslofjord area, it is assumed that estimations and assumptions can be used.

When finding the frequencies, it must be decided what the output parameters shall be. Is it number of accidents, number of fatalities or environmental consequences? In the study by (Thevik, Sørgård, & Fowler), the output was number of accidents per area per year. To be able to better compare the results, this will also be used as output parameters for the frequency part. Since the purpose of this study is not to find an accurate risk picture of the Oslofjord, it is assumed that the best solution is only to look at the number of accidents for the frequencies and then use an event tree or consequence classes to find the consequences.

The basic events that need input data are:

- Not effective close quarter measures
- Human errors leading to navigational errors
- Technical errors leading to navigational errors

- Human errors leading to loss of control
- Technical errors leading to loss of control
- External conditions leading to loss of control

The reason why there are different input data for human and technical errors is because navigational errors and loss of control are caused by different types of human and technical errors. Examples of human and technical errors leading to navigational error and loss of control are shown below in Table 3-2.

Table 3-2 Example of human and technical errors leading to loss of control and navigational error

Source: (Ombler & Skollevold, 2010)

Loss of control		Navigational error	
Technical errors	**Human errors**	**Technical errors**	**Human errors**
Propulsion failure	Drug and alcohol abuse	Communication equipment failure	Planning errors
Steering failure	Poor judgment	Navigational system failure	Poor judgement
Too high speed	Too high speed	Navigation lights failure	Fatigue

Since no first hand data is available for this study, other sources must be used to find the failure rates. In (Antão & Soares, 2006) it is assumed a failure rate of 0.0004 for human failures and 0.0001 for technical failures. It is often cited that human errors are the direct or indirect cause for 75 %- 90 % of all accidents. (Kristiansen, 2005). Even though it is difficult to give an absolute percentage one can assume that the majority of accidents are caused by human errors. It is therefore reasonable to have a higher failure rate for human errors than for technical errors, as in (Antão & Soares, 2006).

In (Dahle, Fowler, Hauso, & Kristoffersen, 1997), the most common cause for ship collision is defined as "less than adequate navigation due to bad seamanship". The same paper shows that navigational error is a common cause, and that technical error is the cause in a minority of the collisions. In addition, about half of the collisions in good weather is said to be due to operational fault on other ship. For poor weather, this counts for about 33 % of the collisions. Based on this, it is assumed that the probability of failure is equal for both vessels involved in the collision, even though this is only the case if two similar vessels are involved in the collision.

In (Hokstad, et al., Risikoanalyse for innenriks fergetransport, 1997), the causes for ship-to-ship collision are divided into four groups. The percentages show how often the listed group was the main cause for the collision. The data is collected from the database of NMD.

1. External conditions (28.9 %): for instance poor marking of fairway, weather and errors from meeting traffic
2. The ferry (2.2 %): for instance for navigational equipment or poor manoeuvrability
3. Personnel/passengers/cargo (60.0 %): for instance errors from crew
4. The ship owner (8.9 %): For instance lack of safety and quality systems

Due to this division, it may be inaccurate to extract percentages for single causes, such as poor weather or inadequate look-out. However, it can be seen that human errors are the main cause and that technical errors (the ferry) is not commonly the cause for collision. The fourth group points out an important factor, the organisational factor. For accident analysis, it is easy to only see the direct cause for an accident. However, when investigating the causes further, it is often shown that organisational factors are causes for the direct causes. It is better to include organisational factors in a Bayesian network than in a fault tree analysis. Since quantitative analysis of Bayesian networks will not be focused on in this study, organisational factors will neither.

Since the probability of navigational error is higher than the probability of loss of control, the probability of human and technical errors leading to navigational errors is higher than those leading to loss of control. The probability of human and technical errors will be based on the numbers from (Antão & Soares, 2006). It is also important to remember that the probabilities of both human and technical errors are dependent on vessel type and the surroundings. How easy the fairway is to follow, varies with where in the Oslofjord area the vessel is. The more difficult the fairway is to follow, the higher the probability of errors is. Different vessel types have different crew with different experience. Ferries in the Oslofjord have a short distance which is sailed many times a day, and the work is much routine work. Small leisure vessels may have people on board with little experience and the speed is often high. Many vessels in the Oslofjord are also accompanied by pilots, and one may assume that the probability of human error which can lead to navigational error is smaller in those cases. It is therefore difficult to find an accurate value which is valid for all vessel types in all area of the Oslofjord.

The probability that external conditions will lead to loss of control is assumed to be small since the Oslofjord is not exposed to very hard weather. Nevertheless, according to (Haukland, Chief pilot, Norwegian Coastal Administration, 2011), the wind can cause problems with drifting, especially with large vessels, such as container vessels. In (Hokstad, et al., Risikoanalyse for innenriks fergetransport, 1997), external conditions are, in addition to weather, defined as errors from meeting traffic. In the fault tree used in this study, failures on both vessels involved in the collision are included at the top level. It will therefore not be correct to include errors from meeting traffic in both external conditions and as a single branch in the fault tree. In (Ombler & Skollevold, 2010), the probability that external conditions lead to loss of control have been assumed to be 1.0E-5. This number is only based on assumptions, and since no data have been found, the same number will be used in this study.

The last probability that must be found is the probability that the vessel will not be able to manoeuvre away from the other vessel. This probability much depends on the type of vessel and speed. Small vessels at low speed are assumed to easier be able to steer away from a collision course. Large vessels such as cruise ship are slower to respond to a shift in course and high speed vessels have shorter response time before a collision may happen. As mentioned, no differentiation in vessel types will be made at this stage of the study. In (Montewka, Hinz, Kujala, & Matusiak, 2010), the collision probability is defined as $P=N_A \cdot P_C$, where N_A is the geometrical probability of collision course and P_C is the probability of failing to avoid a collision when on a collision course. P_C is given as 1.3E-4 for crossing courses and 4.9E-5 for meeting courses. To find a mean value for this probability, the number of meeting versus crossing vessels should be used. This number also varies for different vessel types and different times of the year. It is therefore assumed that the number of crossing and meeting vessels are equal, and the probability of failing to avoid a collision is therefore assumed to be 0.9E-5.

Based on the above information, the following failure rates are assumed and will be used as a basis in this study.

- Human errors leading to navigational errors: 3.0E-04
- Technical errors leading to navigational errors: 8.0E-058
- Human errors leading to loss of control: 1.0E-04
- Technical errors leading to loss of control: 2.0E-05
- External conditions leading to loss of control: 1.0E-05
- Not effective close quarter measures: 0.9E-05

The probability of human errors are summarised to be 4.0E-04 and technical errors 1.0E-4. These are the same numbers as in (Antão & Soares, 2006). The distribution between errors leading to navigational errors and loss of control is based on assumptions. Navigational error is a more common cause for collision than loss of control. This is reflected in the probabilities.

In (Kristiansen, 2005), the probability of losing navigational control is said to vary from 0.8E-4 to 3.3E-4. Based on this, a mean value of 2.0E-4 is proposed. With the probabilities used in this study, the probability of loss of control is said to be 1.3E-4. This is in accordance with (Kristiansen, 2005).

With the use of the program CARA FaultTree, the frequency of the top event was calculated to be 1.18E-04 per passage with the use of upper bound approximation.

It is important to remember the difference between probability and frequency. The probabilities in (Kristiansen, 2005) are given per passage. Since the probabilities in this study are in accordance with these probabilities, per passage is used for all probabilities. This means that the number of passages per year must be found to find the frequencies for one year. The number of passages is directly multiplied with the probability to find the frequency and therefore influence the frequency linearly. Due to the large uncertainty for the value of this parameter, it will therefore give the frequency much more uncertainty. As a first assumption, the number of passages is set to one per hour. This includes both head-on and crossing vessels. The total calculated frequency will be compared with historical data, and the number of passages will be corrected according to this. One passage per hour equals:

$$1\frac{passage}{hour}\cdot 8760\frac{hours}{year}=8760\frac{passages}{year}$$

This gives a collision frequency of

$$8760\frac{passages}{year}\cdot 1.18\cdot 10^{-4}\frac{collisions}{passage}=1.033\frac{collisions}{year}$$

The frequency of crossing and meeting vessels has a large effect on the collision probability. If the number of passages per hour is doubled, so is the collision frequency. In the formula above, a constant flow of meeting and crossing vessels is assumed, both when it comes to time of day and time of year. This is not in accordance with the reality. In addition, the number is highly uncertain due to lack of information about the traffic pattern in the Oslofjord. Therefore, historical data must be found to see if the collision frequency from the fault tree is in accordance with reported incidents.

It has not been made any differentiation between different vessel types in this fault tree analysis. This is because this would have caused more uncertainty in the result due to lack of data. However, it is reasonable to say, and is in accordance with the formula above, that the vessel types that have a higher traffic frequency, such as ferries, have a higher probability of collision.

3.5 Historical data

With the use of fault tree analysis, the frequency of the top event is very dependent on both which basic events that is included and the input data for the basic events. It is difficult to include all basic events that can lead to the top event. The frequency of the top event from a fault tree is often compared with historical data to see if the fault tree yields results that are reasonable. This will also be done in this study, even though the fault tree data are based on assumptions.

When it comes to historical data, one must be sure that the boundaries of the fault tree analysis are the same as in the historical data which is used as a comparison.

In the study by (Thevik, Sørgård, & Fowler) where MARCS was used, four vessel types were included; oil tanker, bulk carrier, general cargo and ferry. The model is the same for all vessel types, but the input data and statistics varies. The traffic in the Oslofjord consists of many vessel types, from large cruise vessels and cargo ships to small leisure vessels. In (Dahle & Hassel, 2011), oil tankers, cargo vessels and passenger vessels are included. To be able to compare the results from this study with the MARCS model, the same four vessel types will be included, since it is also in accordance with the vessel types used in (Dahle & Hassel, 2011). In addition, fishing vessels will be included. Leisure vessels are only included if the collisions involved one of the vessel types mentioned above, which is in accordance with the NMD database.

In (Thevik, Sørgård, & Fowler), the accident data that was used was collected from NMD and the time period for the accidents was from 1991 till 1996. Also in (Ombler & Skollevold, 2010), NMD was used, but the time period was from 2005 till 2009. The newer the data are, the more relevant they are. On NMD's website www.sjofartsdir.no, where the database can be found, it says that the database was last updated 5.2.2010. It is therefore decided that accidents from 2005-2009 shall be included in this study.

To find the correct data, a definition of what is the Oslofjord area must be defined. In (Thevik, Sørgård, & Fowler), both the inner and outer part of the Oslofjord is included. The accurate position of the accidents is often included in the database from NMD. A rough description of the position of the Oslofjord is between 59°-60° North and 10°-11° E. (Maps of World) (Thevik, Sørgård, & Fowler). Maps of the area can be found in appendix B.

To find the relevant entries for this study, the filtering of geographical area must be done manually. In addition, entries which do not have a position listed or where the information is less than adequate are removed.

The results after the final filtering show that a total of 10 ships have been reported to NMD in the period between 1.1.2005 and 31.12.2009 for being involved in a ship-to-ship collision in the Oslofjord area. Table 3-3 shows an overview of the collisions, including date and vessel type.

Table 3-3 Historical data for collisions in the Oslofjord area, 2005-2009, from Norwegian Maritime Directorate's database

Date	Type of vessel nr 1	Type of vessel nr 2
10/3-2006	Cargo vessel	Cargo vessel
29/3-2006	Fishing vessel	Passenger vessel
11/8-2006	Cargo vessel	Fishing vessel
30/5-2007	Passenger vessel	Cargo vessel
31/5-2008	Leisure vessel	Bulk carrier

No injuries or fatalities on persons are reported in the accidents mentioned above. The fishing vessel which collided with the cargo vessel 11/8-2006 was reported with severe damages on the vessel, but besides that only minor or no injuries have been reported. Environmental damages are not listed in the database. However, it is reasonable to assume that since the material damages are so small, none of the collisions have caused any significant environmental damage.

The number of reported collisions is very limited. Small changes in the number of collisions will have large effect on the probability. As can be seen, the number of collisions varies much from year to year. In 2006, three collisions were reported and in both 2005 and 2009, none collisions were reported. The larger time frame that is used, the more data is available and therefore the more accurate the frequency can be calculated. Nevertheless, it is important to be aware of changes that affect the risk of collision. If for instance traffic separation scheme is implemented, this should reduce the risk and the historical frequency data before the implementation is not comparable with the frequency data after the implementation for use in frequency calculations.

Even if it is difficult to find an accurate estimation for the frequency of collisions per year, it is assumed that a five year period is enough to be used as a basis. Five collisions during a five year period, gives an average of 1 collision per year. This is including fishing vessels.

Historical data used in the study by (Thevik, Sørgård, & Fowler), gives the following frequencies for collision, in accidents per year. These data are found in the database from NMD and are for the period from 1991-1996. These numbers do not include fishing vessels, as the frequency in Table 3-3 does.

Table 3-4 Historical data for collisions based on Norwegian Maritime Directorate's database, 1991-1996

Source: (Thevik, Sørgård, & Fowler)

Tanker	0
Bulk Carrier	0
General cargo	0.4
Ferry	2.2
Total	**2.6**

In (Thevik, Sørgård, & Fowler), it is not stated clearly if the collision frequency is for each collision or if it is for number of vessels involved in a collision. When looking at an area and not a specific vessel, like in this study, it is assumed that the best solution when it comes to frequency is to look at number of collisions and not number of vessels involved in a collision. This is due to lack of information regarding vessel types operating in the Oslofjord and the large differences in collision frequency for the different types. To find out whether the numbers in Table 3-4 are for number of collisions or number of vessels involved in collisions, the database from NMD which is used in (Thevik, Sørgård, & Fowler) is checked. A quick filtration of the database in accordance with the limitations in (Thevik, Sørgård, & Fowler), yields approximately 14 entries. Then the vessel types passenger vessels and cargo vessels are included. A closer look shows that this is neither 14 separate collisions nor 14 vessels involved in 14 different collisions, but a mix of the two. It is therefore difficult to say whether it is in average 2.6 collisions per year or 2.6 vessels involved in a collision per year.

If, in addition to cargo and passenger vessels, fishing vessels and entries without specified vessel type is included, 29 entries are shown. Most of these, 26, are reports of one collision where two vessels are involved, which gives 13 collisions. Quite a few of the entries, 11 of 29, from the period 1991-1996 does not have a specified vessel type. It is not known how this is dealt with in the study by (Thevik, Sørgård, & Fowler). Since fishing vessels is included in Table 3-3, and the entries from NMD from the period 1991-1996 have some degree of uncertainty and inaccuracy, it is decided that the best solution is to use the numbers from (Thevik, Sørgård, & Fowler) as they are.

It can seem like that the risk of collision in the Oslofjord have decreased during the last 15 years. Especially if fishing vessels is not included in the data from 2005-2009, only four collisions was reported. This gives an average of 0.8 collisions per year, which is well below the average of 2.6 calculated in the study by (Thevik, Sørgård, & Fowler). It can also be seen a large difference between the different vessel types. Ferries have a much higher collision frequency than other vessel types, as is also mentioned in Fault tree analysis.

3.5.1 Comparison of frequency from fault tree and historical data

Below is a summary of the different frequencies which is mentioned in this study, given in collisions per year.

Table 3-5 Summary of collision frequencies in number of collisions per year from the studies mentioned, including the frequency calculated in this thesis

Method/Study	(Dahle & Hassel, 2011)	(Thevik, Sørgård, & Fowler)	This thesis
Traffic –based	0.69	2	N/A
Fault tree	N/A	N/A	1.03
Historical data	N/A	2.6	1 including fishing vessels 0.8 not including fishing vessels

In the study from (Dahle & Hassel, 2011), it is important to remember that only the inner Oslofjord area was included. It is also important to remember the issues with the numbers from (Thevik, Sørgård, & Fowler), as discussed in Historical data. It must also be remembered that the numbers found in the fault tree analysis in this thesis, is highly uncertain.

With this in mind, one can see that the numbers from this thesis is approximately in the middle of the numbers from the two other studies. It is reasonable that the frequency is higher than the frequency found in (Dahle & Hassel, 2011) where only the inner part of the Oslofjord is included.

The numbers from the fault tree analysis is in accordance with the historical data used in this study, even though the fault tree results are highly uncertain. However, one cannot be sure that the historical data is correct. Wrong entries in the database when it comes to location of collision and vessel type in addition to the fact that it may be that not all collisions are reported, have an effect on the final result. Nevertheless, the result from the fault tree analysis is assumed to be reasonable and will therefore be used for the consequence analysis.

3.6 Consequences

The consequences can be given in many different units, dependent of what the results from the risk analysis shall be used for. Some examples are financial loss, number of injuries or fatalities or environmental consequences often in combination with a time or distance unit, for instance per year or per passenger kilometres. In F-risk the unit was number of fatalities per year. In MARCS both ton of oil lost per year and number of fatalities per year was included. The Norwegian Maritime Directorate is mainly concerned about the risk associated with fatalities and personal injuries and the Norwegian Coastal Administration have the responsibility for the environmental risk along the Norwegian coast. Material damages are known to be the ship owner's problem and responsibility. (Gåseidnes, 2011) The three consequences; fatalities, environmental and material damages, are of course related since one of them often are caused by or can lead to another. A ship-to-ship collision will often lead to material damages, but it is difficult to calculate the extent of it.

For a collision scenario near the coast, environmental consequences are relevant. There have been some examples of oil spills along the Norwegian coast which have had severe consequences for the nature. (Full city, Godafos) For oil spills, it is important to differ between the different vessel types.

3.6.1 Oil spills

As can be seen in Table 3-3, no oil tankers were involved in a ship-to-ship collision in the relevant timeframe. In the study from (Thevik, Sørgård, & Fowler), only oil spills from crude oil tankers was included. However, not only oil tankers can be the cause for oil spills. The last years, two cargo vessels, Full City (2009) and Godafoss (2011), caused oil spills near the Oslofjord area. Even though both were because of grounding, it shows that it is important to include other vessel types than oil tankers when looking at oil spills. However, the probability of hitting the bunker tanks is assumed to be very small. In (Dahle & Hassel, 2011), the probability of hitting the bunker tanks is assumed to be negligible for both head-on and crossing collisions. Oil spill of bunker oil will therefore not be included in this study.

In (Dahle & Hassel, 2011), it is said that only oil of type IFO 380 will cause environmental damages. The other oil types will evaporate quickly. IFO380 is said to be 4% of the total cargo oil for tankers which arrives in Oslo harbour each year. In the same study, the frequency of oil spills due to collisions is calculated. The numbers are for all oil types, but are only for cargo oil from oil tankers. For oil spills between 100 and 1000 tons, the probability is calculated to be 3.45E-05. For spills above 1000 tons, the probability is calculated to be 2.22E-04. This number is much influenced by the number of oil tankers in the respective area. According to the database from NMD, no oil tankers have been involved in a collision in the Oslofjord area since the database was started in 1981. Based on this, oil spills will not be focused on in this study.

3.6.2 Number of fatalities

In the study by (Dahle, Fowler, Hauso, & Kristoffersen, 1997), a table of hazard distribution and number of fatalities for Ro-ro/passenger vessels (RoPax) in Europe is given. The numbers are based on data from IHS Sea-Web. The table below shows only the numbers for the collision scenario.

Table 3-6 Consequence distribution for collision scenario for ro-ro passenger vessels in Europe

Source: (Dahle, Fowler, Hauso, & Kristoffersen, 1997)

No/minor damage	Major damage	Total loss	Expected fatalities per incident
0.88	0.1	0.02	0.32

In the same study, an equation for the expected number of fatalities for other ships than Pass/Ro-Ro vessels is listed.

$$\begin{aligned} &Number\ of\ fatalities\ per\ incident \\ &\qquad = (0{,}09 \times 0{,}5 + 0{,}11 \times 0{,}1) \times number\ of\ persons\ on\ board \\ &\qquad = 0{,}06 \times number\ of\ persons\ on\ board \end{aligned}$$

This equation is based on that 9% of all ship-to-ship collision causes a vessel to sink and that 50 % of the crew is then expected to be lost. Fire and explosion will be the result in 11 % of the collision accidents, and here it is assumed that 10 % of the crew will be lost. Other escalation scenarios of a ship-to-ship collision are not expected to give any fatalities.

The equation is only based on number of persons on board at the time of the accident. The same assumption is also done in F-risk. According to Gåseidnes, this is a weakness with the model. (Gåseidnes, 2011) Different vessel types have personnel with different kinds of experience which can affect the consequence of an accident.

According to the database of fatalities and injuries from NMD two fatalities are registered in the Oslofjord area in the years from 2005 till 2009, but none of these where due to ship-to-ship collision. The statistics does not include leisure vessels. The risk associated with drowning accidents in relation with leisure vessels is an area which is much focused on every summer in Norwegian media. However, due to the many differences in risk associated with commercial vessels and leisure vessels, this will not be included in this study. Examples of differences are experience of captain, size of vessel, safety culture and regulations in relation with use of life saving equipment.

3.7 Event tree

To find the distribution of the consequences, an event tree can be used. The top event of the event tree shall be the same as the top event in the fault tree; collision when on collision course. An event tree shows the chain of events after the collision.

Based on events for collision in (Hokstad, et al., Risikoanalyse for innenriks fergestransport, Del 2, Vedlegg, 1997), the following event tree will be used in this study.

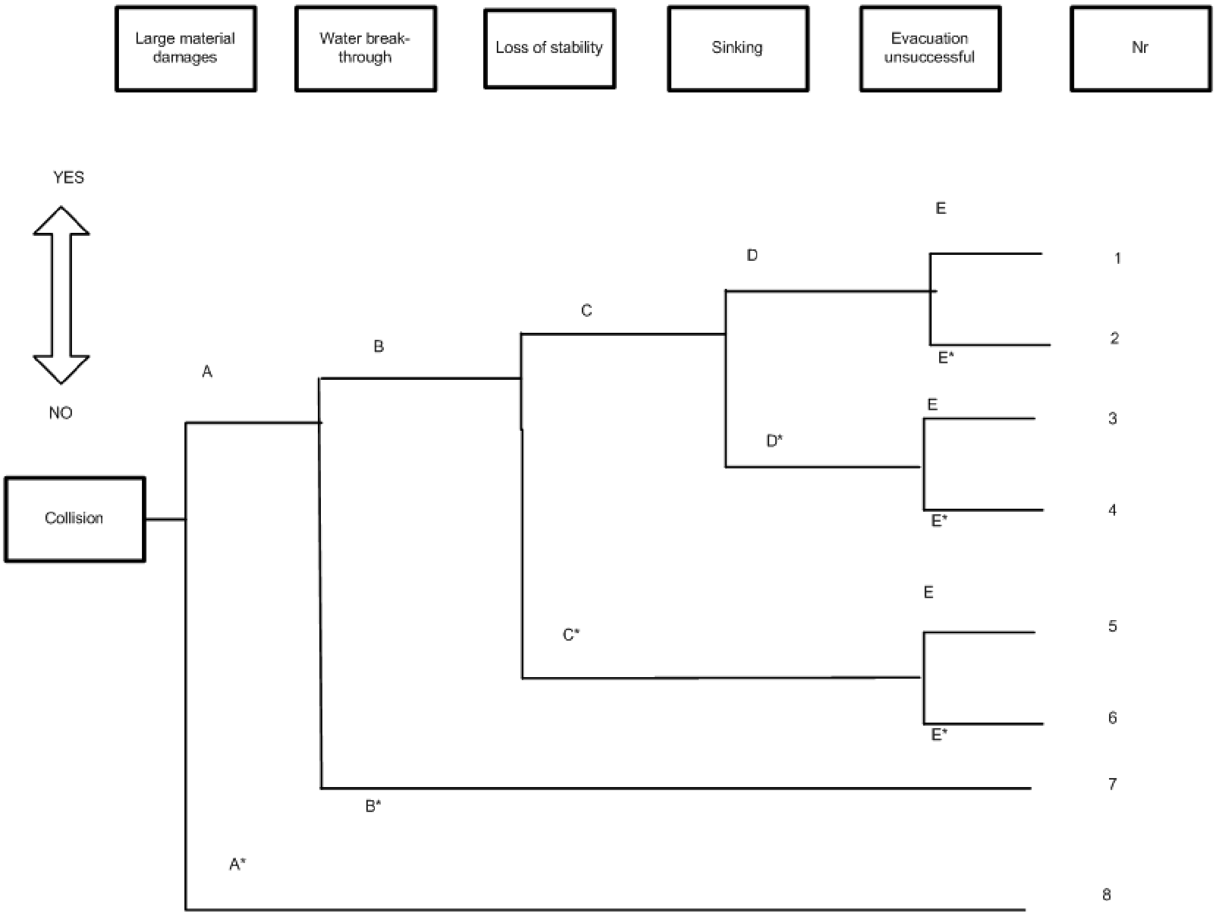


Figure 3-6 Event tree for collision scenario used in this thesis

The worst consequence is on the top and the least severe is on the bottom of the event tree. Each event in the event chain is given a letter and if the letter is marked with a star (*), it means that the event did not happen.

The following assumptions are used for the construction of the event tree:

- If material damages are small, no immediate actions are necessary
- The focus is on personal injuries/fatalities
- If the evacuation is unsuccessful, fatalities among crew/passengers is said to be likely.
- Oil spills is only relevant for oil tankers, and is therefore not included in the general event tree
- Unsuccessful evacuation is defined as no evacuation takes place or that fatality occurs.

It is important to notice that this event tree is valid for all vessel types and it has not been made any differences between them when it comes to the event chain. The differences between the different vessel types are mainly valid when looking at the quantitative part of the consequence analysis. The only difference is, as mentioned, that oil tankers can cause oil spills. Oil spill would therefore be added as an extra event in the event tree.

An example of how oil spill could be inserted in the event tree is shown below. The same event chains after the oil spill event are used both when oil spill occurs and if it does not occur.

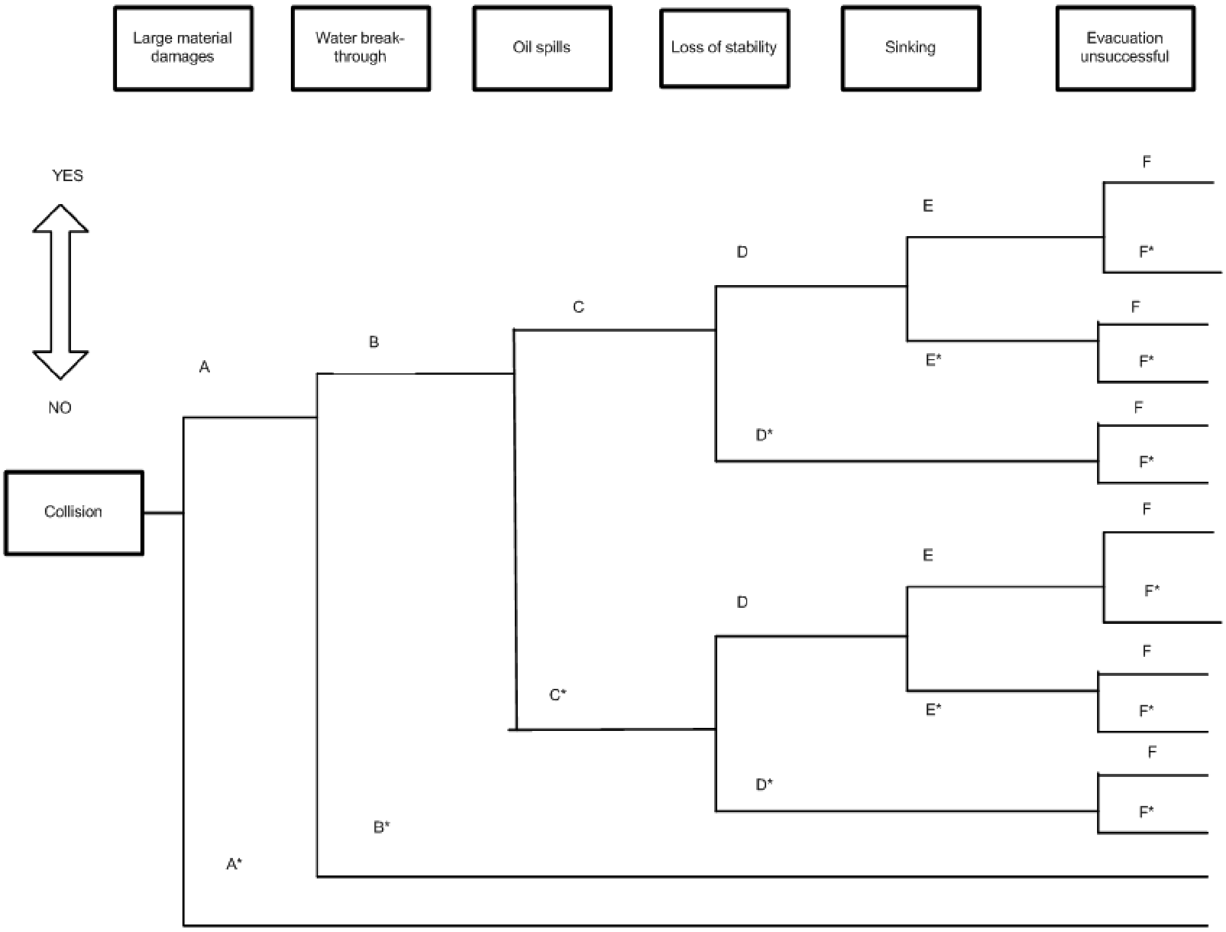


Figure 3-7 Event tree including oil spill

Below is a description of the consequences numbered 1-8, following the numbers given in Figure 3-6.

Table 3-7 Event chains and their consequences with numbers in accordance with Figure 3-6

Nr	Including events	Consequence
1	$A\cap B\cap C\cap D\cap E$	Vessel is lost and fatalities of passengers/crew
2	$A\cap B\cap C\cap D\cap E^*$	Vessel is lost and injuries/possible fatalities
3	$A\cap B\cap C\cap D^*\cap E$	Stability of vessel is lost and fatalities
4	$A\cap B\cap C\cap D^*\cap E^*$	Stability of vessel is lost and injuries/possible fatalities
5	$A\cap B\cap C^*\cap E$	Large material damages and injuries/possible fatalities
6	$A\cap B\cap C^*\cap E^*$	Large material damages and serious injuries
7	$A\cap B^*$	Large material damages and injuries
8	A^*	Small material damages and possible injuries

3.7.1 Quantification of event tree analysis

The probability of each event in the event tree is often difficult to find due to large differences between the different vessel types, location of accident and other factors influencing the final consequence. Therefore, the uncertainty related to these numbers is important to have in mind when analysing the results. In addition, the probability for each event chain is multiplied with the frequency of the top event. As mentioned earlier, this frequency also has a large degree of uncertainty. How this uncertainty affects the final result will be discussed later. However, it is worth noticing that for each step in the risk analysis, more uncertainty is introduced.

Below is a table of the probability for each event in the event tree. The numbers are based on data given in (Dahle, Fowler, Hauso, & Kristoffersen, 1997) and (Dahle & Hassel, 2011), in addition to assumptions. The probability of unsuccessful evacuation is based on numbers found in (Kristiansen, 2005, p. 442). The probabilities are given that the events earlier in the event chain have occurred. (Rausand & Utne, Risikoanalyse - teori og metoder, 2009). The probability of an event not happening, is one minus the probability of the event happening; e.g. P (A*) =1-P (A)

Table 3-8 Probabilities for events according to the event tree in Figure 3-6

	Description	**Probability**	**Remarks**
A	Large material damages	0.12	Probability given collision
B	Water break-through	0.7	Probability given large material damages
C	Loss of stability	0.6	Probability given water break-trough
D	Vessel sinking	0.4	Probability given loss of stability
E	Evacuation unsuccessful	0.35	

Based on the probabilities above, one may calculate the probability for each event chain.

Table 3-9 Probabilities for event chains

Nr	**Including events**	**Consequence**	**Probability**
1	A∩B∩C∩D∩E	Vessel is lost and fatalities of passengers/crew	P(K1)=0.0071
2	A∩B∩C∩D∩E*	Vessel is lost and injuries/possible fatalities	P(K2)=0.0131
3	A∩B∩C∩D*∩E	Stability of vessel is lost and fatalities	P(K3)=0.0106
4	A∩B∩C∩D*∩E*	Stability of vessel is lost and injuries/possible fatalities	P(K4)= 0.0197
5	A∩B∩C*∩E	Large material damages and injuries/possible fatalities	P(K5)= 0.0118
6	A∩B∩C*∩E*	Large material damages and serious injuries	P(K6)= 0.0218
7	A∩B*	Large material damages and injuries	P(K7)=0.036
8	A*	Small, if any, material damages and possible minor injuries	P(K8)=0.88

To get a better overview of the consequences, the probability of total loss, fatalities and large material damages are summarized from the relevant event chains.

$$P(total\ loss) = P(K1) + P(K2) = 0.0202$$

$$P(fatality) = P(K1) + P(K2) + P(K3) + P(K4) + P(K5) = 0.0622$$

$$P(large\ material\ damages) = P(K1) + P(K2) + P(K3) + P(K4) + P(K5) + P(K6) + P(K7) = 0.12$$

These numbers are based on, and in accordance with, the numbers given in Table 3-6.

The results in Table 3-9 are the probability that the each event chain will happen given that a collision has already taken place. To find the frequency of each event chain, the frequency of a collision must be multiplied with the results. The frequency of the top event is in the fault tree analysis found to be 1.03 collisions per year. Based on this the following consequences are the results.

$$f(total\ loss) = 1.03 \cdot 0.0202 = 0.021\ per\ year$$

$$f(fatality) = 1.03 \cdot 0.0622 = 0.064\ per\ year$$

$$f(large\ material\ damages) = 1.03 \cdot 0.12 = 0.124\ per\ year$$

This means that a collision in the Oslofjord will lead to total loss approximately once every 47 year, a fatality once every 15.5 years and to large material damages once every 8 year.

Both when it comes to fatalities/injuries and material damages, the severity depend on if the subject vessel is the one which hits another vessel or if it is the one which is being hit. According to (Dahle & Hassel, 2011), the vessel which hits another vessel has a higher probability of severe consequences than the one which is being hit.

The number of fatalities is not calculated in this study due to the large variation between the different vessel types. However, the number of fatalities is of large importance if a cost-benefit assessment shall be performed. In (Dahle & Hassel, 2011), it is calculated that a collision leading to up to 20 fatalities will happen once every 9.2 years, and above 20 fatalities will be the consequence once every 6.6 years. Ferries have both a larger probability of a collision than other vessel types and have often many passengers on board. This can explain why it is a higher probability for more than 20 fatalities than below 20.

In (Dahle & Hassel, 2011), it is calculated that the material damages in a collision scenario will be moderate every second year and serious every 5.5 years, which is somewhat more frequent than the results in this study. One important factor is the definition of large material damages. Is this only serious damage or also moderate damage? This will not be further discussed, but may lead to more uncertainty when comparing the calculated results with historical data.

With the use of fault tree and event tree analysis and a comparison of these results with historical data, a final result for the collision risk in the Oslofjord has been found. These results are based on many assumptions and quite often lack of data causes problems when trying to estimate the risk. So how can one make these assumptions more accurate? Often experts are used, and this will now be discussed further.

4 Expert judgements

Groups of experts can be used to give their opinion both concerning the qualitative and quantitative part of the risk assessment. Every case requires their own approach on how to use experts. Expert judgements can be used at different stages of the risk assessment process; hazard identification, risk estimation, risk evaluation and analysis of options, and the different phases require different functions for the experts. (Rosqvist, 2003)

The main difference between the use of experts and the use of data is that experts will always be influenced by their background and the situation; the opinions will be subjective. An important aspect when it comes to the use of experts is therefore how to put together the best possible group. One must be familiar with the background of the different experts to have an understanding of why they make the choices they do.

How to gather the information from the experts is also important. According to (Paté-Cornell, 1996) there are three standard ways to aggregate expert opinions.

1. The analytical approach:
   The experts give their opinions separately and a “super expert” decides the final outcome
2. The iterative approach:
   The opinions are given separately and dealt with by the analyst. The results are then sent back to the experts who can revise their opinions based on what the other experts have said.
3. The interactive approach:
   Here the experts debate and explain their judgements.

The last approach deals with an important aspect; it is important that the experts give a reason for their opinions. In a report from (Herrera, Hårbrekke, Kråkenes, Hokstad, & Forseth, 2010), the following is said about the use of experts:

“…In the working meetings the different answers from the experts were discussed in plenary where each individual could state the reason for their answer, and where the experts could to a certain degree, agree on a common answer.”

It is also worth mentioning that another approach on how to use experts is the “expert information” approach given by Kaplan. Instead of asking the expert of their opinions, one should ask for their information and evidence. The approach focuses on the experts own experience and knowledge rather than their ability to process this knowledge into opinions. This approach could then be mixed with other available approached to find the best solution for each case. (Kaplan, 2002)

The approaches mentioned above, have differences when it comes to the degree of uncertainty and subjectivity they add to the result. Will expert opinions reduce the uncertainty from the fault tree and event tree analysis or will the result be too subjective? And at what stage of the process will it be most profitable to use experts? This is important questions to answer to be sure that the decisions which are made, are the correct ones.

4.1.1 Quantitative use of experts

According to (Skjong, Chief Scientist, Det Norske Veritas, 2011) one tries to use statistical data as much as possible, but in some cases little or no data is available and expert judgements are necessary. Several mathematical methods exist to utilize the expert opinions. (Bedford & Cooke,

2001) When trying to estimate failure rates, experts could either use given values as basis or they could find relevant data for other similar systems, if it exists. If the latter is the case, one should always be sure that the data which is used is relevant for the selected system. (Falck, 2011) In addition, as mentioned in (Modarres, 2006, p. 184) ”*people think they can estimate such values with much greater precision than is actual the case*”. Experts can both underestimate and overestimate the failure rates and this is important to be aware of when analysing the results. For quantitative analysis, expert judgements are also used to establish factors used in the analysis, for instance risk reducing factors. (Hassel, 2011)

In the fault tree and event tree analysis earlier in this study, lack of accurate data was a major problem. The final result, especially for the frequency analysis, did not seem to differ too much from the reported historical data. Nevertheless, the results were based on many assumptions and the final result is therefore not accurate.

For the fault tree analysis, the values that could be estimated by experts is the fault tree input data and the traffic frequency. When it comes to the traffic frequency, this can be found based on traffic data from relevant sources, especially since the area which is looked at in this study is limited. This has not been available for this study. It is therefore assumed that the traffic frequency would preferably not be estimated by experts but found by detailed data of the traffic in the Oslofjord area, as is done in (Dahle & Hassel, 2011) and (Thevik, Sørgård, & Fowler). The input data for the fault tree is in this study both based on other literature and assumptions. Relevant data for collision risk in the Oslofjord could most likely be found for other similar areas where more data exists. However, experts could be used to share their own experience with similar and relevant cases and decide which cases that is relevant for this study. Ship-to-ship collision is assumed to be a relatively common scenario in maritime risk analysis, and it is therefore assumed that relevant data exists and should be used as a basis even though experts are used to determine the final failure rates.

For the event tree analysis in this study, the consequence probabilities are highly uncertain. However, it is also here assumed that relevant data is available and should be used as a basis. Except for the frequency of the top event from the fault tree, no other data was used. The results are therefore much dependent on the construction of the event tree.

4.1.2 Qualitative use of experts

The qualitative analysis describes the risk without the use of numbers and frequencies. (Hassel, 2011). For the qualitative analysis, experts can be used to determine which risk reducing measure that is relevant, which is a later phase of the risk assessment process than those included at this stage of the study.

For this study, the fault tree and the event tree is the basis for the analysis and the construction of these should therefore be given much attention. For the fault tree, the level of detail is dependent on the availability of data. The level of detail and the relevant basic events could be determined with the help of experts. As seen in the fault trees from (Thevik, Sørgård, & Fowler), (Antão & Soares, 2006) and (Hokstad, et al., Risikoanalyse for innenriks fergestransport, Del 2, Vedlegg, 1997), these are much more extensive then the fault tree used in this study. Several experts may come up with more relevant basic events than one single expert. It is, nevertheless, important to not include too many basic events if the input data is not available. The number of basic events is also dependent on if the purpose of the fault tree is to find the basic events or to calculate the frequency of the top event.

For the event tree the final result is, perhaps even more than for the fault tree analysis, dependent on the construction of the tree. To make sure that all the relevant barriers are included, a discussion should preferable be held and here experts could be involved. In addition, the sequence of the barriers is important. In this study, the barriers were based on (Hokstad, et al., Risikoanalyse for innenriks fergestransport, Del 2, Vedlegg, 1997). For both the fault tree and the event tree, similar studies were used as a basis and experts who have experience with similar cases could use this knowledge to determine the relevant barriers.

5 Risk control options and risk acceptance criteria

After the risk has been established, the next step is dependent on the purpose of the analysis. For some analyses, the purpose is to compare the results with results from previous analyses to see whether the risk has changed or not. Examples of such analyses are the annual reports that are published by the NMD on domestic ferry traffic in Norway, based on the F-risk model. For other analyses the purpose is to decide whether or not the risk is acceptable and which measures that can be implemented to reduce the risk, if this is found beneficial. This may also be included in studies such as the ones where F-risk is used, if the risk has increased to an unacceptable level, but is often an independent study where data from several years are used. These analyses with different purposes will both be affected by inaccurate data. However, it is assumed that if the purpose of the analysis is solely to compare with previous similar studies, the uncertainty in data will be much the same for all the studies, and the comparison will therefore not be affected too much. Even if this is not the case, the problems related to uncertainty in data may be easier to deal with for such studies since data and results exist from previous studies. Inaccuracy and uncertainty in data is therefore assumed to have a larger effect on studies where decisions regarding risk control options are involved, and especially where cost-benefit assessments are used. For these calculations, the level of accuracy in data affect whether the correct decision is made or not.

As mentioned, the purpose of this study is to see how uncertainty in data affects the risk analysis result. Hence, risk control options and risk acceptance criteria will be included and discussed and cost-benefit assessment will also be included later in the study.

Both new and existing safety measures should be focused on when deciding the correct risk control options. Risk control options can either focus on reducing the frequency or mitigate the severity or both and can be related to the technical, human or organizational aspect of the operation. (Kristiansen, 2005)

5.1 Risk acceptance criteria

Risk acceptance criteria is a topic which is well covered and discussed in the literature. The establishment of the criteria will not be thoroughly discussed in this study. The focus will rather be how the acceptance criteria affect the decision-making. For more information about risk acceptance criteria, the study by (Johansen, 2010) is recommended.

It is worth mentioning that even though the term “acceptable risk” is used in this study the term “tolerable risk” is suggested used by the Health and Safety Executive (HSE) in the UK as a more appropriate term. The difference is that if a risk is acceptable, it means we can live with it without much further concern. If the risk is tolerable, it means that we do not look at it as negligible, but as something which should be given further attention and may be reduced. (Rimington, Harbison, & al., 1992) In this study, the term “acceptable” will be used since this is the most common used term in relevant literature and standards. Another discussion concerns the differences between risk acceptance criteria and risk evaluation criteria. According to (Skjong, Risk Acceptance Criteria: current proposals and IMO position, 2002), IMO have decided to use risk evaluation criteria instead of acceptance criteria. This is to imply that the criteria should not be the only criteria for decision and that other criteria or considerations could be used in combination. Since risk acceptance criteria is the most common term used, this will be used in this study.

To decide which risk control options that shall be discussed for implementation, one first needs to find the areas where such measures are necessary. The list below describes such areas. (Kristiansen, 2005, p. 294)

- Unacceptable risk level: if the results from the calculations from the risk assessment is found to be unacceptable
- Risks within the ALARP region: if the calculated risk is found to be within the ALARP region, measures should be implemented if they are found (cost-)beneficial
- High probability: Even if a scenario has a low severity, they may be found to be unacceptable due to high probability.
- High severity: Even if a scenario has a low frequency, they may be found to be unacceptable due to high severity.
- Considerable uncertainty: Considerable uncertainty in probability, severity of both could be a reason to take precautions in terms of implementing extra or redundant risk control measures.

In this study, only a general ship-to-ship accident scenario is included and it will therefore only be this scenario which is relevant for the risk acceptance criteria.

5.1.1 ALARP

A risk acceptance criterion defines a limit for acceptable and unacceptable risk and can be expressed by words, numbers or a combination. In the list above, the term ALARP (As Low As Reasonable Practicable) is introduced and is one of several principles which are used when it comes to establishing risk acceptance criteria. Other examples of such principles can be found in (Skjong, Vanem, & Endresen, Risk evaluation criteria, 2005). In this study, only the ALARP-principle will be introduced.

Instead of only one limit between acceptable and unacceptable risk, the principle includes an ALARP area.

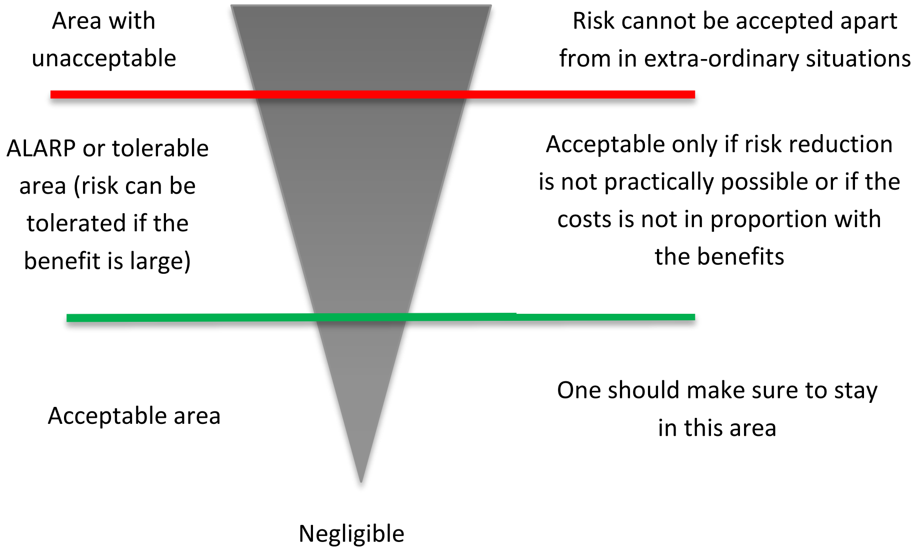


Figure 5-1 ALARP-principle Source: (Rausand & Utne, Risikoanalyse - teori og metoder, 2009)

The ALARP-principle is often based on a combination of cost-benefit assessment and Pareto-optimisation. The theory about Pareto-optimisation means that one should implement measures which reduce the risk or improve the situation for someone until the point where there is an increase in the risk for others due to the implementation of these measures. (Aven, Boyesen, Heinzerling, & Njå, 2003)

There are many ways to establish the risk criteria. In (Skjong, Risk Acceptance Criteria: current proposals and IMO position, 2002) the following methods are mentioned:

- Compare with other hazards: for instance compare the risk with other relevant industries
- Compare with natural hazards: the risk due to human activity should be a small portion of the risk due to natural hazards
- Comparison with risk we normally take: the risk should be smaller than the risk we take during a normal day, such as crossing the street or driving a car
- Comparison with previous decisions: compare the risk with standards from earlier relevant projects
- Comparison with well informed decisions in democratic forums: the risk is sometimes evaluated and discussed in large forums and the results could be used as a comparison

One can also differ between societal, individual and environmental risk. In (Skjong, Vanem, & Endresen, Risk evaluation criteria, 2005), individual risk is described as *"risk to life and health of individuals exposed to the hazards of a given activity*". Societal or group risk relates to accidents which have a major societal concern and where many people can be affected. In this study, the focus will be on individual risk as it is assumed that a collision in the Oslofjord will not be of a catastrophic extent.

There are many ways to describe the risk acceptance limits. In (Skjong, Vanem, & Endresen, Risk evaluation criteria, 2005), the following limits for individual risk are suggested. They are based on nuclear power stations, but is said to also be valid for other areas.

Boundary between broadly acceptable and tolerable risk	10^{-6} per year
Maximum tolerable risk for workers (e.g. crew members)	10^{-3} per year
Maximum tolerable risk for public (e.g. passengers)	10^{-4} per year

In (Rausand & Utne, Risikoanalyse - teori og metoder, 2009), it is said that the upper tolerable limit is often set to $1 \cdot 10^{-4}$ - $3 \cdot 10^{-4}$ and that the limit for acceptable risk is set to 10^{-6}. These limits express the additional risk a person is exposed to because of a given task or situation. 10^{-6} is a very low frequency and makes it difficult to classify potentially dangerous scenarios as general acceptable. Most scenarios will therefore be within the ALARP region and will be subject to cost-benefit assessment.

As can be seen in the numbers above, it is a somewhat higher tolerable risk for crew than for passengers. The reason for this is that passengers are not as well informed of the risk as the crew, they are not paid and they are less in control of the situation. (Skjong, Risk Acceptance Criteria:

current proposals and IMO position, 2002) In this study, there have not been made any difference between risk for crew and risk for passengers.

In (Skjong, Vanem, & Endresen, Risk evaluation criteria, 2005, p. 18), the following figure, Figure 5-2, can be found which shows the individual fatality risk per year for crew of different vessel types. The proposed ALARP-limits are also shown. All vessel types are within the ALARP-region, some close to the intolerable risk limit. This does not mean that within these groups, none of the vessels are above the tolerable risk limit, and the graph below can therefore give the wrong impression of the safety level for the different vessel types. (Skjong, Chief Scientist, Det Norske Veritas, 2011)

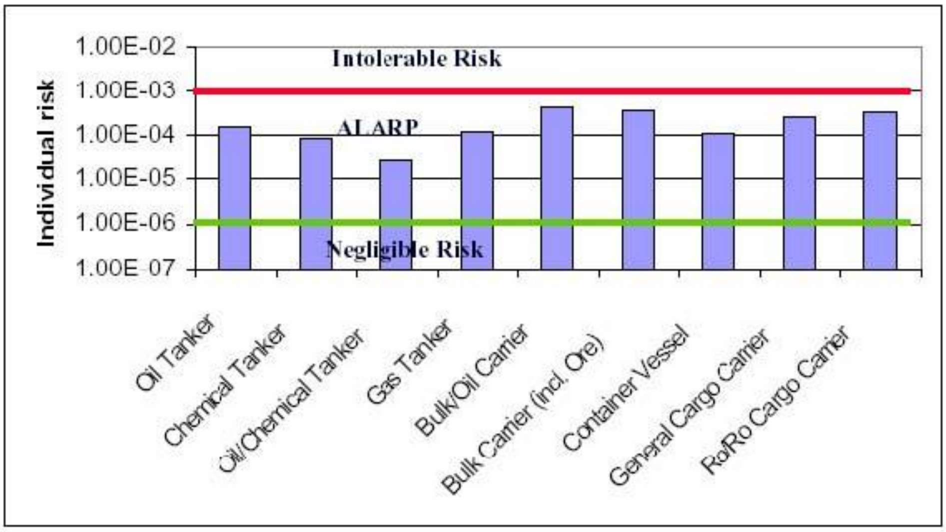
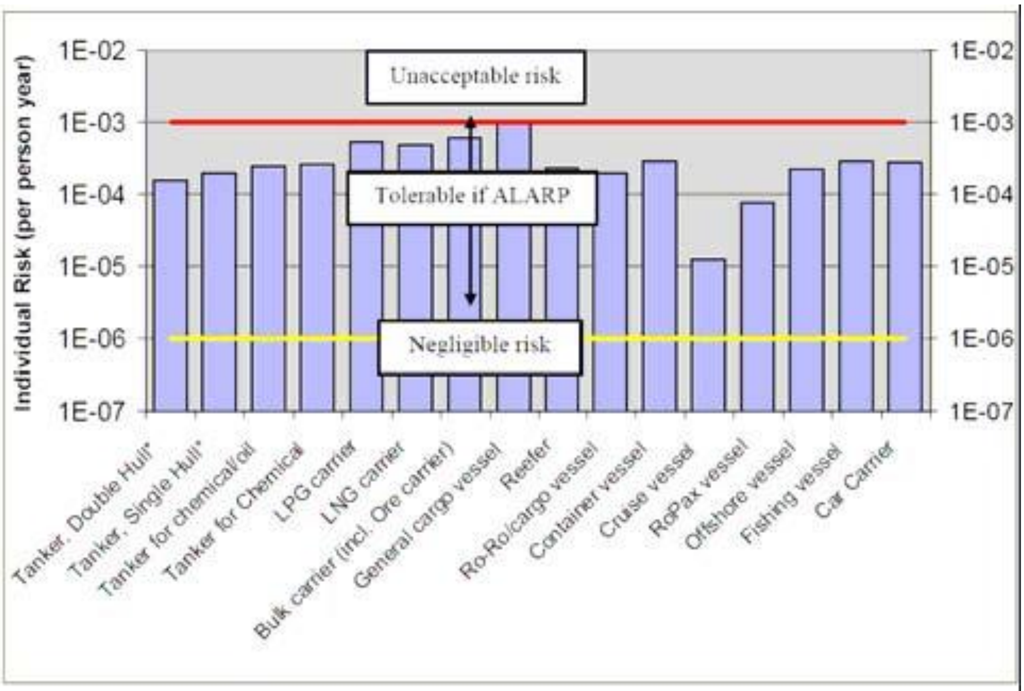


Figure 5-2 Individual fatality risk for different vessel types
Source: (Skjong, Vanem, & Endresen, Risk evaluation criteria, 2005)

In (Huss, 2007), a similar figure is found. In Figure 5-3 one can see that some of the vessel types are very close to the unacceptable risk level. The category general cargo vessel has even reached the limit. As seen in Table 3-3 and Table 3-4, general cargo vessels are well represented on the historical accident statistics for collisions in the Oslofjord area.



* Based on vessels built 1980 and later

Figure 5-3 Individual fatality risk for different vessel types 2 Source: (Huss, 2007)

In this study, the probability of a fatality given a collision scenario was calculated to be in the order of 10^{-2}. This is not the same as the numbers given for the risk limits. The individual fatality risk is the probability of being killed due to a specific task or situation, for instance being on board a vessel in the Oslofjord area. (Rausand & Utne, Risikoanalyse - teori og metoder, 2009) The numbers found in this study are the probability of being killed given a collision scenario. To find the individual fatality rate, one must have information about the number of passengers/crew exposed to the risk and this information has not been found for this study. Therefore other terms for the risk acceptance limits will be used.

In (Hokstad, et al., Risikoanalyse for innenriks fergetransport, 1997) the following acceptance limits are given for Norwegian domestic ferry traffic in total.[1]

> A1: Average individual risk shall not exceed 2 fatalities per billion passenger kilometres. If average individual risk exceeds 0.5 fatalities per billion passenger kilometres, cost effective measures shall be implemented (ALARP)
>
> A2: It shall at most be one accident every 100 years which have more than 10 fatalities. If it is estimated that accidents with more than 10 fatalities occurs more often than once every 1000 years, cost effective measures shall be implemented.
>
> A3: It shall at most be one accident every 10 000 years with more than 100 fatalities. If it is estimated that accidents with more than 100 fatalities occurs more often than once every 100 000 years, cost effective measures shall be implemented.

As can be seen, high consequence – low frequency accidents are included here. These types of accidents are often difficult to find estimations for due to lack of historical data. In this study, the

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[1] Translated from Norwegian to English by the author

focus has been on small accidents and therefore acceptance criteria A1 is most relevant. 2 fatalities per billion passenger kilometres is approximately the same as 0.6 fatalities per year when yearly passenger kilometres are included and hence 0.5 fatalities per passenger kilometres corresponds to approximately 0.15 fatalities per year. (Risikoanalyse for innenriks fergetransport, 1997)

In this study it was calculated that the number of fatalities is 0.063 per year. This is well below the acceptance limit for domestic ferry traffic. The frequency of 0.063 is for all vessel traffic in the Oslofjord, except for leisure vessels. This means that some vessel types may be closer to the acceptance limit. As can be seen in Table 3-3, Table 3-4, Figure 5-2 and Figure 5-3 there is a big difference between the collision risk and fatality risk for the different vessel types. In addition, in the acceptance limits from (Hokstad, et al., Risikoanalyse for innenriks fergetransport, 1997), several other accidents scenarios are included, such as grounding, fire and dangerous cargo accidents. In addition they have included an accident category called “other personal injury” which has the highest number of fatalities per year. The collision scenario is therefore only a small part of the total number of fatalities.

One should not establish risk acceptance criteria after the risk has been calculated. However, the acceptance criteria in this study will only be used to show how uncertainty in data and underreporting of accidents affect the final result of a risk assessment; therefore it will be established after the risk has been calculated. It is assumed that the collision risk is within the ALARP region, and that the risk should be reduced as long as it is reasonable practicable.

According to table 6.1 in (Hokstad, et al., Risikoanalyse for innenriks fergetransport, 1997, p. 50), it is estimated that the total number of fatalities per year for all ferry connection and all accident categories is 1.0 and of these the scenario *collision during operation* is responsible for 0.14 fatalities per year. Based on this, one can say that 14% of the estimated fatalities are due to collision. If we compare this with the risk criteria A1, 14% of 0.6 fatalities per year, which is the upper acceptance limit, is 0.084 fatalities per year. The lower acceptance limit is for all accident scenarios 0.15 fatalities per year, and 14% of 0.15 is 0.0.21 fatalities per year. These numbers are only for the ferry traffic, but since ferries have the possibility for the highest number of fatalities, it is assumed that for this study, these numbers can be used as risk acceptance criteria.

Based on this, one can see that the calculated fatality risk for collision in the Oslofjord, 0.064 fatalities per year, is within the ALARP region, and it is therefore decided to look at relevant risk control options.

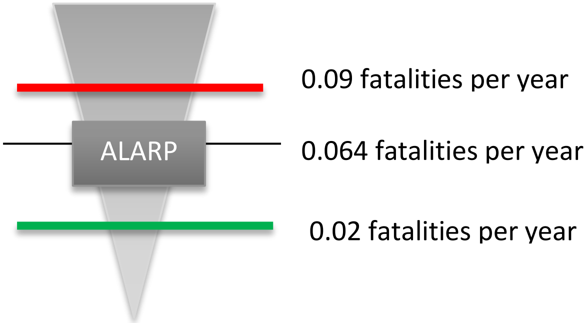

Figure 5-4 Risk acceptance limits for this study according to the ALARP principle

5.2 Risk control options

In this study, only the collision scenario is included and the risk control options will therefore focus on reducing the frequency and consequences for this scenario. According to (Skjong, Chief Scientist, Det Norske Veritas, 2011), it is too much focus on reducing the consequences instead of the frequency because it is easier to find data for consequences than for frequencies causes, where human failures are a major contributor.

For the risk acceptance criteria, the focus has been on fatalities. When deciding risk control options, it is also important to have in mind the risk of injuries. Even though one may assume that when reducing the risk of fatality due to collision, one also reduces the risk of injuries, it is important to separate these when performing a cost-benefit assessment due to the differences of the costs related to fatalities and injuries.

When discussing risk control options, one must be aware that the implemented measure can have effects not only on the component or action in mind, but for all parts of the operation, both in a positive and negative way.

In (Hokstad, et al., Risikoanalyse for innenriks fergetransport, 1997), the following measures are proposed specific for collision, based on risk indicators. The measures are both related to frequency and consequence.

- Requirements regarding damage stability
- Requirements regarding double hull
- Bridge design
- Electronic surveillance of navigator
- Two independent radars
- Standardisation of manoeuvring equipment
- Two main engines
- Two independent engine rooms
- Communication equipment
- Speed limitations
- Rerouting of traffic

In addition to these, many operational measures are proposed related to the safety culture, training of crew, inspection routines and routines related to the ship owners.

In (Dahle & Hassel, 2011) one main measure was used in the calculations. This was to remove several banks in the inner Oslofjord and then introduce a traffic separation scheme (TSS). Below is a summary of additional suggested measures:

- Better communication between the ferries and other nearby vessels
- The crossing point between ferries and cargo vessels shall be moved
- Make sure that the ship officers does not leave the entire responsibility for navigation to the pilot
- Request that cruise vessels shall use diesel oil as fuel instead of IFO oil

The two lists above indicate only a small part of possible risk control options. When choosing relevant measures to use for further cost-benefit assessment, it is important to not just include measures which surely will be cost-beneficial, but also those that may not be. This is because it is important to remember that neither the risk acceptance criteria nor the cost-benefit assessment alone necessarily give the correct basis for decision-making regarding which measures to implement. Some factors, like organisational and human factors, are often difficult to find precise data for instance for cost and failure rates. How risk reducing measures may affect these factors, can be more related to a qualitative analysis.

In this study, the focus is not to determine the most appropriate risk control options. Therefore, only a small variety of measures related to both frequency and consequence and human and technical failures will be included.

It is better to prevent an accident from happening than to mitigate the consequences when it has already happened. In general the most cost-effective is to implement measures that are as far back in the event chain as possible. (Pedersen, 2010) One should therefore concentrate on implement frequency reducing measures, but because the causes of an accident are often complex, it is difficult to find the correct measures to reduce the frequency. However, it is well known that human factors are the direct or indirect cause to the majority of accidents; a common used estimate is 80%. In (Kristiansen, 2005) it is cited from IMO's website that 80% of available resources are spent on design and technical parameters and only 20% is spent on the human element. If this is still the case, one may, very simplified, say that 80% of the resources is spent on the factors which is the reason in 20% of the scenarios and 20% is spent on the residual 80%.

To prevent a collision, communication is of vital importance. Measures to improve the communication between the VTS and the vessels and between the vessels themselves should be discussed. Speed restrictions can also be introduced. There are already speed restrictions in the Oslofjord area, but (Haukland, Chief pilot, Norwegian Coastal Administration, 2011) states that it is not always suitable for large vessels to keep within the limits due to drifting. Speed restrictions can both prevent an accident due to longer response time and lower the severity if a collision takes place. When it comes to human factors, communication and attention is important. This can be improved by working with the safety culture on board and within the company. Human and organisational factors can be difficult to include in calculations, unless very specific actions are suggested. For instance implement regularly meetings on board where safety is discussed, and where representatives from the ship-owners are also present. (Hokstad, et al., Risikoanalyse for innenriks fergetransport, 1997)

To reduce the consequences of a collision, measures relating to vessel design are important. For all vessels, the strength of the hull is important. In addition, especially for passenger vessels, how the passengers and crew are located if a collision occurs, can affect the severity of the collision. And of course, proper routines for evacuation and how to handle emergency situations is of vital importance. Specific measures relating to mitigate the consequences of a collision can be that no passengers are allowed to stand in stairs during operation. However, collision with quay is a more common scenario than ship-to-ship collision. When entering a quay, the passengers are often preparing themselves to leave the vessel and this often means that they are walking or standing in stairs and the prohibition would therefore maybe not be so effective.

It is a large difference between measures which is applicable globally, like requirements for hull design, and locally, like the manning routines on the ferries in the Oslofjord. The boundaries for the geographical area for the cost-benefit assessment should be defined, and is in our case the same as the area which is included in the risk assessment. Since the variety of vessel types is so large in this study, it is difficult to implement measures that are valid for all vessels. Unless it is specific regulated for the Oslofjord area, one cannot for instance tell all the vessel which approaches Oslo that they must change the manning routines and it is difficult to change the safety culture for an entire shipping company based on regulations in one specific area.

When it comes to suggestions for risk control options, it is wise to also get suggestions from those who have practical experience with the relevant area. Rune Haukland, pilot in the Oslofjord, has given suggestions for risk control options for collision based on his own and other pilots and captains experience. (Haukland, Chief pilot, Norwegian Coastal Administration, 2011)[2]

- It is not believed that further traffic separation schemes can improve the safety in the Oslofjord. Flexibility is the key word, so that it is possible for the captain/pilot to steer safely out of "difficult" situations. Safety is said to best be controlled from the bridge.
- Communication and language: for instance that everyone should speak a Scandinavian language or English on the communication net so that "everyone" can understand and hear what is going on.
- Dynamic (updated) information from the VTS and not nonrecurring information as it often is today.
- Compulsory pilotage is kept as it is today. This will ensure proper communication and the same treatment for all vessels. Pilots at the VTS's are also a good contribution to increased safety.
- Follow-up on new rules concerning pilot exemption certificate (PEC). If the rules are followed-up by exams/tests this will increase the quality of navigators along the entire coast.

These suggested measures are all focused on reducing the probability of a collision. As can be seen, the first suggestion from Haukland is not in accordance with the main suggestion in (Dahle & Hassel, 2011). This shows that it is important to include all relevant parties when discussing risk control options.

Based on the above, the following risk control options will be included in the cost-benefit assessment:

- One additional pilot at the VTS
- More frequently controls during the summer months to ensure that the speed limits are followed
- Exam/test annually after PEC is issued

Environmental consequences have not been included in neither the risk acceptance criteria nor for the risk control options. This is because, as mentioned earlier, it is assumed that the probability that an oil tanker will be involved in a collision is very small and that no other collision scenarios will cause environmental damages.

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[2] Translated from Norwegian to English by the author based on e-mail correspondence

It is mentioned in chapter 5.1 that one should pay special attention to areas where the uncertainty is high. In this study, there are no areas that are significantly more uncertain than other. All the data used in both the fault tree and event tree have a high degree of uncertainty. It is therefore not specifically focused on areas where the uncertainty is high in this thesis.

6 Cost-benefit assessment

The purpose of the cost-benefit assessment is to try to systematically compare the costs and the benefits of a project, in this case regarding risk reducing measures. The costs and benefits for all the suggested measures are expressed in a common value, usually monetary, so it is easier to compare the different measures.

It is never possible to reduce the risk to zero, some risk will always remain, but it is important to make sure that the risk has been reduced to a level “as low as reasonably practicable” when using the ALARP-principle. However, at some point, the cost of implementing a measure will be too high with respect to what is gained by implementing it. What is seen as this point, is very dependent on who you ask, what kind of risk is involved, geographical location and many other aspect. There is much discussion regarding the cost-benefit principle used in safety and health aspects. Much of the discussion is based on how one can establish a monetary value for fatalities and injuries and how one can address the different problems such as risk perception (Skjong & Wentworth, Risk Judgement and Risk Perception). Based on this, one can see that uncertainty is an important factor also in cost-benefit assessment.

A cost-benefit assessment can vary from very simplified to very thoroughly. In this part of the study the purpose is not to perform an extensive analysis, but to show the basic principles and how uncertainty in data can affect the final result.

6.1 Qualification of cost-benefit assessment

The first step in the cost-benefit assessment is to identify the costs and the benefits for the measures suggested in the previous step. It is important to include all the costs and benefits for each measure, also those who affect the risk or system/activity in a negative way. It is, however, important not to include a cost or a benefit more than once in the calculations. Examples of costs and benefits that can be included are listed below. (Kristiansen, 2005)

Table 6-1 Examples of costs and benefits used in a cost-benefit assessment Source: (Kristiansen, 2005)

Costs	Benefits
Capital/investment costs	Reduced number of fatalities/injuries
Installation and commissioning cost	Reduced casualties with vessel
Operation and recurrent cost	Reduced environmental damage
Labour cost	Increased availability of assets
Maintenance	Reduction in costs related to search, rescue and salvage
Training	Reduced cost of insurance
Inspection, certification and auditing	
Downtime or delay cost	

The costs and benefits from the measures suggested in chapter 5.2 are listed in Table 6-2 below.

Table 6-2 Costs and benefits for the suggested risk control options

1. One additional pilot at the VTS	
Costs	Labour costs Training costs
Benefits	Reduced casualties with vessels Reduced number of fatalities/injuries Better communication with the vessels

2. More frequently controls during the summer months to ensure that the speed limits are followed	
Costs	Operation Labour
Benefits	Reduced casualties with vessels Reduced number of fatalities/injuries

3. Exam/test annually after PEC is issued	
Costs	Operation Labour Certification
Benefits	Better awareness of the rules Better quality of navigators

6.2 Quantification of cost-benefit assessment

Now that the costs and benefits for the suggested measures are listed, it is time to quantify these. There are several methods available and much discussion regarding what it the correct way to compare the costs and benefits for the different measures.

It is not assumed that the risk of collision in the Oslofjord is above the unacceptable limit. The risk is said to be in the ALARP-region, according to Figure 5-4. This means that one must decide what is a reasonable low risk and this can be done with the use of a cost-benefit assessment. In this part of the study, some methods will be introduced on how to decide what is reasonable and these will be used on the measures suggested above.

Earlier in this study, only the term cost-benefit assessment has been used. In a cost-benefit assessment, all risk is converted into monetary units, also for instance the risk of fatality. How one can set a monetary value for a life, is much discussed in the literature. In (Skjong, 2002) another term is therefore used; cost effectiveness assessment. Cost effectiveness assessment does not put a monetary value to the benefits, but presents a ratio of costs to benefits. The term cost effectiveness assessment is not a common term used literature. For instance, both the guidelines from IMO on FSA (IMO, Guidelines for formal safety assessment (FSA) for use in the IMO rule-making process, 2002), chapter 9 and 10 in (Kristiansen, 2005) and the report concerning marine risk assessment from HSE ((HSE), 2002) only use the term cost-benefit assessment even though it is referred to formulas and equations where the benefits do not have a monetary value (CAF-formulas; Equation 3 and Equation 4). Based on this, the term cost-benefit assessment will still be the used term in this study.

The advantage of including a monetary value of a statistical life and other injuries is that any safety measure can be expressed in a common unit. However, what this value shall be based on is subject to much discussion and uncertainty, and ethical aspects are of course important. The later years, it has been more common to not include a value of a statistical life and it is recommended by IMO not to do so. (Skjong, Risk Acceptance Criteria: current proposals and IMO position, 2002). It will therefore not be included in the calculations for this study.

Instead, two equations are commonly used where only the *reduction* in risk is included, e.g. number of reduced fatalities. This is then compared with the difference in cost. One wants to find options where a large reduction in risk can be made by a small increase in cost. The terms for the two equations are Gross Cost of Averting a Fatality (GCAF) and Net Cost of Averting a Fatality (NCAF). According to (Skjong, Risk Acceptance Criteria: current proposals and IMO position, 2002), GCAF is in preference to NCAF.

The equations are as follows:

$$GCAF = \frac{\Delta Cost}{\Delta Risk}$$

Equation 3

$$NCAF = \frac{\Delta Cost - \Delta Economic\ Benefits}{\Delta Risk}$$

Equation 4

ΔCost is the additional cost of a risk control options and ΔRisk is the reduced risk in terms of fatalities averted. ΔEconomic Benefits is included in cases where the risk control options cannot be justified based only on safety reasons. ΔRisk is also sometimes given as ΔPLL, where PLL is Potential Loss of Life.

Another approach, which is given by HSE, is the Gross Disproportion principle. This states that *"something is reasonable practicable unless its costs are grossly disproportionate to the benefits"*. (Health and Safety Executive) This principle has been proven difficult to use in practice and will not be further discussed in this study. ((HSE), 2002) The focus will therefore be on GCAF and NCAF.

The CAF values do not say if an option is cost-effective or not, it only gives a value for which can be used as a reference. Limits must therefore be established for what is beneficial. There are many ways on how to establish these limits and it is much dependent on which sector and country is relevant and who you ask. The table below is found in (Skjong, Risk Acceptance Criteria: current proposals and IMO position, 2002) and shows different CAF values for different sectors and countries. These numbers are from 1994-1998.

Table 6-3 Published CAFs in use as evaluation criteria

Source: (Skjong, 2002)

(ECU is the predecessor to Euro and 1 ECU= 1 Euro, NOK= Norwegian kroners, $= US dollars, £ = British pounds)

Published CAFs in use as evaluation criteria		
Organisation	Subject	**CAF**
US Federal Highway administration	Road transport	**$2.5m (£1.6m)**
UK Department of Transport	Road transport	**£1.0m**
UK Health and Safety Executive	Industrial safety	**As above or higher**
Railtrack (UK rail infrastructure controller)	Overground railways	**As above to £2.65m**
London Underground Ltd	Underground railways	**£2m**
EU	Road transport	**ECU 1 m (£0.667m)**
Norway	All hazards	**NOK 10m (£0.8)**

In ((HSE), 2002), it is said that values below £1 million is said to be cost effective, and values between £1m and £5- £10m could be considered. In (Hokstad, et al., Risikoanalyse for innenriks fergetransport, 1997), it is said that risk reducing measures are cost effective if the costs do not exceed 20 million NOK for each prevented fatality. It is also suggested to consider measures which have a cost between 20 million NOK and 500 million NOK per prevented fatality.

It is important to remember that the limit of what is said to be cost effective should be seen in combination with how close to the intolerable limit the risk is. If the risk is found to be high in the ALARP region, the limit of what is cost effective should be higher than if the risk is low in the ALARP region.

Based on this, the values used in this study for what is cost-beneficial is said to be 20 million NOK and that the measures could be implemented if the cost does not exceed 200 million NOK, since the risk of fatality due to collision is found to be approximately in the middle of the ALARP region (see Figure 5-4).

6.2.1 Input values

Due to lack of data, the values for the costs and benefits will be much simplified in this study and are only based on assumptions.

To be able to compare the reduction in risk, only the number of averted fatalities is included, so that the dimension for GCAF is NOK/fatality prevented. However, as seen in Table 6-2, other benefits are included. These other benefits may, if not included in the reduction in number of fatalities, be included when finally deciding which risk control measures to include. Risk of injuries can be dealt with either explicitly or implicitly. In (Skjong, 2002) it is suggested to deal with reductions related to fatalities, injuries and ill health separately. Due to simplifications, no differentiation has been made between these three severities in this study.

Another issue to discuss is the time perspective of the suggested measures. A problem can be that the costs are often at the start of the project, but the benefits may not be relevant for many years after the start. Since money is more valuable today than in the future, due to the possibility of investments, discounting rates can be used. Discounting rates should not be used when it comes to reduction in number of fatalities, since the value of a life today is the same as the value of a life in the future. (Skjong, 2002) For the risk control options relevant in this study, it is assumed that reduction in risk can be seen right after the measure is implemented, even though this might not be the case for option number 3, Exam/test annually after PEC is issued.

Below is a table of the costs for the different risk reducing options suggested in this study. The costs are only based on assumptions.

Table 6-4 Values for costs for the suggested risk control options used in this study

1. One additional pilot at the VTS		
Costs	Labour costs	500 000 NOK/year
	Training costs	100 000 NOK/year

2. More frequently controls during the summer months to ensure that the speed limits are followed		
Costs	Operation	100 000 NOK/year
	Labour	400 000 NOK/year

3. Exam/test annually after PEC is issued		
Costs	Operation	100 000 NOK/year
	Labour	100 000 NOK/year
	Certification	50 000 NOK/year

As with the cost, the reduction in number of fatalities is only based on assumptions. It is assumed that option 2 will both reduce the risk of fatalities, injuries and material damages better than if one additional pilot would be at the VTS, which is option 1. This is because when controlling, one is present where the accidents may happen and can prevent them right away. In addition, experience from the road traffic shows that when the police is visible in the traffic, one tends to drive slower and safer and this is assumed to be the same for vessel traffic. (ht.no, 2008) However, this option is mostly applicable during the summer months when there is much traffic in the Oslofjord and many leisure vessels. Option 1 is assumed to also reduce the number of collisions, and hence the number of fatalities. This option is applicable to all vessel types and for the whole year. Option 3 will not directly prevent collisions, and it is therefore assumed that the reduction in risk is the lowest of the three options. The numbers are also chosen to be quite large so that one can see a reduction in number of fatalities, since the original number of fatalities per year is quite small. The numbers for reduction of number of fatalities due to implementation of a risk control option can be seen in Table 6-5 below.

Table 6-5 Reduction in number of fatalities for risk control options

1. One additional pilot at the VTS		Reduction in risk
Benefits	Reduced casualties with vessels Reduced number of fatalities/injuries Better communication with the vessels	25% reduction Equals a reduction of 0.016 fatalities/year

2. More frequently controls during the summer months to ensure that the speed limits are followed		Reduction in risk
Benefits	Reduced casualties with vessels Reduced number of fatalities/injuries	45% reduction Equals a reduction of 0.029 fatalities/year

3. Exam/test annually after PEC is issued		Reduction in risk
Benefits	Better awareness of the rules Better quality of navigators	17% reduction Equals a reduction of 0.011 fatalities/year

Based on these numbers, one can calculate the GCAF for each risk control option, according to Equation 3.

$$Option\ 1: GCAF = \frac{600000}{0.016} = 37.5\ million\ NOK$$

$$Option\ 2: GCAF = \frac{500000}{0.029} = 17.4\ million\ NOK$$

$$Option\ 3: GCAF = \frac{250000}{0.011} = 22.9\ million\ NOK$$

As can be seen, only option 2 is regarded as cost-beneficial, but the other options are not much above the limit of 20 million NOK. However, it is not the purpose of this study to decide which risk control options to implement.

Now the GCAF have been calculated for three different options. The frequency and consequence analysis was the start of the risk assessment which now has ended with the GCAF values. The next step now is to go back to the frequency and consequence analysis and see to what degree the final calculations are dependent on these values.

7 Change in data

The risk and cost related to risk control options have now been calculated based on the initial data. Which risk control options to be implemented are decided based on these results. But, as is mentioned several times, these data are highly uncertain. So how man one be sure that the correct measures are implemented? How much must the input data in the fault tree, event tree and cost-benefit assessment be changed before the result changes?

The following chain can be used to show how the final result is dependent on each step of the risk assessment:

Figure 7-1 Steps in a risk assessment, without hazard identification

As can been seen, the uncertainty in data from the fault tree analysis have effect all the way to the decision-making process. And if the uncertainty on the fault tree analysis is combined with the uncertainty in the other steps of the process, one may understand that the final result is highly uncertain. It is therefore important to get as accurate data as possible from the start and be aware of the problems uncertainty may lead to.

The focus in this part of the study will be on the frequency and consequence part of the analysis, and mainly uncertainty due to underreporting of accidents. This is because uncertainty in risk assessment is a wide topic which covers uncertainty in models, parameters, completeness and how the uncertainty is dealt with. (Rausand, Uncertainty and Sensitivity, 2010) The frequency analysis is the second step in the risk assessment. The first step is hazard identification, which is not included in this thesis. Inaccurate frequency data will therefore have a direct effect on all the other steps in the assessment and it is important that the frequency data is as accurate as possible. When it comes to the consequence analysis, the number of fatalities per year is a much used number in the further assessment and is much dependent on the frequency in addition to the results from the event tree analysis.

Uncertainty analysis, in terms of Monte Carlo simulation and other mathematical models will not be used in this study. A simplified sensitivity analysis will be performed, but the focus will be on discussion regarding how to address the uncertainty in the frequency and consequence analysis.

7.1 Change in frequency data

In this study, the frequency was found with the use of a fault tree analysis and then the result was compared to reported accident data from NMD. It was found that the frequency from the fault tree was in accordance with the historical data, even though the calculations from the fault tree were based on many assumptions, especially for the number for traffic density. Even though fault tree analysis is a common method when finding the frequency, sometimes only historical accident data is used. One may assume that the historical data is more reliable than fault tree analysis, but this is not necessarily the case.

According to (Psarros, Skjong, & Eide, 2010), 41% of the accidents relevant for the NMD database are not reported. One way of correcting for this is to make a correction factor for underreporting. However, if such correction factors shall be accurate, one must know the degree of underreporting and that is seldom the case. It is assumed that the more severe the accident is, the higher the probability is of it being reported to an accident database. Even though the collision scenario is assumed to have a better degree of reporting than for instance groundings, there is some degree of underreporting, but the degree is not known. In addition to accident type, the degree of reporting varies with factors such as geographical area, flag state and vessel type. This means that one correction factor is only applicable for one specific area, accident scenario and vessel type. In the study by (Psarros, Skjong, & Eide, 2010), only tanker accident data was included in the analysis. The degree of reporting of 59% is therefore not necessarily valid for this study.

When it comes to experts, they are often used when establishing the fault tree and the failure input data. According to (Hoffmann, 2011), experts do not always have a solid reason for their statements when it comes to failure rates and much is then based upon assumptions and not always accurate estimates. In addition, it may be difficult for third parties to know the background for the decisions. For instance in (Fowler & Sørgård, 1998), total loss probabilities and loss of live factors for different accident scenarios and vessel types are listed. It is said that these numbers are subjective judgments made by the authors, but it is not given more information of the background for these numbers. But if there is a lack of data, it is better to have an expert make assumptions rather than someone who does not have the sufficient knowledge about the scenario. According to (Brandsæter, 2011), one is usually conservative in the risk assessment and therefore the final result will not vary too much from the true risk picture.

If it is assumed that 60% of the collisions in the Oslofjord are reported to NMD, one may introduce a correction factor of 1.67 for the frequency. If one should be even more conservative, one may add a safety factor of 2, which can be set by experts. How will these numbers affect the risk assessment? A frequency of 1.03 collisions per year was calculated in the Oslofjord area. If only historical data was used, without including fishing vessels, the result is 0.8 collisions per year. It is the frequency from the fault tree which is used in this study, and it will therefore also be used when including the correction factors. When including the correction factor for underreporting, the frequency will be 1.72 collisions per year and if the safety factor of 2 is used, the frequency will be 2.06 collisions per year. These factors may seem a bit high, and it can be argued that a lower correction factor should also be included. It is therefore decided to also include a correction factor of 1.4. This gives a frequency of 1.44 collisions per year. This factor corresponds approximately to a reporting degree of 70 %.

7.2 Change in consequences

The consequence data is based on data found in literature, but as mentioned earlier, it is often difficult to know how these numbers have been established. If one look at historical data, only one of the five reported collisions in the Oslofjord from 2005-2009 caused large material damages according to the NMD database. No injuries were reported to the database. However, a search for collision accidents in the Oslofjord on the internet shows that two of the reported accidents have been covered by the media. One of them is the one where a fishing vessel collided with a passenger vessel in 2006 and the fishing vessel got severe material damages. (Prang, 2006) Small personal injuries are also mentioned. (Dahl, 2006) The other scenario is the one between the leisure vessel and the bulk carrier in 2008. (Andersson, 2008) Here it is reported of injury of one person, but this is not registered in the NMD database. Injuries are not a separate consequence category in this study. It is assumed that the collision scenarios where it are large material damages or injuries/fatalities have a much higher degree of reporting than if the consequence is only small material damages or minor injuries. A total loss is assumed to always be reported. However, as seen in the above examples, even though the accident is reported to NMD, it is not sure that all the details about the severity are reported.

The NMD have, in addition to the ship accident database, a database for personal incidents related to ship accidents. When filtering out fatalities and injuries related to collisions in the Oslofjord area, one can see that there have been two accidents with three fatalities in total from the database was created in 1981; one accident in 1987 which caused two fatalities and one accident in 1989 which caused one fatality. This gives three fatalities during 22 years (up to 2009), and on average 0.14 fatalities per year. It is also worth noticing that the last reported fatality due to collision in the Oslofjord was in 1989. So it has not been a fatality for 20 years, which is higher than the return-period that was calculated in chapter 3.7 which was 15.5 years, but it was three fatalities during three years from 1987-1989.

Since only fatalities, and not injuries, have been included in the final calculations for risk control options and cost-benefit analysis and it is assumed that fatalities have a high degree of reporting, it is difficult to say to what degree underreporting of accidents affect the consequence calculations other than the direct influence from the frequency analysis. In addition, since there are so few fatalities that have been reported it is difficult to give an accurate return period for the scenario studied in this thesis. It is therefore decided to not change the consequence probabilities to start with, but to only see how the result is affected by a change in the frequency data.

7.3 Results when frequency is changed

The new frequencies that will be used are 1.44 and 2.06 collisions per year. Below is a short summary of the different steps when these frequencies are used.

7.3.1 Consequence

When the correction factor of 1.4 is used, the following frequencies for the consequences are calculated, following the same formulas as in chapter 3.7.1:

$$f(total\ loss) = 1.44 \cdot 0.0202 = 0.029\ per\ year$$

$$f(fatality) = 1.44 \cdot 0.0622 = 0.0895\ per\ year$$

$$f(large\ material\ damages) = 1.44 \cdot 0.12 = 0.173\ per\ year$$

For the correction factor for underreporting, 1.67, the following frequencies are found:

$$f(total\ loss) = 1.72 \cdot 0.0202 = 0.035\ per\ year$$

$$f(fatality) = 1.72 \cdot 0.0622 = 0.107\ per\ year$$

$$f(large\ material\ damages) = 1.72 \cdot 0.12 = 0.206\ per\ year$$

For the safety factor of 2, one gets the following frequencies for the different consequences:

$$f(total\ loss) = 2.06 \cdot 0.0202 = 0.041\ per\ year$$

$$f(fatality) = 2.06 \cdot 0.0622 = 0.128\ per\ year$$

$$f(large\ material\ damages) = 2.06 \cdot 0.12 = 0.247\ per\ year$$

Below is a table showing the return period for the consequences with respect to the different frequencies for collision.

Table 7-1 Return period for the different frequencies and consequence classes

Frequency for collision per year	Return period - Total loss	Return period - Fatality	Return period - Large material damages
1.03	48 years	15.5 years	8 years
1.44	34.4 years	11.2 years	5.8 years
1.72	28.8 years	9.35 years	4.84 years
2.06	24 years	7.8 years	4 years

7.3.2 Cost-benefit assessment

The risk control options are considered to be the same independent of what the frequencies are. The next step where the change in frequency has an effect is therefore in the cost-benefit assessment. There are much uncertainty related to the costs and the reduction in risk and this uncertainty do of course have a great impact on the results from the CBA. But these uncertainties will not be further discussed because of lack of relevant data. Therefore the costs will remain the same and so will the reduction in risk.

Table 7-2 Risk reduction for different frequencies in number of fatalities per year

Option	Risk reduction in %	Reduction in number of fatalities/year for original data	Reduction in number of fatalities/year for correction factor = 1.4	Reduction in number of fatalities/year for correction factor = 1.67	Reduction in number of fatalities/year for safety factor of 2
1	25	0.016	0.022	0.027	0.032
2	45	0.029	0.040	0.048	0.058
3	17	0.011	0.015	0.018	0.022

These numbers do not give much meaning presented like this. The GCAF value will be found for each option and frequency. Remember that the formula for GCAF=ΔCost/ΔRisk (Equation 3).

Table 7-3 GCAF (gross cost of averting a fatality) for different frequencies

Option	Original frequency from fault tree	Correction factor of 1.4	Correction factor of 1.67	Safety factor of 2
1	37.5 mill NOK	26.9 mill NOK	22.4 mill NOK	18.7 mill NOK
2	17.4 mill NOK	12.4 mill NOK	10.4 mill NOK	8.7 mill NOK
3	22.9 mill NOK	16.4 mill NOK	13.8 mill NOK	11.5 mill NOK

7.4 Results

The cost-benefit limit is assumed to be kept at 20 million NOK. If a correction factor of 1.4 is added to the frequency found in the fault tree, both option 2 and 3 would be below the cost-benefit limit. This also applies if a correction factor of 1.67 was added. If a safety factor of 2 was added, all the risk control options would be implemented without further discussion.

Table 7-4 Summary of which risk control options to be implemented with the different frequencies

RCO	Original data from fault tree	Correction factor of 1.4	Correction factor of 1.67	Safety factor of 2
1	No	No	No	Yes
2	Yes	Yes	Yes	Yes
3	No	Yes	Yes	Yes

It is stated in literature that a cost-benefit assessment should not be the only basis for decision-making. The CAF values found for the different RCO are not too far from the cost-benefit limit that was set, and it is therefore reasonable to assume that options which are above the limit would be considered either way. But it is no doubt that a change in frequency will affect the decision-making when it comes to risk control options.

In this study, only the change in frequency has been included and it has been assumed that the frequency found from fault trees and historical data is optimistic compared to the reality. Uncertainties in the event tree analysis and cost-benefit assessment have not been included. These uncertainties can both have a conservative and optimistic effect on the results. The risk control options and the results from the cost-benefits for the different frequencies are only examples of how a change in the frequency can change the basis for the decision-making when it comes to implementing risk control options. As mentioned earlier, there are uncertainties in every step of the risk assessment process. The correction factor related to underreporting is also based on assumptions, so it can be said that the correction factor is only a way to be slighter less conservative then if the safety factor of 2 is used. It is assumed that the results from the risk assessment, if they are wrong, give an optimistic picture of the risk and that one should therefore be conservative in the assessment. But at some point the assessment becomes too conservative. For instance, as seen when implementing the safety factor, the result can be that all suggested risk control options can be said to be cost-effective, even if this is not the case. So an important question is how can one know where the limit is between being too optimistic and implement too few risk control options and being too conservative and implement too many[3].

7.4.1 Risk acceptance criteria

When the correction factors and safety factors are introduced, it is not only interesting to see how this affects the decision regarding risk control options, but also to see if the risk becomes above the tolerable limit according to the ALARP-principle. The risk acceptance criterion was established in chapter 5.1 and Figure 5-4 shows the limits chosen for this study. The upper limit was set to 0.09 fatalities per year and the lower limit was set to 0.02 fatalities per year. The number of fatalities per

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[3] Too many risk control options is with regards to the costs, because one can argue that it cannot be too many measures that can reduce the risk of for instance a fatality.

year when the different factors was included was calculated in chapter 7.3.1. Below is a graphical presentation of these results.

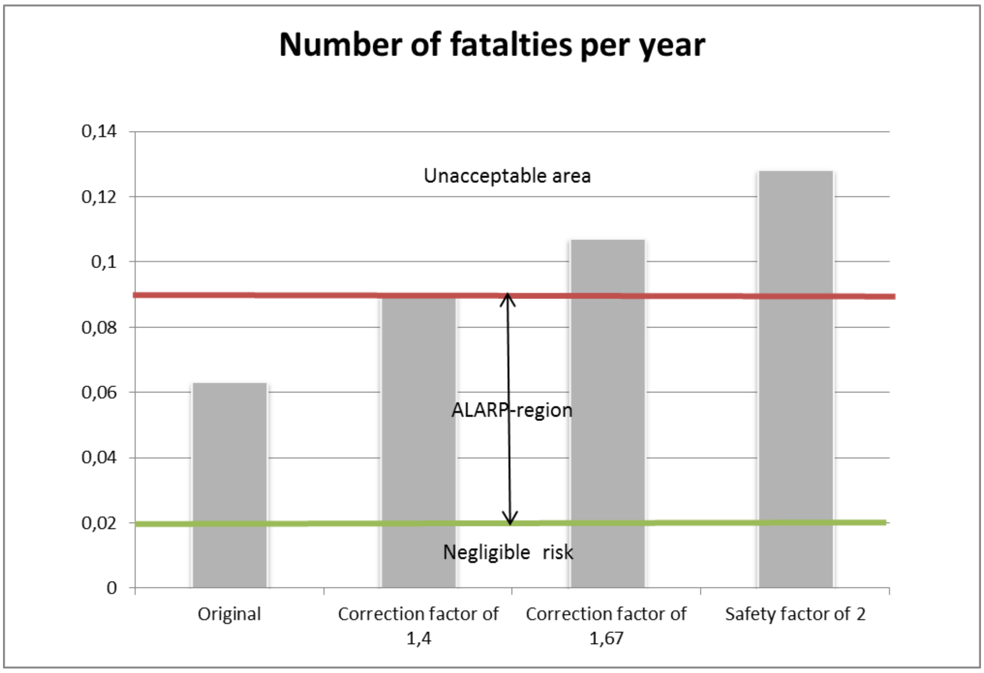

Figure 7-2 Graphical presentation of the difference in number of fatalities per year for the different frequencies

As one can see, the risk is above the tolerable limit if a correction factor of 1.67 is included, which corresponds to an underreporting degree of 40 %. If a safety factor of 2 is included, it will of course be even higher above the acceptable limit. This means that the risk should be reduced regardless of what is cost-beneficial until it has reached or is below the intolerable limit of 0.09 fatalities per year. If a correction factor of 1.4 is included, it is just below the limit and is hence in the ALARP-region. But the fact that it is so close to the intolerable limit it should be taken into regard in the decision-making process.

This shows that a sensitivity analysis should be performed before the cost-benefit assessment to see how much the frequency must change before the risk is in the unacceptable area according to the ALARP-principle. However, it is also important to calculate the sensitivity with regards to the risk control options and cost-benefit assessment, as can be seen in Table 7-4. Together, Table 7-4 and Figure 7-2 shows that a change in frequency can have large effects on the decision regarding if the risk is unacceptable and what measures one should implement to lower it to a tolerable level.

8 Uncertainty in FSA reports

A risk assessment can be used as a basis for discussion regarding rules and regulations made by the International Maritime Organization (IMO). For this purpose a formal safety assessment is a common tool which includes calculating the risk and finding risk control options and performing a cost-benefit assessment.

According to the FSA guidelines by IMO (IMO, Guidelines for formal safety assessment (FSA) for use in the IMO rule-making process, 2002) it is important to be aware of the uncertainty related to the risk assessment. In section 3.1.2.1 in the guidelines it is stated that:

"Whenever there are uncertainties, e.g. in respect of data or expert judgment, the significance of these uncertainties should be assessed."

When looking through some FSA-reports from the SAFEDOR project (www.safedor.org), it is often mentioned that there are uncertainty in the data, but the uncertainty is discussed in various degrees. Three FSA studies have been used to see how uncertainty is dealt with in FSA reports, all based on the SAFEDOR project. These reports can be found on DNV Research's website (DNV Research).

- (IMO, FSA - Liquid Natural Gas (LNG) Carriers, Details of the Formal Safety Assessment, 2007)
- (IMO, FSA - RoPax ships, Details of the Formal Safety Assessment, 2008)
- (IMO, FSA - container vessels, Details of formal safety assessment, 2008)

In the FSA guidelines it is stated that the uncertainty should be assessed, but it is not well stated how. Below is a brief summary of how the uncertainties are assessed in the three FSA reports mentioned above, with focus on uncertainty related to the accident frequencies.

8.1 FSA – LNG

In the FSA report concerning LNG carriers, it is mentioned that the number of accidents is few and that the degree of underreporting is too large to draw any definitive conclusions about what type of LNG carriers that have the highest number of accidents. However, this is not taken into account.

Only historical statistical data have been used to find the frequency of the initial event, hence fault tree analysis have not been used. The uncertainty in frequency due to underreporting is not mentioned.

When it comes to the event tree analysis, expert opinions have been used. It is mentioned that expert opinions differ considerably, and that this leads to much uncertainty, but the estimates is assumed to be conservative.

There is an own chapter in the FSA report about uncertainties (chapter 7.1). Here the subjectivity in the analysis due to lack of data is mentioned as an important uncertainty factor. A table (Table 8-1) is also included with an overview with some of the assumptions and whether they affect the result in a conservative or positive way. Uncertainty related to some of the models used is also mentioned.

Table 8-1 Table of assumptions from FSA report on LNG carriers

Source: (IMO, FSA - Liquid Natural Gas (LNG) Carriers, Details of the Formal Safety Assessment, 2007)

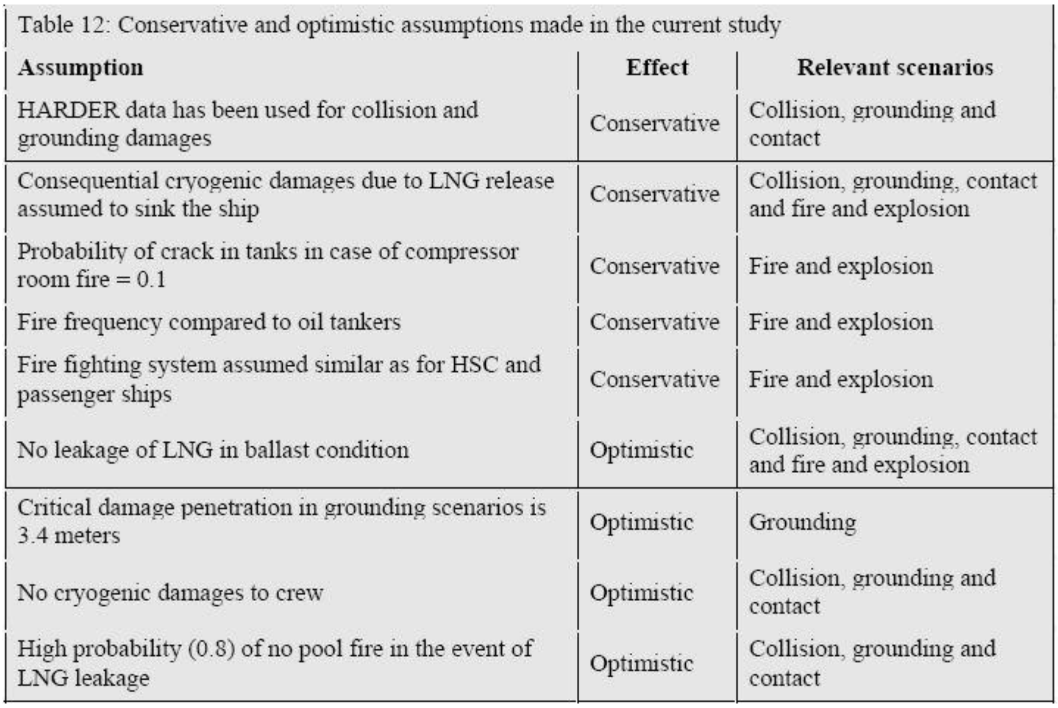

Table 12: Conservative and optimistic assumptions made in the current study

Assumption	Effect	Relevant scenarios
HARDER data has been used for collision and grounding damages	Conservative	Collision, grounding and contact
Consequential cryogenic damages due to LNG release assumed to sink the ship	Conservative	Collision, grounding, contact and fire and explosion
Probability of crack in tanks in case of compressor room fire = 0.1	Conservative	Fire and explosion
Fire frequency compared to oil tankers	Conservative	Fire and explosion
Fire fighting system assumed similar as for HSC and passenger ships	Conservative	Fire and explosion
No leakage of LNG in ballast condition	Optimistic	Collision, grounding, contact and fire and explosion
Critical damage penetration in grounding scenarios is 3.4 meters	Optimistic	Grounding
No cryogenic damages to crew	Optimistic	Collision, grounding and contact
High probability (0.8) of no pool fire in the event of LNG leakage	Optimistic	Collision, grounding and contact

No quantification of the uncertainty can be found in the FSA report concerning LNG carriers.

8.2 FSA – RoPax

In the FSA report on Ro-ro/passenger vessels (RoPax), uncertainty is mentioned in the consequence analysis when it comes to the fatality rates. The fatality rates are only based on historical data. The frequencies of the accidents are also only based on historical data. It is said that the use of expert opinions is kept at a minimum.

When it comes to the risk control options, four options are included. For each of these options, the sensitivity of the risk level is tested for different level of the frequency of accident scenarios included. A reduction in the incident rate (ΔIR) is used to find how the risk level and number of fatalities is reduced when implementing the risk control options. These numbers are then further used in the cost-benefit analysis where the CAF value is the main parameter. Table 8-2 shows an extract of the table for one of the risk control options found in the FSA report.

Table 8-2 Extract from sensitivity analysis on risk control options from FSA-report on Ro-ro/passenger vessels

Source: (IMO, FSA - RoPax ships, Details of the Formal Safety Assessment, 2008)

RCO id	RCO description	ΔC (in USD)	ΔIR - Reduction of accident frequency	PLL (per ship year)	ΔR (% of PLL)	Averted fatalities per ship	GCAF (USD)
1.1	On board safety and security centre	9 682 085	25 %	1,99E-01	10 %	0,6	16 136 808
			50 %	1,78E-01	19 %	1,3	7 447 758
			75 %	1,57E-01	29 %	1,9	5 095 834
1.2	Automatic logging of information	45 629	25 %	1,99E-01	10 %	0,6	76 048
			50 %	1,78E-01	19 %	1,3	35 099
			75 %	1,57E-01	29 %	1,9	24 014
1.3	Two officers on bridge	9 524 085	25 %	1,99E-01	10 %	0,6	15 873 475
			50 %	1,78E-01	19 %	1,3	7 326 219
			75 %	1,57E-01	29 %	1,9	5 012 676

There is no mentioning of underreporting or other types of uncertainty than the one related to the fatality rates.

8.3 FSA – Container vessels

For container vessels, the FSA report contains an own chapter (chapter 4.6) where the topic is uncertainty and several areas and factors which is subject to uncertainty are mentioned. It is also said that the assumptions is based on a conservative approach.

The initiating event probabilities are mainly based on historical data and problems with incomplete accident statistics is mentioned. For the event tree analysis it is said that this includes a number of assumed probabilities which cannot be statistically verified.

A rough sensitivity analysis is included to see what impact some of the uncertainty has on the final result. A table (Table 8-3) is included to illustrate some of the examples used in the sensitivity analysis. PLL stands for potential loss of life and is the statistical number of persons within a given group which is killed due to a specific accident each year. (Rausand & Utne, Risikoanalyse - teori og metoder, 2009, p. 56)

Table 8-3 Extract of table of sensitivity analysis from FSA on container vessels

Source: (IMO, FSA - container vessels, Details of formal safety assessment, 2008)

Parameter	Original value	Modified value	PLL before modification	PLL after modification	Effect on total PLL
Collision: Frequency of initiating event	1,61E-02	(+30%) 2,10E-02	6,11E-03	7,98E-03	21 %
Collision: Relation of struck and striking vessel	50/50	60% striking 40 % struck	6,11E-03	4,88E-03	-14 %
Collision: Minor damage only at full speed struck	20 %	2 %	6,11E-03	7,41E-03	14 %

It is said that the impact of the uncertainties is considered not to be significant and that the results are accurate enough to be used as a basis for conclusions.

No uncertainty is mentioned in relation with risk control options or cost-benefit assessment.

8.4 Summary

The three FSA reports above is all part of the same project (SAFEDOR) and is all submitted by Denmark, but the focus on uncertainty and underreporting varies. It has not been included FSA reports from other studies, therefore it cannot be said that the focus on uncertainty and underreporting found in these three reports reflects the general focus for all FSA reports.

Only one of the three reports has performed a sensitivity analysis with respect to the frequency, but this is not further included in the cost-benefit analysis. One of the reports includes a sensitivity analysis for the risk control options which is further included in the cost-benefit analysis. Underreporting of accidents is mentioned as a topic, but not taken into regard in the analyses.

It may seem like even though the uncertainty is mentioned, it is not always included in the analysis. Often it is said that the results are accurate enough for the purpose of this study without any use of sensitivity analysis. It may be that those who perform the analysis are experienced enough to see if the relevant study does not require more information about the uncertainty, but then it should be clearly stated that where the uncertainties are and how the assumptions are made.

It would be interesting to perform the same type of sensitivity analysis for the three FSA reports listed as was performed in this study. However, this is difficult due to lack of transparency in the process.

It has been focused on transparency in the process of this study so it is easy to follow the steps from the top event frequency in the fault tree to the cost-benefit assessment. Transparency is important when analysing the results from a risk assessment. In addition, often relevant literature is used when finding data for instance for event tree analysis and cost-benefit assessment. If the background for these data is not known, it is also difficult to know the degree of uncertainty in these data. This is especially the case where expert judgments have been used. In the guidelines on FSA from IMO (IMO, Guidelines for formal safety assessment (FSA) for use in the IMO rule-making process, 2002), it is said that the FSA "*can be used as a tool to facilitate a transparent decision-making*". The FSA reports can be updated if new information and knowledge is available. It is therefore important that the process is transparent so one knows what is done and how it is done.

9 Approaches to correct for underreporting

So far, this study have focused on how the uncertainty in data, with focus on underreporting, affects the final result of the risk assessment when it comes to risk reducing options. A risk model has been made so one can see concrete results on how a change in frequency affects the process all the way to the cost-benefit assessment. In this chapter and the next, a more thorough discussion regarding the problems related to underreporting and decision-making and what the best option is to correct for this.

In this chapter, three different approaches will be dealt with to see how it is best to correct for underreporting. First, is it best to use the “original” data? Or is it best to let experts do the final decision regarding failure data, consequence probabilities and costs? Or can correction factors be used to be sure that the calculated results are within the acceptable limits?

Below a brief description will be given concerning the drawback and advantages for both methods.

9.1 Correction factors

Correction factors for underreporting of maritime accidents have not been focused on in earlier literature and studies and no suggestions for correction factors are found. When it comes to accidents related to road transport, correction factors for underreporting have been suggested in several studies. In a report from the Transport Research Laboratory (TRL) (Robinson, Hulshof, Robinson, & Knight, 2010) several correction factors from different studies are listed.

The most extensive study is a report as part of the HEATCO project from the EU. In this study correction factors for different means of road transport and different degree of severity are suggested. The factors are based on statistical data from six different countries. (Robinson, Hulshof, Robinson, & Knight, 2010) In the report from the HEATCO project, an average correction factor was suggested based on the correction factors from the different countries.

Table 9-1 Suggested correction factors for unreported road accidents Source: (Bickel, et al., 2006)

	Fatality	Serious injury	Slight injury	Average injury	Damage only
Average	1.02	1.50	3.00	2.25	6.00
Car	1.02	1.25	2.00	1.63	3.50
Motorbike/moped	1.02	1.55	3.20	2.38	6.50
Bicycle	1.02	2.75	8.00	5.38	18.50
Pedestrian	1.02	1.35	2.40	1.88	4.50

These numbers cannot be said to be without any uncertainty. In addition, it is large variations between different countries, different transport modes and severity rates.

The correction factors in Table 9-1 are mainly based on comparison of hospital data and police records. This can also be done for the maritime industry by for instance compare data from yards (what is repaired and why) and insurance companies.

It is assumed that the higher severity the higher the degree is of reporting, which is in accordance with Table 9-1. Even though the high severity accidents are important to focus on, it is also important to focus on those incidents that could have led to a serious accident. This is because one can both learn what went wrong and so one can learn why it did not evolve into a high severity accident. To find the total number of accidents, including low severity and near-misses, one can use a well-known figure which describes the relation between, fatal accidents, serious accidents and non-serious accidents. The numbers in Figure 9-1 are subject to discussion, and they will vary with different sectors and conditions and what is defined as major and minor accidents and incidents.

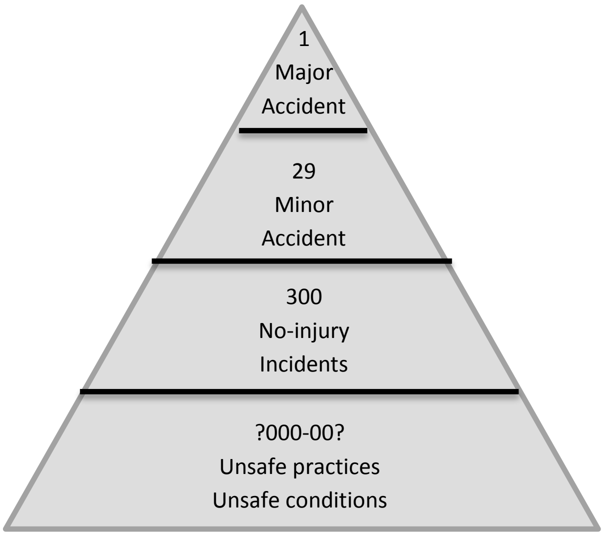

Figure 9-1 The Iceberg theory Source: (Kristiansen, 2005)

If it is assumed that all the major accidents are reported, one can found the number of minor accidents and non-serious accidents and create an underreporting factor based on this. This was the basis in a study concerning underreporting by Peter Hoffmann at DNV. A ratio between the number of non-serious accidents and serious and fatal accidents was multiplied with a trend factor to find an underreporting factor. The trend factor takes into consideration that the number of accidents per year is not constant. (Hoffmann, 2011) (Kjemperud, 2011)

As mentioned earlier, the availability of data must be good to be able to make correction factors and one must one the degree of underreporting. Otherwise, only more uncertainty will be added to the result and the correction factors may be characterised as safety factors.

9.2 Expert opinions

Experts are often used in several steps of the risk assessment, as mentioned in chapter 4. Experts are often used to estimate data where it is not possible to find historical data and these estimations are not accurate. Experts can also be used to assess the uncertainty in the data based on their knowledge and experience. But expert opinions are subjective and the answers will vary dependent on who you ask and how you formulate the problem. If experts are used to estimate the uncertainty in the frequencies, it is important that the estimations are clearly stated. If the frequencies are only based on statistical data, experts with knowledge about underreporting can be used. If the frequencies are based on expert opinions, it may be difficult for them to assess their own uncertainty and that other experts should assess the uncertainty. On the other side, an expert is better aware of what is the background for his/her own opinions than anyone else and if the expert is well aware of the weaknesses with his/her own assumptions, this could be used to find good estimates for the uncertainty.

Underreporting of accidents is only one of several uncertainty parameters in a risk assessment. Experts could be used to assess the uncertainties related to for instance the model and other parameters such as consequences and costs. In addition, it is not always the best solution to quantify the uncertainty. For instance when it comes to human errors, it may be best to qualitatively describe the uncertainties related to this.

9.3 Safety factors

In the sensitivity analysis in chapter 7 in this study, a safety factor of 2 is included. This means that it is assumed that only 50 % of the accidents are reported. A safety factor can be compared with a correction factor. The main difference is that a correction factor should be based on studies of the degree of underreporting. If the degree of reporting is now known, a safety factor can be used instead for a conservative approach. As mentioned earlier, one must make sure that the safety factor is not too far from the real frequencies, and this means that some knowledge about the degree of underreporting must be present. Safety factors can be used at other stages of the process where there are uncertainties, for instance when it comes to consequences. For each case and at each stage of the process one should discuss where it is important to be conservative and then apply safety factors based on this.

10 Discussion

There is no doubt that there is a large degree of underreporting of maritime accidents. For most of the risk assessment studies, this is not taken into account and other types of uncertainty are often only briefly mentioned. A risk assessment is often the basis for decision-making regarding risk reducing measures and historical accident data is often used as basis. One should therefore think that there is a focus on correct frequencies of historical reported accidents, but this not seem to be the case for the majority of the reports studied during the work with this thesis. In the report from (Thevik, Sørgård, & Fowler), underreporting of accidents is not mentioned at all, even though historical accident data is the basis for the calculations. In the study by (Dahle & Hassel, 2011), it is mentioned that the database from NMD most likely have a degree of underreporting, but this is not taken into consideration when calculating the risk. In the study by (Thevik, Sørgård, & Fowler), it is even mentioned that some of frequencies found by MARCS is higher than the historical frequencies. Underreporting of accidents could be a contributing factor to this and it may therefore seem strange that this is not mentioned at all.

In chapter 9, three approaches to deal with uncertainty in the data are described. None of them seem to be a perfect solution to make up for underreporting, mainly because the implementation of one of these methods will lead to more uncertainty. For most of the risk assessments and FSA reports studied in this thesis, the approach seems to be conservative in the estimations and assumptions. However, how conservative the assumptions are, is not further described.

As can be seen in chapter 9.1, the road transport sector has made suggestions for correction factors based on studies from several countries. Even though there is some degree of uncertainty in these numbers as well, this shows that it is possible to get some results if the topic is focused on. It has not been found any reports where these numbers have been used in a risk assessment, so to what degree these numbers are used is difficult to say. It is important to remember that even though there are guidelines for how a risk assessment should be performed, it is not always that these guidelines are followed. It is often a difference between how things are meant to be done and how it is done in reality. This can for example be seen in the FSA-reports when it comes to how the uncertainties in the data and model are dealt with. In the FSA-guidelines it is stated that uncertainty should be assessed in the FSA-reports, but it is not mentioned how or to what degree. If it was stated clearer what is meant by “assessing the uncertainty”, it would perhaps be easier for the authors of the FSA-reports to do this in an adequate way. Nevertheless, the authors should try to get as accurate results as possible and uncertainty is therefore important to focus on regardless of what the guidelines say.

Originally one of the purposes with this thesis was to make suggestions for correction factors for underreporting of maritime accidents. A general correction factor for all accident types, vessel types and geographical location would be purposeless due to the large differences in degree of reporting. Ship-to-ship collision in the Oslofjord area was chosen as the scenario for this thesis. One could try to make a correction factor for underreporting of this scenario, but due to lack of data and information this has not been done. To make an accurate correction factor for underreporting one must know the degree of underreporting for the specified area and accident type, and this is should be written as a separate study due to the extent of the topic. In addition, it must be discussed what the purpose of the correction factor is. For a risk analysis where the collision risk in the Oslofjord is the relevant scenario, it would be useful to have such correction factors. Both to be sure that the frequency used in the risk analysis is correct and to show that it should be more focus on underreporting and how it affects risk assessments. However, for studies such as the annual reports on the ferry risk in Norway from NMD mentioned in chapter 2.1, correction factors would perhaps not be so useful since the purpose of the reports is to compare the risk with the risk calculated in the previous years. On the other hand, if it is assumed that the degree of reporting varies from year to year, correction factors could perhaps give a more correct picture of the risk. Nevertheless, establishing correction factors is time demanding and one must decide whether the time is best used on other areas of the project.

The "problem" with the maritime industry is that it is an international sector. The vessels travel across the world and the report routines for accidents and near-misses varies much with location of accident and flag state of vessel. This makes it difficult to make one correction factor which is valid for all flag states and geographical location. Different vessel types also have different degree of accident reporting. However, it is assumed that if one flag state starts with focusing more on the influence underreporting have on the risk assessment results, perhaps also the IMO will focus more on this. Or if IMO starts to focus on this, the flag states will as well.

In this study, a fault tree analysis has been used to find the frequency. A traffic-based model can also be used to find the frequency of an unwanted event, as mentioned in chapter 3.2.1. For a traffic-based model, accident statistics are not used, but information about the specific fairway is needed. Since accident statistics is not used, the frequency is not affected by underreporting. However, much data is needed and it may be difficult to for instance get accurate data concerning crossing/meeting traffic. Even though both the F-risk model and the MARCS model have used collision models to find the probability of a collision scenario, fault tree is also used. In addition, the results have been compared with statistical accident data. If all the three approached; fault tree, traffic-based and statistical data, are used one can compare the results with each other and it is reasonable to assume that the result will be closer to the real accident frequency. Nevertheless, it is important to be aware of the uncertainties related to all three approaches and one should also have in mind what the purpose of the risk assessment is. If for instance the purpose is to find the accident causes, a collision model is not the preferred approach.

Expert opinions have also been studied in this thesis and both advantages and disadvantages have been mentioned. Expert opinions are useful where there is lack of data. It is better to have inaccurate data than no data, but then it is important to clearly state the inaccuracies and uncertainties. But it is important to remember that a guess is a guess even if it is a qualified guess made by an expert. On the other hand, experts could discuss aspects which are difficult to quantify, such as human errors. It seems to be the opinion that experts must be used, but should be used as little as possible, especially for quantitative estimations. (Skjong, Chief Scientist, Det Norske Veritas, 2011) But perhaps it is better to look at how they are used instead of saying that one should use them as little as possible, for instance by focusing more on the expert information approach suggested by Kaplan. If one tries to explain how the expert opinions are used in a risk assessment, it is easier to be aware of the background and reason for the expert's opinions and then include that in the analysis.

The discussion regarding risk acceptance criteria is also important, even though it has not been focused on in this thesis. The limits for what is regarded as tolerable risk will decide whether or not it is beneficial to implement a risk reducing measure. For many assessments the best solution is to not have an absolute criterion but to see how close to the limit the calculated risk is and then make decisions based on this. At the same time one could take into regard the uncertainty in the initial frequency. If the degree of underreporting is assumed to be high and there is much uncertainty in the rest of the data used, this should be included by perhaps be somewhat less strict with what is the tolerable lower limit. Because it may be that if the limit or the frequency was slightly changed, the outcome would be different, as seen of the examples in chapter 7.4.

11 Conclusion and further work

The purpose of this thesis was to find out how underreporting affects the final result of a risk assessment and how this can be corrected for. It is clear that a change in frequency of the initial event can have large effects on the choice of risk reducing measures. Underreporting is seldom mentioned and to be sure that the frequency for the initial event is not too low, the approach in most reports is to be conservative in the assumptions. Based on the discussion regarding correction factors for underreporting it may seem like this is a better alternative than include correction factors. If correction factors should be implemented, one must have knowledge about the degree of underreporting and take into regard the vessel types, location, accident scenario, flag state and other factors which may have an impact on the degree of accident reporting. This does not mean that underreporting shall not be included in the risk assessments, but it is perhaps better to first map the extent of underreporting in different areas and learn how other sectors like the road, rail and air transport have dealt with the subject, if they have.

Even though the uncertainty could be better discussed and calculations could have been made, it is better that uncertainty is mentioned than if it is just ignored. If it is mentioned, further discussions can be made later. Some risk assessments needs to be further discussed and worked on at a later stage when more data has been found and perhaps other persons are involved. It is therefore important that it is mentioned if there are uncertainties in the data so one could later assess these uncertainties. So as mentioned earlier, transparency is important.

It is important to remember that underreporting is only one of many uncertainty factors relevant for a risk assessment. Perhaps other types of uncertainties affect the final result more than a change in frequency. This must be evaluated for each case, but it does not mean that one should not try to get the initial frequency as accurate as possible. It should be a goal that one should have as little uncertainty in the data as possible, based on in the time and cost limits of the project.

It is believed that sensitivity analyses should be a part of more risk assessments. The simplified sensitivity analysis performed in this thesis shows the importance of calculating how a small change in frequency affects the final result. And not only should the frequency be dealt with, ideally should the uncertainty in all the steps of a risk assessment should be discussed throughout the process. This especially applies to reports where the results can have an influence on decisions regarding rules and regulations, such as FSA-reports from IMO.

Experts are an unavoidable part of a risk assessment, but it is important to be aware of the fallacies. One should always be aware of the background for the opinions and not take the opinions as an absolute truth. But experts can often provide useful and necessary information and perspectives where there are uncertainties and problems which are subject to discussion.

Based on the work in this thesis, it is not recommended to focus on using correction factors for underreporting in risk assessment, but instead focusing more on how these correction factors can be established. By co-operating with other industries one can share experience with how underreporting is dealt with. It is a fact that in every industry and situation where there are accidents, there is a degree of underreporting and it is not only the maritime industry where it is important and of interest to focus on this.

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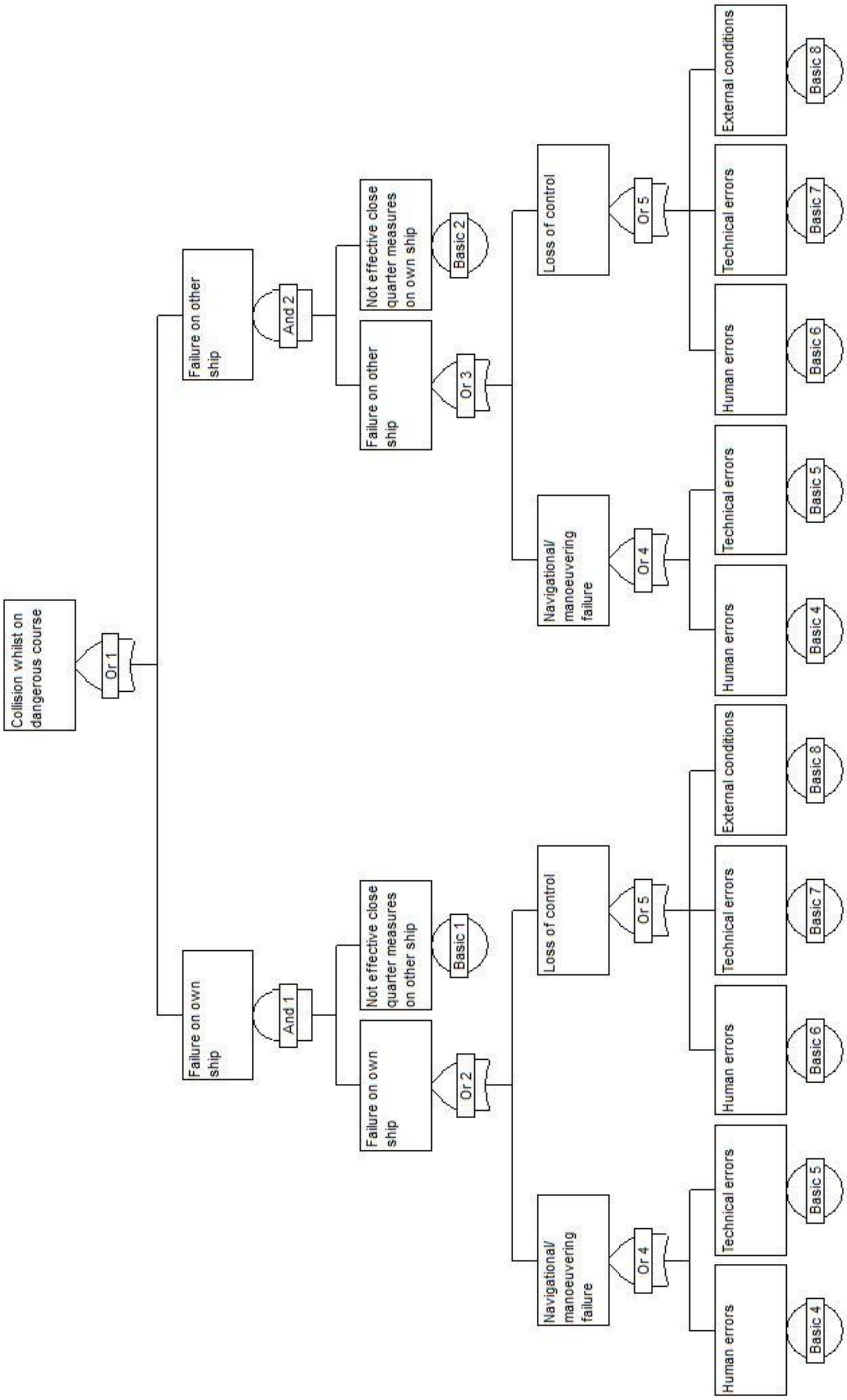
Appendix A – Complete fault tree used in the fault tree analysis made by CARA Fault tree program



Appendix B – Maps of the Oslofjord area

Below are two different cuttings of maps of the Oslofjord area.

Figure B-1: The line shows approximately the geographical limits for the Oslofjord area.

Source: (Kystinfo Kart)

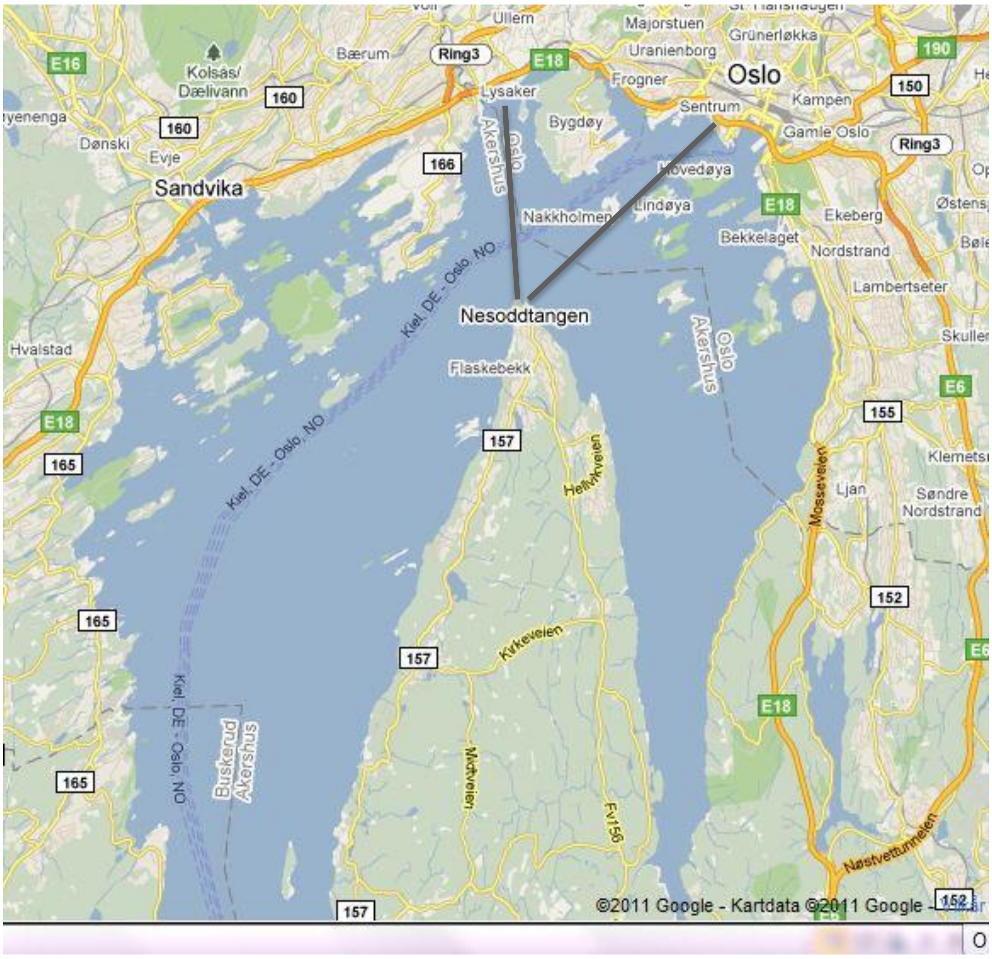


Figure B-2: Maps of the inner Oslofjord area

Source: (Google Maps)

The figure shows the inner Oslofjord with all the islands. As one can see, the fairway consists of many small islands and ferries have a route between Nesoddtangen and Lysaker and between Nesoddtangen and Oslo city. In addition to the leisure vessel and large cruise vessels which are present during the summer months, one can understand that the inner Oslofjord area can be a busy area when it comes to ship traffic.