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Operational Risk in the Norwegian Barents Sea

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Master Thesis

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Anyone can hold the helm when the sea is calm. – Publilius Syrus

PREFACE

This Master thesis was written in the spring of 2013 at the Norwegian University of Science and Technology, NTNU, Department of Marine Technology, in cooperation with Det Norske Veritas, DNV. The work corresponds to 30 credits at NTNU.

The aim of this master thesis was to investigate relevant operations and emergency preparedness scenarios in the Norwegian Barents Sea, using barrier management, focusing on what makes them different there compared to the rest of the Norwegian Continental Shelf.

This master thesis treats the same topic as my project thesis written in the fall of 2012, and can be seen as a continuation of this project. The topic then was the somewhat broad "Risk Control in the Arctic", and the work performed on more specific operations in this master thesis benefitted from the knowledge obtained while writing the project thesis.

The workload of 30 credits for this master thesis was evenly distributed throughout the semester, following a project plan that was made in early January. The majority of the work took place abroad, and I would like to express my sincere gratitude to all of those who have responded to my e-mails and provided me with necessary information. However, while most responded, some did not, and in some areas it proved difficult to obtain data. My initial lack of knowledge regarding offshore operations was also a point of concern, and I wish to direct special thanks to Helge Samulesen for receiving me at the Ship Modelling & Simulation Centre in Trondheim.

For their support through the project I wish to thank Professor II Jan Erik Vinnem, who acted as my supervisor at the Department of Marine Technology, NTNU, and to Børre Johan Paaske, my supervisor at Det Norske Veritas, DNV.

Trondheim, June 8th 2013

Sondre Henningsgård

EXECUTIVE SUMMARY

With the estimated increase in demand for energy in the World by one-third within the next 25 years, the findings and estimates in the Arctic are of great importance. Equipment, procedures, training, facilities, logistics, EER and production are only some of the many challenges for the industry moving north. The industry must be prepared for the public eye, as high societal expectations to companies must be anticipated. There are great differences between the areas in the Arctic; therefore this thesis focuses on areas that are currently open for petroleum activities in the Norwegian Barents Sea, considering two operational scenarios and two emergency preparedness scenarios.

1. Operation scenarios
    a. Off-loading by shuttle tanker
    b. Flotel connected to rig
2. Emergency preparedness scenarios
    a. Emergency landing with helicopter on water (Ditching)
    b. Man over board (MOB)

The overall question to be answered was whether the Norwegian Barents Sea is significantly rougher than the North Sea and thus if it is possible to carry out the selected scenarios? This was split into three parts:

1. What is required and/or needed for these operations to be performed with a satisfactory level of risk?
2. How will this influence the availability?
3. Is it possible to conduct operations in the Norwegian Barents Sea at this point, without unreasonably high cost?

By satisfactory it is meant *as good as the North Sea*.

Background material regarding Barents Sea conditions and the operations investigated was thoroughly studied before a qualitative risk analysis was performed. The Bow Tie method was selected for this analysis, based on scenarios created for the particular operation or emergency preparedness cases; focusing on the differences between the Norwegian Barents Sea and the rest of the Norwegian Continental Shelf. The main differences found for the area of interest were; rapid weather changes, icing, polar night, lower temperatures and underdevelopment.

The analysis has revealed that the selected operations in the area of interest can be carried out with a satisfactory risk level, with extra attention paid to operational planning and some minor adjustments to requirements. The Norwegian Barents Sea stands out as an Arctic area that will allow for petroleum activity without unreasonable added costs.

The analysis and research has found that the conditions in the Norwegian Barents Sea are not significantly different from what the industry faces in other areas of the Norwegian Continental Shelf. The main issue found was the underdevelopment of the area and no area emergency preparedness. Uncertainties with weather forecasts are also an issue; however these are expected to improve as more observations are made. The forecast models for polar lows need to be improved. With gradual development and

improved infrastructure, the investigated scenarios will not represent any greater risk in the Norwegian Barents Sea than other areas on the Norwegian Continental Shelf.

Communicating the risk level to the public is a challenge for the industry. Industry partners seem to agree on the challenges and risks, and that they are not significantly different or worse than in the North Sea. The analysis' performed in this thesis do not challenge this view. Public opinion seems to be that the Norwegian Barents Sea is something completely new and different from the rest of the Norwegian Continental Shelf. At least for the cases studied in this thesis, this simply is not true.

SAMMENDRAG

Verdens energibehov forventes å øke med en tredel innen de neste 25 årene. Funnene og estimatene i Arktis er derfor svært viktige. Utstyr, prosedyrer, trening, fasiliteter, logistikk, EER og produksjon er bare noen av utfordringene for industrien som beveger seg nordover. Industrien må være forberedt på offentlig søkelys på grunn av de forventningene som stilles fra samfunnet. Det er store forskjeller mellom områdene i Arktis, derfor fokuserer denne oppgaven på områdene som er åpnet for petroleumsaktivitet i det Norske Barentshavet. To driftsoperasjoner og to nødsituasjoner har blitt undersøkt.

1. Drift
    a. Off-loading med shuttle tanker (Bøyelasting)
    b. Flotel ved installasjon
2. Nødsituasjoner
    a. Nødlanding med helicopter på vann (Ditching)
    b. Mann over bord (MOB)

Det overordnede spørsmålet var hvorvidt det Norske Barentshavet er signifikant verre enn Nordsjøen og om det er mulig å utføre de overnevnte scenarioene. Dette ble igjen delt opp i tre spørsmål:

1. Hva er nødvendig for at utføre disse operasjonene med et tilfredsstillende risikonivå?
2. Hvordan vil dette påvirke tilgjengeligheten?
3. Er det mulig å gjennomføre disse operasjonene i det Norske Barentshavet uten urimelige økte kostnader?

Med tilfredsstillenede menes her *så godt som i Nordsjøen.*

Bakgrunnsmateriale om forhold i Barentshavet og operasjonene ble nøye undersøkt før en kvalitativ risikoanalyse ble gjort. Bow tie metoden ble valgt til analysen og basert på scenarioer utviklet for de aktuelle operasjonene og nødsituasjonene. Fokus her var forskjeller mellom det Norske Barentshavet og resten av den Norske Kontinentalsokkelen. Hovedforskjellene som ble funnet var; raskt skiftende vær, ising, mørketid, lavere temperaturer og underutvikling av området med hensyn til petroleumsaktivitet.

Analysen viste at de utvalgte operasjonene er gjennomførbare og at nødsituasjonene er håndterbare med et tilfredsstillende risikonivå. Ekstra oppmerksomhet må rettes mot operasjonell planlegging og noen mindre endringer i kravene må gjøres. Det Norske Barentshavet skiller seg ut som et arktisk område der petroleumsaktiviteter kan gjennomføres uten urimelig økning i kostnadene.

Analysen og undersøkelsene fant at forholdene i det Norske Barentshavet ikke er signifikant forskjellige fra det industrien allerede håndtere andre steder på den Norske Kontinentalsokkelen. Hovedproblemet som ble funnet var underutviklingen av området og mangelen på områdeberedskap. Usikkerhet i værmeldinger er også et problem, disse forventes å forbedres raskt ettersom flere observasjoner gjøres. Prognosemodellene for polare lavtrykk må forbedres. Med en gradvis utvikling og forbedring av infrastrukturen vil ikke operasjonene og nødsituasjonene undersøkt i denne oppgaven representere

større risiko i det Norske Barentshavet enn andre steder på den Norske Kontinentalsokkelen.

Risikokommunikasjon mot det offentlige er en utfordring for industrien. Industriaktørene virker å være enige om utfordringene og risikoen, og at disse ikke er signifikant annerledes eller verre enn i Nordsjøen. Analysen i denne oppgaven utfordrer ikke dette synspunktet. Folkeopinionen virker å være at det Norske Barentshavet er noe fullstendig nytt og annerledes enn resten av den Norske Kontinentalsokkelen. For de scenarioene som er undersøkt i denne oppgaven kan det ikke konkluderes med annet enn at denne oppfatningen er feil.

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1. INTRODUCTION

The Arctic sea ice is in rapid decline, and the southern Norwegian Barents Sea is ice free. At the time of writing, the Arctic ice-cap is at its lowest since accurate measurements began some 30 years ago. The decline in ice coverage is expected to persist into the foreseeable future, and with a World that is in need of more energy, the Arctic is ever more interesting. It is estimated that the global demand for energy will increase by one-third within the next 25 years. IEAs World Energy Outlook 2006 even estimates that this number may be as high as 53 % within 2030[2]. An open Arctic Ocean represents many opportunities, and its importance will increase in the coming years.

In order to realise the full potential of the Arctic, current technology and experience is in need of improvement. The international oil and gas industry currently applies recognised technical standards that are used worldwide. The ever growing focus on oil and gas exploration has raised the need for satisfactory standards and industry practices. Due to the great differences between areas in the Arctic, this thesis will focus on the Norwegian Barents Sea, and it is the purpose of this thesis to look into two operational scenarios and two emergency preparedness scenarios.

Petroleum activities in the Norwegian Barents Sea were first allowed in the 1980's. Development has however been scarce. The opening for petroleum activities in the Norwegian Barents Sea provides opportunities; however it also presents the industry with several challenges; especially proving that they are able to handle conditions beyond what are found in other exploited areas. With the amount of hydrocarbons that are expected to be found in the Barents Sea and the Arctic, it is no longer a question of *if* companies will move in, and in some cases beyond *when.* This Master thesis originated from a project thesis concerning risk control in the Arctic. After a thorough run through of the current issues in the Arctic and the Barents Sea development, it was decided that the focus of this thesis should be on operations, rather than looking into what the risks are.

The scenarios and operations for this thesis were selected in cooperation between the supervisors, Professor II Jan Erik Vinnem (NTNU), Børre J. Paaske (DNV) and the author; rooted in key risk factors identified through projects such as the Barents 2020, and reports such as the RNNP 2011 report from the Norwegian Petroleum Directorate.

1.1 PROBLEM DESCRIPTION

The purpose of this thesis is to analyse scenarios relevant for operations in the Norwegian Barents Sea. There are many relevant issues that could have been selected for this thesis. The focus area is the differences between operating in the Barents Sea compared to areas in the Norwegian sector where petroleum activities are already taking place. In order to investigate this, four scenarios were selected.

The scenarios have been divided into two regular operation scenarios and two emergency preparedness scenarios:

3. Operation scenarios
    a. Off-loading by shuttle tanker
    b. Flotel connected to rig
4. Emergency preparedness scenarios
    a. Emergency landing with helicopter on water (Ditching)
    b. Man over board (MOB)

1.2 PURPOSE

Due to the many uncertainties involved in moving the industry to the north, this thesis will investigate, in a mainly qualitative manor, what happens when the above scenarios are moved from the North Sea to the Norwegian Barents Sea?

Questions that this thesis aims to answer are:

1. What is required and/or needed for these operations to be performed with a satisfactory level of risk?
2. How will this influence the availability?
3. Is it possible to conduct operations in the Norwegian Barents Sea at this point, without unreasonable cost?

The overall questions are whether the Norwegian Barents Sea is significantly rougher and thus if it is possible to carry out the selected scenarios?

1.3 STRUCTURE

The report consists of four parts:

1. Background material on the Norwegian Barents Sea.
2. Theory and methods.
3. Analysis.
4. Discussion and conclusions.

The background regarding the Norwegian Barents Sea, issues and current status is covered in chapter 2 and in appendixes. The main focus here is on Barents Sea specific issues, that separates it from the rest of the Norwegian Continental Shelf. This includes; metocean conditions, logistics, human factors and some regulations.

Theory and methods are covered in chapter 3, and also some additional material in appendix. Here, risk management with focus on barriers is the topic.

The analyses in chapter 4 are the main part of this thesis. For each, general criteria for the operation as well as some background information are provided before a bow tie analysis is performed. After the bow tie analysis, some key factors are discussed before the identified barriers and issues are presented.

The Flotel chapter differs from the others due to lack of data. Here, it was necessary to suggest a model fitting the case.

The final discussion and conclusions are presented in chapter 5.

1.4 LIMITATIONS

There were some limitations to the work performed that should be mentioned.

The first limitation was focusing on the southern part of the Norwegian Barents Sea, that is; the region opened for petroleum activities (see chapter 1.4.1).

The majority of this thesis was written abroad and most contact with sources and supervisors was made via e-mail. Some sources with potentially important data and knowledge did not respond. Access to this information may have influenced some of the results. In addition, some data was hard to obtain.

For the content and evaluations made in this thesis, the information that was made available during the time of writing, the operations and the created scenarios are among other factors that are of importance. Also, the author's limited experience with offshore operations may have influenced some of the scenarios.

It was not the purpose of this thesis to rediscover Barents Sea risk factors or climate, thus chapter 2 and the related appendixes will mainly present results from the former project thesis by the author and previous work performed by others, creating a summary of the various conditions in the Norwegian Barents Sea. These were considered known and were therefore included in appendix.

1.4.1 GEOGRAPHICAL AREA

The Arctic and also the Barents Sea are a great many things, and creating scenarios and operational studies that would actually be relevant for all areas is unrealistic. This report is focused on the areas that are presently opened for exploration and exploitation of petroleum resources in the Norwegian sector of the Barents Sea. This corresponds to the area from approximately 15° E to 31° E and 70° N to 74,5° N which is the area between the coast of northern Norway and Bjørnøya (Bear Island). This area is shown on the map in figure 1.

The demarcation line between Norway and Russia, from the coast to the North Pole, was agreed in April 2010, after being disputed for roughly 40 years. The relatively new border is shown in figure 2.

1. Introduction

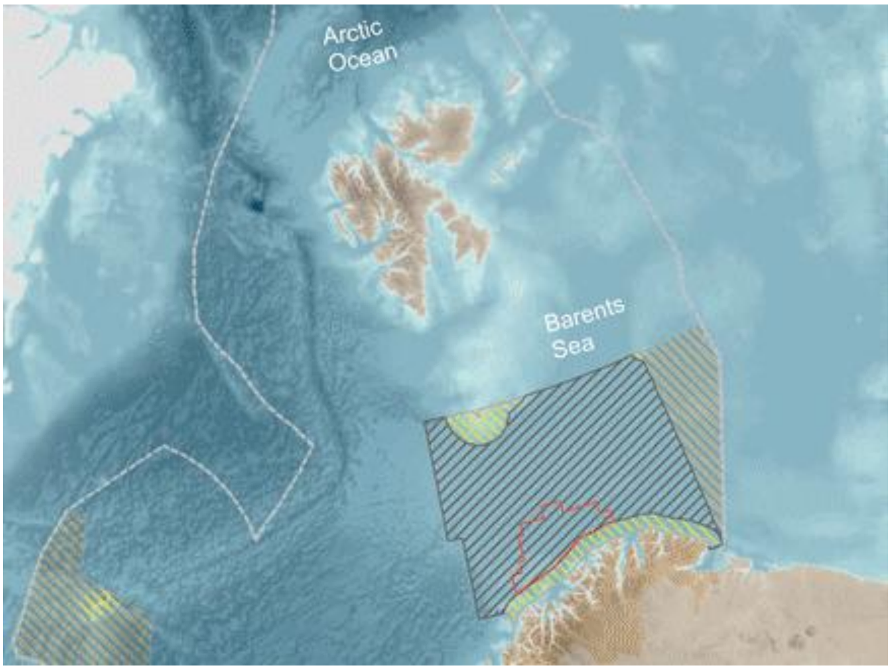

FIGURE 1 - THE NORWEGIAN BARENTS SEA WITH THEA AREA OPENED FOR PETROLEUM ACTIVITIES MARKED [3]

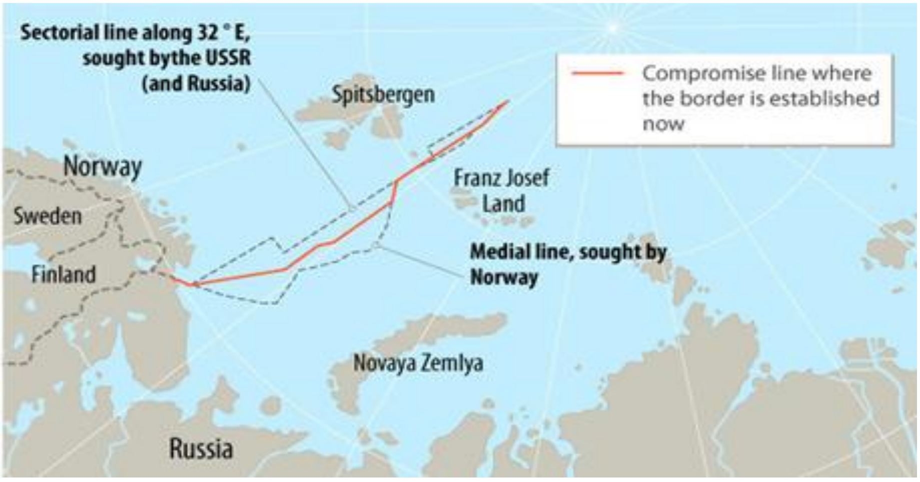

FIGURE 2 - MAP DISPLAYING THE COMPROMISE LINE BETWEEN RUSSIA AND NORWAY [4]

2. BACKGROUND

Before we take to the sea, we walk on land… Before we create, we must understand…

Ernest Hemmingway

With the petroleum industry moving north, there is need for research in many areas. The risk factors in the Arctic have been documented over the years, and several research projects have been conducted and more are under way. This thesis will look into operation analysis, not a new, but a less explored topic.

In order to present the operations in their contexts, it is important to be aware of some of the key features and limitations in the Norwegian Barents Sea. This chapter gives a brief overview of the conditions the petroleum industry will be facing, and appendix B provides additional information.

2.1 THE BARENTS SEA

The Barents Sea is a marginal sea bordering on the Arctic Ocean in the north, the Greenland and the Norwegians Seas in the west, the Kara Sea in the east and the east coast of the Kola Peninsula in the south [5]. The Barents Sea has its greatest depths, as deep as 600 metres, in the central part and a vast shelf with depths of less than 100 metres predominating in the southeast and near the coast of the Svalbard Archipelago.

The Barents 2020 phase 4 report looked into many aspects of operating in the Barents Sea and divided the Barents Sea into eight zones[1]:

FIGURE 3 - BARENTS SEA DIVIDED INTO EIGHT ZONES (FIGURE ADAPTED FROM [6])

This report is limited to the Norwegian Barents Sea, south of Bjørnøya, approximately area II in the figure above. This is a part of the western region (comprising of area I and II).

[1] Regions are based on areas with approximately uniform ice conditions: I) Spitsbergen; II) Norwegian; III Franz Josef Land; IV Kara; V Novozemelsky; VI Kola; VII Pechora; VIII White Sea.

The major morphometric characteristics of the Barents Sea, as presented in [6] are:

- Area: 1,424,000 km^2
- Water volume: 316,000 km^3
- Average depth: 222 m
- Deepest depth: 600 m

The Barents Sea surface area is never completely ice covered. Throughout the period of the maximum ice cover, March to April, the sea ice usually covers approximately 55 % to 60 % of the surface area, with open water occupying the rest. The ice cover can be a mixture of multi-year ice up to about 3 m thick, first-year ice generally less than 1.5 m thick and icebergs.

A more thorough description of the Barents Sea climate has been included in appendix B.

2.2 CONCERNS IN THE BARENTS SEA

The Barents 2020 [6] report focus on the entire Barents Sea, and have listed a number of concerns related to emergency preparedness. The major emergency, evacuation and rescue (EER) risks that were identified by the RN04 Work Group in the Barents 2020 phase 4, include the following:

- Traditional EER methods may not be appropriate for most of the year;
- The full range of ice conditions, including icebergs and sea ice, combined with cold weather, wind and other weather conditions which may be encountered;
- The logistics systems that may be available to support any required evacuation from the structure or vessel, including the presence of emergency response vessels;
- The long distances from the potential emergency site to the support bases and other facilities;
- The shortage of duly equipped support vessels that may be called on for assistance, with regards to their manoeuvring and station-keeping abilities in ice;
- The accumulation of ice on external surfaces and its effect on equipment operation;
- The limited amount of time that is available to react to a particular emergency situation;
- The effect of cold temperatures on human physiology and psychology, equipment, materials and supplies;
- The lack of experienced personnel and training facilities for the specific evacuation systems which have been proposed for the Barents Sea;
- The effect of the polar night, with extended periods of darkness, on personnel activities in Arctic conditions;
- Difficulties caused by communication due to magnetic conditions and high latitude, lack of satellite coverage and language differences; and
- The possible lack of qualified medical support.

General operations, logistics, medical and other issues will be discussed in their respective chapters.

2.2.1 ICING

Icing is a serious problem for operations in the Arctic and the Barents Sea. Ice accretion on vessels can threaten the stability of the vessel and even lead to capsizing. This is not such a big problem for larger vessels as it is for smaller vessels (e.g. life boats and fishing vessels). Icing may also affect the availability and functionality of certain types of equipment. Effects from icing include [7]:

- Escape equipment, escape routes, process equipment (valves etc.) that freeze over and/or become blocked
- Gangways and equipment become slippery, posing hazards to both personnel and during maintenance and repair
- People become more prone to errors and accidents
- Dimensions and weights increase, so that loads increase and stability decreases, particularly for floating structures. This applies mainly to sea spray icing, while atmospheric icing, with today´s knowledge, is considered less of a structural hazard than a threat to general safety.
- Increased probability of falling objects (ice lumps etc.) that may be a hazard to personnel and equipment
- Reduction of the effectiveness of radars and communication systems
- Increase in weight due to ice accretion means a decrease in payload.

"Icing" can be formed in many ways; however the two most important in the Barents Sea are; sea spray freezing when striking any type of installation, and atmospheric icing.

According to the Norwegian Meteorological Institute, icing from sea spray may occur when air temperatures are below -2 °C and when the wind speed is greater than 11 m/s (Beaufort 6). In the area of the Barents Sea which is already opened, sea spray icing seems to be a phenomenon occurring mostly in coastal areas, with low temperatures and wind from south and south-east. [8]

Several tons of ice can accumulate in a short period of time causing a vessel to capsize or even sink [9]. These stability problems are, as mentioned, of greater importance for smaller vessels (e.g. life boats and fishing vessels). The Norwegian Coast Guard vessel *Svalbard* accumulated approximately 115 tons of ice in only a few hours without experiencing stability problems. It can cause machinery to stop working and make vessels more top heavy. It can also cause problems for coastal infrastructure, especially in areas that are exposed to storms and sea spray. For a brief introduction to vessel stability, see appendix C.

FIGURE 4 - ICING ON SHIP

Atmospheric icing occurs in combination with precipitation and low air temperature. This form of icing will normally lead to less ice development on structures than sea spray ice accretion. Atmospheric ice generally has a higher density than sea spray ice due to the salinity. Atmospheric icing may also affect antenna- and communication equipment, and this ice must either be removed mechanically or by having de-icing installed.

The ice accretion potential on vessels and offshore structures is directly related to the surrounding environmental conditions. A short summary is given below. [10]

- Air temperature.
- Wind speed and direction. Beaufort force 6 equivalent to 10,8 m/s is normally considered as the minimum wind speed to start ice accretion [11].
- Sea-surface temperature
- Sea state: When the sea state worsens due to the increase in wind, waves can release sea spray either when breaking or upon impact with a vessel. Beaufort force 6 corresponds to waves of H_s[2]=~3 m with maximum waves of H_s=~4 m.
- Size and type of structure or vessel: ice accretion due to sea spray does not normally occur at heights more than 15 to 20 m above sea level. Reports of sea spray icing up to 60 m are known. The type and shape of super structures are also important.
- Relative movement of vessel and waves/wind: Icing can be reduced by decreasing vessel speed and optimising the vessel heading.
- Impairment of communications equipment.

Icing must be expected in the area, and in the northern parts, extensive icing (2-4 cm added per hour) is probable for shorter periods. Icing is also considered to be more of a problem for vessels and means of evacuation than for fixed facilities. Mitigation against icing should as far as possible be made during design.

Icing on aircrafts can also be a challenge. Icing leads to an increase in air resistance, decrease in effect (icing on rotors), increased weight and deterioration of wing lift capacity. In addition to rain, clouds or fog consist of small water droplets, and may freeze upon contact with the aircraft. If the air temperature is below 0 °C, the water in the air may freeze. The most severe ice accretion is likely to occur in temperatures just below 0 °C, and it has been shown that there is approximately a 50% chance of conditions favourable for icing from November until May in the selected area [13]. There are a number of ways of preventing icing on aircrafts, either by de-icing (pre-flight) or by using anti-icing systems such as; electrical heating of exposed surfaces, using engine heat to warm the edge of the wing or by using inflatable rubber mouldings that can be inflated and break the ice off. Other effective ways of avoiding icing is to fly around areas with observed or forecasted icing.

Antenna and communication systems may not work in severe icing conditions. Particularly atmospheric icing is an issue here. In February 2012, severe weather on Svalbard caused radio blackout due to icing on an antenna at SvalSat [14]. This could be

[2] Significant wave height: approximately equal to the average height (trough to crest) of the highest one-third waves in the indicated time period. 12. Det Norske Veritas, *Recommended Practice Det Norske Veritas DNV-RP-H103 - Modelling and Analysis Of Marine Operations*, 2011.

a problem for most operations in the Barents Sea, and should be taken into consideration.

In appendix Q, an icing prediction model is presented. There are several different methods for predicting icing. The one presented in the appendix Q is used by NOAA for North Atlantic and Alaskan waters. From the figure in appendix Q it can be observed that the rate of icing increases almost exponentially when the sea temperature is closer to freezing and below.

2.2.2 WEATHER FORECASTING

Proper weather forecasting is of utmost importance for safe operations in the petroleum industry. Reliable weather forecasts are challenging in the Barents Sea due to the low number of observation stations that are located in the area. Also, small scale weather features may escape the rather coarse observation network. Polar lows have proved especially difficult to predict [15]. With the increased activity no-doubt the reliability of forecasting and weather data will improve.

It is a concern among industry partners that weather forecasting will be more conservative in the Barents Sea compared to the rest of the Norwegian Continental Shelf, thus causing more downtime due to weather outside the limitations of the operations. According to [16] there is no reason to believe that this will be the case. The same model is applied; however an increased number of observations will increase the accuracy of the forecasts.

The findings in other research reports are not that the metocean conditions are worse in the Norwegian Barents Sea. The concern lies in uncertainty in forecasts, particularly forecast for polar lows. [7] says: *Metocean data does not represent a "hazard" in the Barents Sea that is not experienced in the North Sea. The industry has learned to cope with the same challenges in North Sea over several decades.*

Polar lows may occur without weather stations registering them and produce strong winds locally. This is the greatest concern for weather forecasting in the Barents Sea. With the models used today the Norwegian Meteorological Institute estimate that most polar lows will be detected 6-12 hours before they are fully developed.

2.2.3 POLAR LOWS, A GENERAL DESCRIPTION

Polar lows are small and forceful low pressure systems found in Arctic regions. They are formed at sea during cold air outbreaks in winter and are often characterised by their sudden and quick development. They develop quickly when cold air from the ice covered regions in the north travel over areas with relatively warm sea. The polar lows dissipate when they move over land because, similar to tropical hurricanes, the driving force, the warmer water, no longer is able to deliver the energy needed to sustain the wind system. See figure 6 for the location of polar lows in the North Atlantic, North Sea, Norwegian Sea and the Barents Sea from 2000 to 2012.

Polar lows can on rare occasions have hurricane force winds, but more normal are gale or storm force winds. Heavy snow showers, icing and changing wind directions all occur during polar lows. They have relatively short lifespan, from about six hours to a couple of days and typically have a diameter of 100 to 500 km [17]. In approximately 30 % of the cases, gale winds are found closer to the centre. They may change from breeze to gale in a matter of minutes, and wave height has been observed to increase by 5 m within an hour. Polar lows are also often followed by heavy snow with reduced visibility and closer to the ice edge, heavy icing on vessels occurs. [18]

They are in general hard to predict due to the fact that they occur in areas with few observations and because they have a relatively small scale considering the observation coverage [19]. The meteorological forecast models are improving, and according to [20] most polar lows will be detected within 6-12 hours prior to occurring.

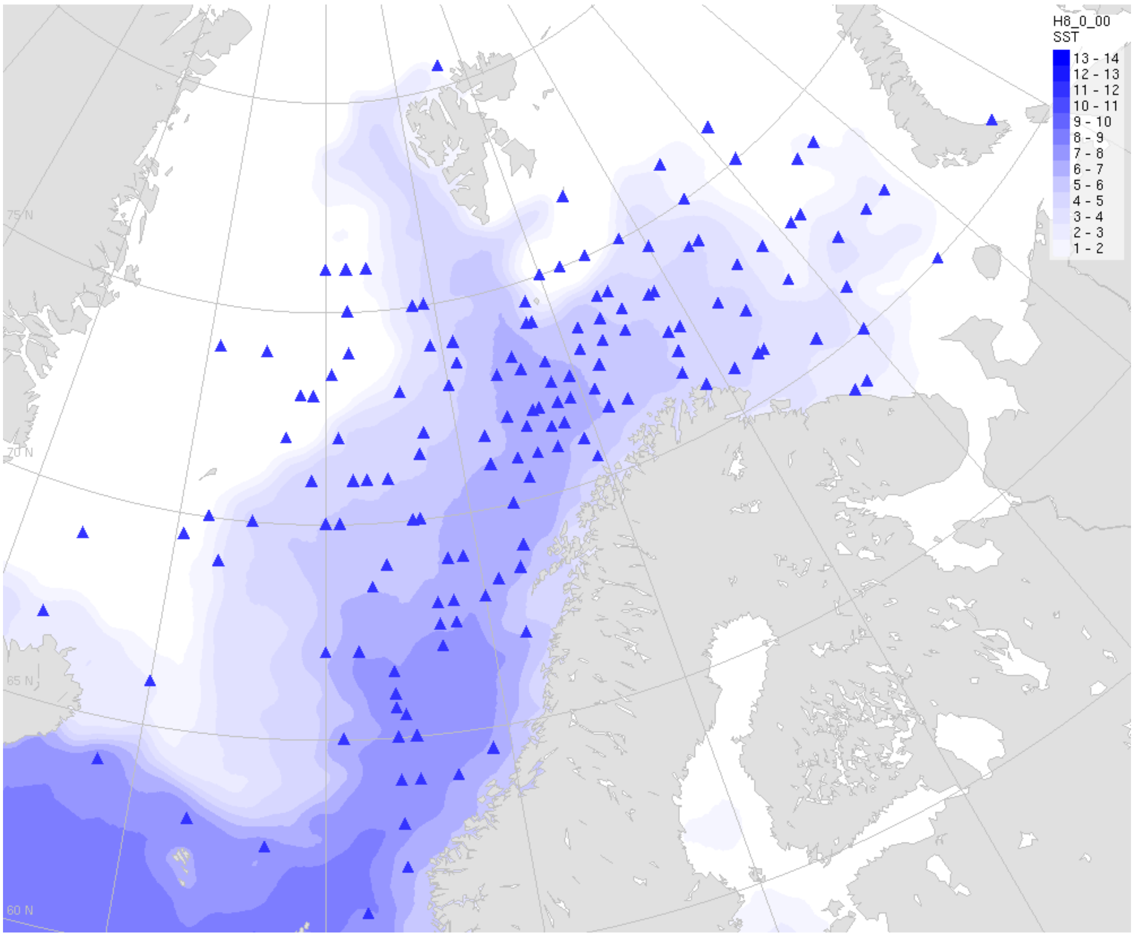

FIGURE 5 - POINT OF ORIGIN OF POLAR LOWS FROM 2000 TO 2009, A TOTAL OF 166 CASES. [19]

Polar lows occur mostly from October until May, and are most frequent from December until March, see figure below. The months at the beginning and end of the polar low season (November and March) have very fluctuating number of occurrences. The point of origin of polar lows from 2000 – 2012 can be seen in the figure above.

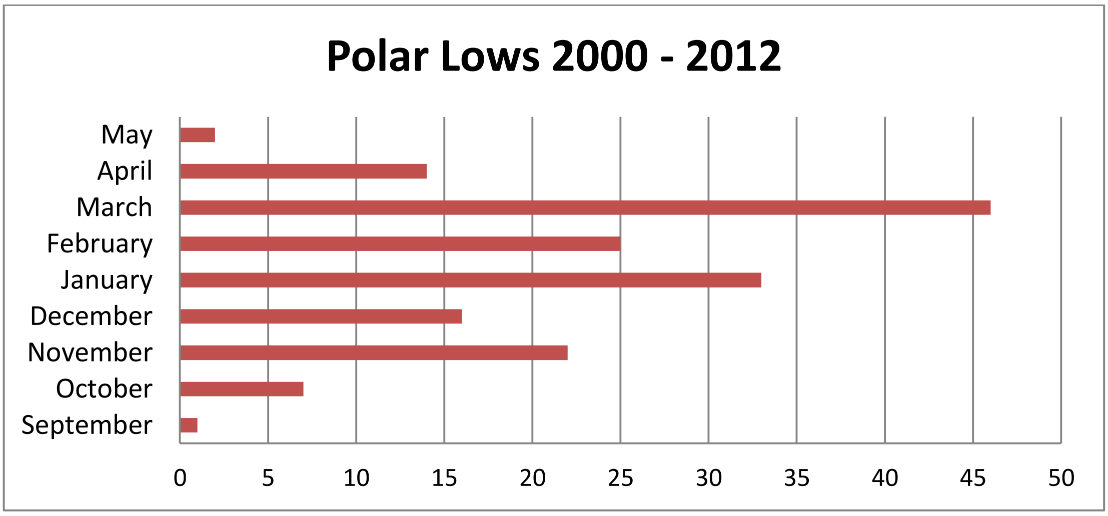

FIGURE 6 - MONTHLY DISTRIBUTION OF POLAR LOWS IN THE NORWEGIAN AND BARENTS SEA, REGISTERED AT THE NORWEGIAN METEOROLOGICAL INSTITUTE FROM 2000 - 2012. (ILLUSTRATION ADAPTED FROM [19])

2.2.3.1 CLIMATE CHANGE AND POLAR LOWS

There are two studies ([21, 22] as per 2012) concluding that there will be a decrease in the number of polar lows as a result of the climate changes. The argument is that as the temperature differences between the ocean and the surrounding air diminishes due to global warming, a more stable atmosphere, with conditions less favourable for polar lows, will be the result. Polar lows are formed solely during unstable atmospheric conditions [19]. These studies also point to the withdrawal of the ice edge (which is expected to move further north) as a big factor. Consequently, the formation area of polar lows is expected to move north, it is however uncertain to what effect this will have for the occurrence of polar lows in the Arctic Ocean.

2.2.3.2 MEASURES FOR IMPROVING SAFETY OF OPERATIONS EXPOSED TO POLAR LOWS

Polar lows are announced using established warning methods, primarily from the Norwegian Meteorological Institute in Tromsø. For land based users, text warnings are the most common ones. The aircraft business has its own standardised warning methods, which to a certain degree cover polar lows. For the offshore industry, WMO-warnings[3] are used. In addition, specialised and more or less automatic warnings for wind, waves, temperature and so on are used in the oil industry. The common denominator is that none of them are particularly well adapted for rapid changes and dynamic weather [19].

[3] World Meteorological Organization

2.3 LOGISTICS, CURRENT INFRASTRUCTURE, FACILITIES AND RESOURCES

The line between disorder and order lies in logistics…

Sun Tzu

Logistics is simply put; the management of the flow of resources between a point of origin and the point of consumption. A common way of describing the logistic nature of an area is to study the current infrastructure, and also to study the distances between two points with respect to geographic sense and the required travel time. These distances will then be different for land, sea and air transportation methods. In the Norwegian Barents Sea, these will be further limited by rapidly changing weather, the occurrence of ice and darkness. This chapter will present some important features of northern Norway, and particularly Finnmark, with regards to petroleum industry development.

2.3.1 TRANSPORT INFRASTRUCTURE

The report on infrastructural needs in the north are thoroughly covered in [23]. This section will focus on airports and roads that are in place, and thus give a short version of the contents in [23].

2.3.1.1 AIRPORTS

Finnmark differs from the rest of Norway with regards to distances between regions. Available airports with proper capacity are an important part of ensuring the flow of resources in the petroleum industry.

There are several airports in Finnmark, as can be seen in figure 7 The biggest airports in Finnmark today are located in Alta, Lakselv (Banak) and Kirkenes, closely followed by Hammerfest. Hammerfest and Alta are currently covering airplane and helicopter traffic for the petroleum industry. Hammerfest airport has great challenges with weather, wind and topography, with strict regulations, and assets were made available in May 2013 for development of a new airport in the Hammerfest area. The conditions of other airports have not been checked in this report, however, with an already existing airport, modifications to suit the needs of the offshore industry should not be too extensive.

Helicopter operations to facilities in the Barents Sea are currently being operated from Hammerfest. The 330 Squadron is stationed at Banak. In figure 9 the areas that can be covered from Hammerfest and Banak are shown, in addition to Kirkenes. The 330 Squadron operate with a practical range limit of 200 nautical miles (nm), as the circles indicate. Tromsø, having the largest hospital is also indicated in addition to Bjørnøya[4].

[4] Bjørnøya does not serve regular air traffic, however it could be used as a base for helicopter traffic.

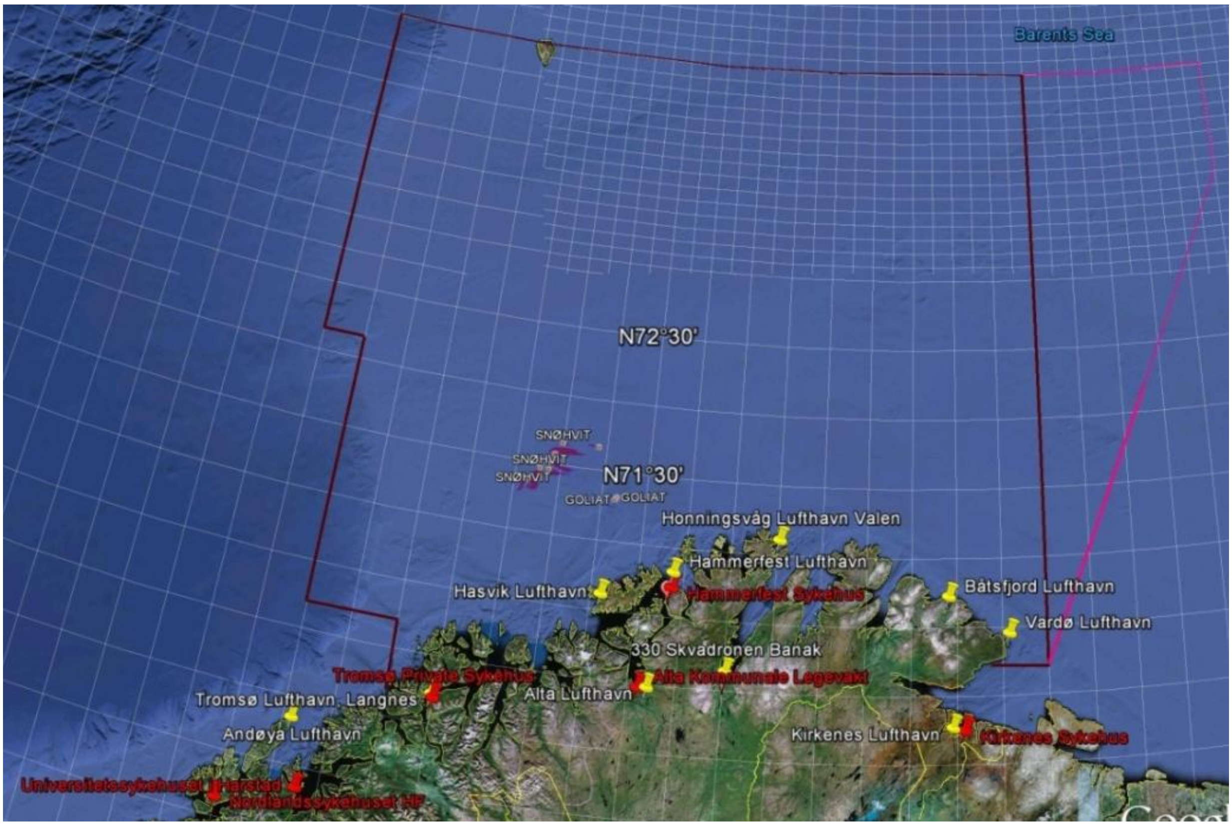

FIGURE 7 - LOCATION OF AIRFIELDS IN THE AREA (YELLOW) AND LOCATIONS PROVIDING MEDICAL SERVICES (RED) (AUTHORS OWN ILLUSTRATION)

2.3.1.2 ROADS

Riksvei 94[5] (Rv94), through Hammerfest, and E6, through Alta, are the busiest roads in Finnmark. Several development projects in the Hammerfest area are planned or finished. The status update[6] from the Norwegian Public Roads Administration (NPRA) showed that:

- Improvements to the main approach to Hammerfest are necessary.
- Efforts towards road-development for Alta airport are suggested.
- Great need of renovation of Rv94 in Hammerfest centre.

In connection with the field developments in the Barents Sea (particularly Snøhvit) traffic has increased considerably. Problems with road transportation were however solved through good planning and use of sea- and aerial transport.

2.3.2 SUPPLY BASES

Activities in the Norwegian Barents Sea are currently supported from Hammerfest. Many of the locations along the coast could in the future become supply bases as well. Kirkenes is also an important location, and the municipality has ambitions of becoming an important strategic location for operations in both Norwegian and Russian waters

[5] English: Classified Road 94
[6] In connection with the National Transportation Plan report on the northern areas (phase 2)

[24]. Activity directed towards the petroleum industry is currently taking place at the following locations:

- Hammerfest: The Snøhvit LNG-plant at Melkøya, operated by Statoil. Polarbase provides service and supply services, technical maintenance and port management. ENI is the operator for Goliat, also developing their operational organisation at Hammerfest. A helicopter base is located at Hammerfest Airport.
- Honningsvåg: Oil-transfer in Sarnesfjorden. Industry and actors for oil spill preparedness.
- Alta: Head office of North Energy ASA, search and field development.
- Kirkenes: Oil-transfer in Bøkfjorden.

2.3.3 PETROLEUM FACILITIES

The Snøhvit field is the only one in production at the moment, and beeing a subsea installation there is no floating or fixed installation in the area. The Goliat FPSO[7] will according to plan be on site in the fall of 2013, and begin production in the third quarter of 2014 [25]. Many other projects are planned, for example the Johan Castberg-project.

2.3.4 SEARCH AND RESCUE (SAR)

Resources for search and rescue (SAR), and also assisting in accidents are paramount for development in the Norwegian Barents Sea. As of today, these resources are limited compared to the rest of the Norwegian Continental Shelf.

SAR in Norway is divided between National and public parties and resources:

- 330 Squadron (Air force)
- Coast Guard
- Fire department (RITS)
- Governmental Tug boat preparedness
- The Norwegian Coastal Administration
- The district governor of Svalbard
- Coastal radio stations
- Police preparedness on the Norwegian Continental Shelf
- The Norwegian Meteorological Institute
- National Air Ambulance Services

Furthermore, voluntary parties and resources, in particular the Norwegian Sea Rescue assist. In addition to the National public parties and resources, there are also private contributions:

- Civilian helicopter companies
- The petroleum industry
- The fishing industry

[7] FPSO - Floating Production, Storage and Offloading

Adding to the National parties and resources, international agreements are also important.

Search and rescue is covered by the Norwegian Coast Guard vessels, helicopters and other vessels operated by Norwegian Sea Rescue, RS[8]. The locations of the RS vessels are shown in figure 8. The coast guard vessels may also be equipped with helicopters. For a more detailed review of SAR resources and organisation, please see [26].

The 330 Squadron (from the Royal Norwegian Air Force) at Banak operates Sea King SAR Helicopters. In addition to this, during exploration drilling, the industry operates an All Weather Search and Rescue (AWSAR) helicopter from Hammerfest, and a transport helicopter.

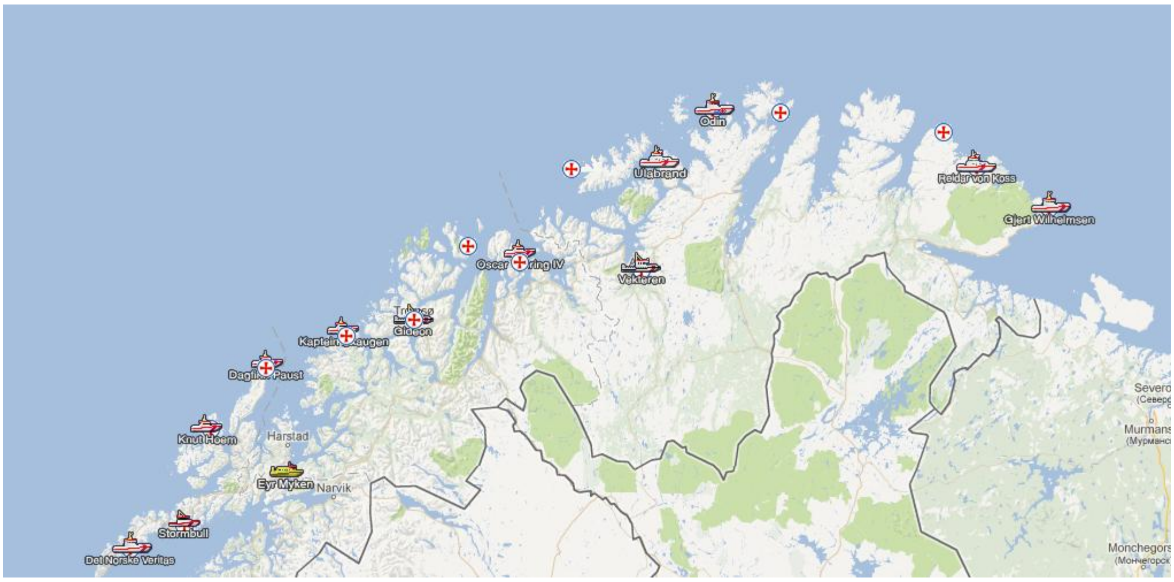

FIGURE 8 - LOCATION OF RS-VESSELS

The distances in the high north means that search and rescue may be time-consuming, increasing response time, and making quick transport to e.g. appropriate hospitals difficult.

Main challenges separating the north from the south regarding SAR is:

- Distance to SAR resources: A special challenge in the northern and Barents Sea areas is the distance to available SAR resources, including necessary land based resources. Lower traffic density also means that available vessels that may contribute in SAR will be less.
- Low air- and water temperatures: survival time in water is shorter, further increasing the need for quick response. Low temperatures may also cause icing on vessels and installations.
- Visibility: darkness, fog and snow: The polar night will complicate SAR, and snow may impede helicopter operations. In the summer, fog is an issue.
- Polar Low: A relatively rare phenomenon, but still a challenge. Rapid change of conditions will hinder effective SAR. They are also hard to predict.

[8] RS - RedningsSelskapet

- Communication: Successful SAR operations require information and communication between participants. In the north, and especially the Arctic, a proven and stable communication infrastructure is not yet developed. North of 75°, satellite communication is the primary tool for communication.

An important factor for the SAR resource picture is the petroleum industry. South of 65° (particularly in the North Sea), there is sufficient access to SAR resources. SAR-capacity in the region has been developed over 40 years, in cooperation between the industry and National authorities, and also through international collaboration. Central elements in this developed SAR capacity are:

- Nearby installations
- Area Emergency Preparedness
- High capacity of transport and feeder service
- Effective traffic surveillance
- Short distance to a developed network of services
- High traffic turnover on data lines
- Maritime traffic information

2.3.5 MEDICAL RESOURCES

In figure 10, all the medical facilities are marked with a red push-pin. The University Hospital in Tromsø is the largest hospital available in the region. In Finnmark, the northernmost county, "Helse Finnmark" has the responsibility for special medical services. They operate two hospitals; one in Hammerfest, the administrative base, and one in Kirkenes. Due to the distances in Finnmark and relatively low population density, the county has a much decentralised organisation. Most of the municipalities have sick bays (in total 40 sick bays in the 19 municipals) in order to provide local healthcare for the inhabitants. [27]

The hospitals in Finnmark are as of today not capable of handling a large scale accident, involving e.g. an entire rig with somewhere in between 50 and 150 people. In the figure below, the range limitation for SAR helicopters are shown.

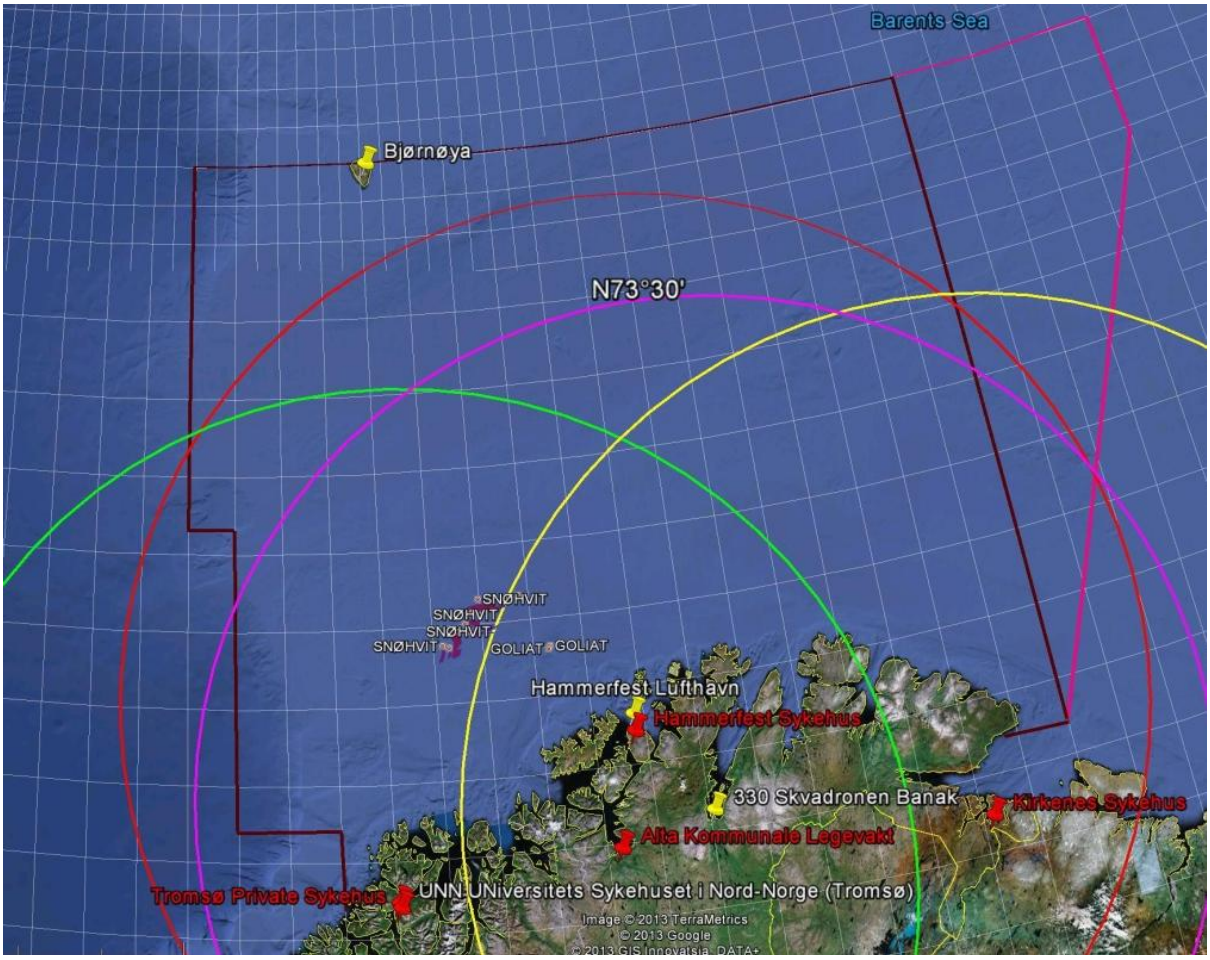

FIGURE 9 - ILLUSTRATION WITH SAR-HELICOPTER OPERATIONAL LIMIT DISTANCES FROM THE BIGGEST HOSPITALS. (AUTHORS OWN ILLUSTRATION)

2.3.6 REMOTENESS

The distances from the installations to stationed Search and Rescue (SAR) helicopters and onshore infrastructure such as hospitals and helicopter bases are critical factors. The Norwegian Barents Sea is for a large part geographically isolated. This brings with it operational challenges as well as causing substantial costs and increasing the potential consequences of risk events. The infrastructure is minimal when compared to the rest of the world's oceans.

In the case of a critical situation the remote locations makes the evacuation of personnel both difficult and time consuming and delays any medical treatment. The reach of helicopters, as shown in figure 9, is also a concern for evacuation [18]. In figure 10 below the practical range (200 nm[9]) of SAR Helicopter, type Eurocopter EC225[10] with de-icing equipment, has been plotted from all possible locations. Hammerfest (Red), the 330 squadron at Banang (Purple), Kirkenes (Yellow), Alta (Green), Honningsvåg (Orange), Hasvik (Turquoise) and Båtsfjord (Blue). Longyearbyen in Svalbard is also included in red from the top. The figure is somewhat confusing, but the point is the area

[9] The squadron at Banak operates with 200 nm (370 km) as a practical range limit for rescue operations.
[10] The same helicopters that are currently stationed in Hammerfest.

outside the circles. It is clear that these helicopters do not have the range needed for full coverage of the area. If a similar circle with a radius of 200 nm is placed on Bjørnøya, there is still a section left without coverage. There is no petroleum activity in the areas not covered by the conventional Sea King helicopters today, however in the future it may become an issue.

For the purpose of SAR, helicopters will be important in the Norwegian Barents Sea; however, as will be discussed in the analysis of the SAR scenarios, having a diverse rescue task force is important. Still, helicopter operations will be a key player.

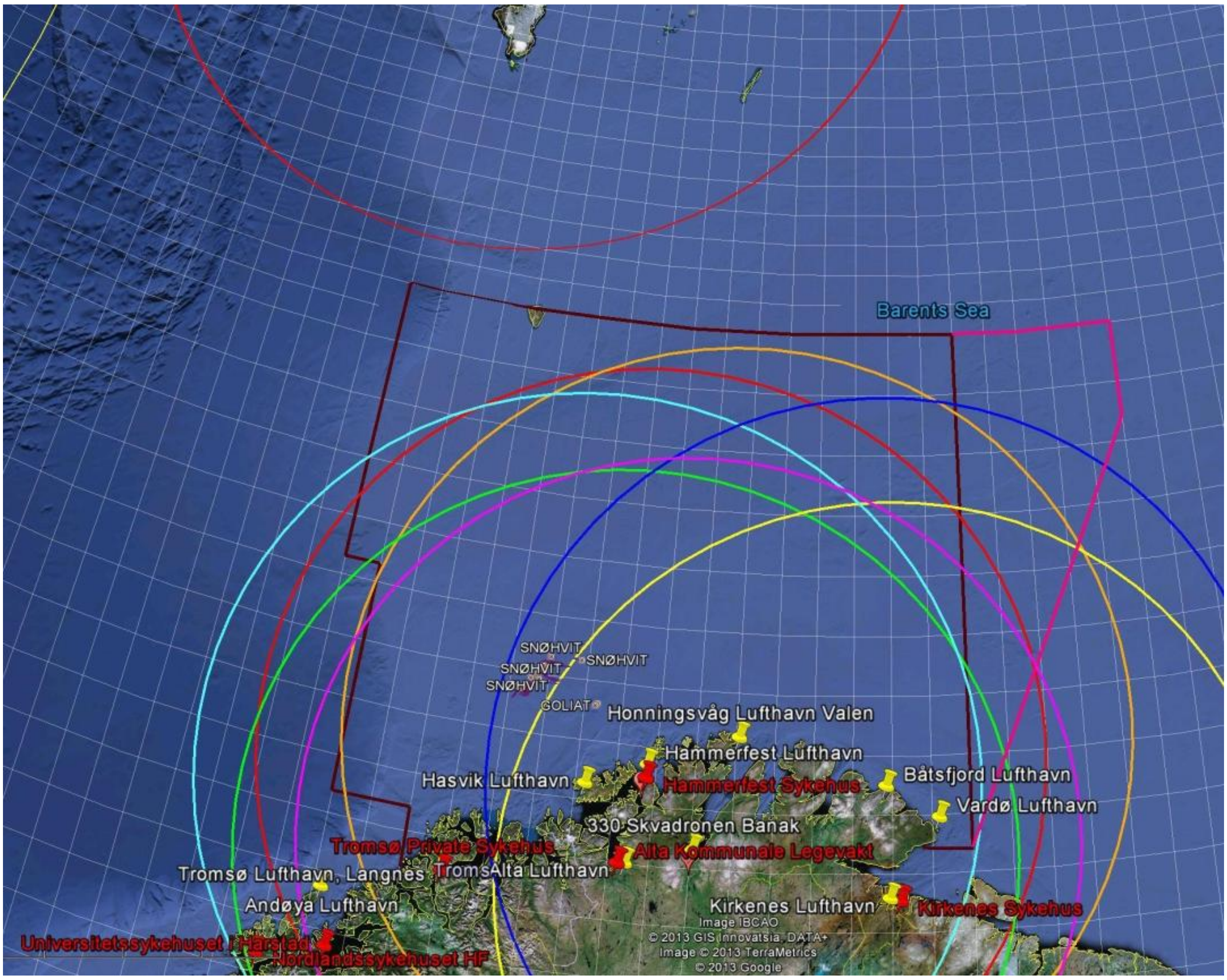

FIGURE 10 - PRACTICAL RANGE (200 NM) OF SAR HELICOPTER (TYPE EUROCOPTER EC225 WITH DE-ICING EQUIPMENT) FROM POSSIBLE LOCATIONS. (AUTHORS OWN ILLUSTRATION)

2.3.7 HELICOPTER OPERATIONS

Helicopters have been the number one mean for transportation of people to and from offshore petroleum installations for several years. Guidelines and regulations relevant for offshore helicopter operations on the Norwegian Continental shelf are specified in Norwegian Oil and Gas guidelines (OLF) number 066 and 095, the Norwegian Oil and Gas Helideck Manual, in addition to the Norwegian Civil Aviation Authority's (N-ACC) rules, particularly BSL D 2-2 and BSL D 5-1. [28-31]

This chapter covers, in brief, the safety status, operational limits, tracking, rescue and reduced visibility and weather forecasts for helicopter operations.

2.3.7.1 PRIVATE EMERGENCY PREPAREDNESS

The helicopter base at Hammerfest Airport provides helicopter services for the petroleum industry in the Barents Sea; Bristow Norway AS, with three helicopters, and CHC Helicopter Service AS, with one helicopter. One of the Bristow Helicopters is a dedicated SAR helicopter, and is equipped with (amongst other things):

- De-icing
- 2 rescue lifts
- Search lights
- Infrared camera
- Satellite communication
- Medical equipment
- Live video stream

2.3.7.2 GOVERNMENTAL EMERGENCY PREPAREDNESS

In addition to Hammerfest, the Air force Squadron 330's at Banak primary purpose is SAR in Northern Troms, Finnmark and the Barents Sea.

TABLE 1 - 330 SQUADRON RESOURCES AT BANAK [32]

Location	Aircrafts	Coverage area in the Barents Sea	Operative range
Lakselv Airfield, Banak.	2x Sea King MK 43 B SAR Helicopters	Mainland in the south, Svalbard in the north, Russian border in the east	400 nm (practical range 200 nm)

The emergency preparedness organisation is such that a helicopter with crew is ready to take off at all times of the day, year round. Their reaction time is approximately 15 minutes. The crew consists of six members on duty:

- Two pilots
- System operator / navigator
- Engineer / rescue lift operator
- Rescuer
- Physician

In an investigation based on 147 operations carried out by Sea King in the Barents Sea it was shown that 33 % of the missions were in darkness. The median evac-time to patient was 3,3 hours, and median time per mission was 7,3 hours. [32]

The in total 12 Westland Sea King rescue helicopters in use today are nearing the end of their useful life. The new AWSAR helicopters are planned to be in place within 2020.

2.3.7.3 SAFETY STATUS

Helicopter operations safety status has been thoroughly documented in three reports made by SINTEF. The third reports, [33] used here, overall objective was to contribute to improved safety in helicopter transport to, and from, fixed and floating oil- and gas installations on the Norwegian Continental Shelf. The report lists a number of observations and recommendations for general improvement of helicopter operations safety[11], and below is an extract of some that are of particular relevance with regards to the Barents Sea:

- RIF[12] 1.2 Continuous Airworthiness.
    - *M08 – Improved availability of spare parts*. With limited infrastructure and the lookout for extensive development in the Barents Sea, the need for a state-of-the-art spare part management system is needed. Also to avoid "cannibalising," i.e. taking parts from one machine and putting it on another.
- RIF 1.4 Operational Procedures and user support.
    - *M11 – Automatic approach procedures / standardised approach*. Out of the 12 accidents that have occurred in the North Sea during the period 1999-2009, three happened in conjunction with approach to helideck during reduced visibility. [34] also states that "It is not possible to achieve completely automated approach procedures, as for airplanes, but the goal must be to introduce an optimal level of automation." 13
    - *M13 – Reduce the number of flights to ships during night conditions and reduced visibility.* Flying at night and during reduced visibility (dense rain, snow or fog) is connected with far greater risk than flying in daylight and in good visibility. This is especially true during approach to the helideck and particularly ships, due to the movement of the helideck in addition to the reduced visibility. M13 can be related to M11. Unnecessary flying should be eliminated through e.g. effective logistics, and as many operations in daylight as possible.
- RIF 1.9 ATS/ANS[14]
    - *Tracking and surveillance of airspace.* Tracking of the helicopters at all times and preferably a total airspace control system (ADS-B[15] is recommended in the report).
    - *Communication coverage.* There is today no satisfactory two-way communication coverage (radio) between pilots and the air traffic control service.
    - *M26 – Continuation / replacement of M-ADS*. M-ADS[16] is a unique system which, among other things, ensures that the helicopter can be located

[11] See section 10 in 34. Herrera, I.A., et al., *Helicopter Safety Study 3 (HSS-3)*, 2010, SINTEF: www.sintef.no. p. 46.
[12] RIF – Risk Influencing Factor
[13] Both Sikorsky and Eurocopter have designed automatic approach methods for their helicopters, and Sikorsky has started selling the product.
[14] Air Tracking / Navigation Service
[15] Automatic Dependent Surveillance – Broadcast. For more information, see www.ads-b.com

immediately following an accident. The chance of saving lives is therefore greater. There are some alternatives to using M-ADS, however the important part here is to be able to locate the helicopter.

- Full hangar offshore for SAR Helicopters. Having a permanently stationed SAR helicopter on the installation (or within a group of close installation) could expand the operational limits of the helicopter. This will however require a high investment cost.
- M32 – Night vision goggles for SAR pilots.
- Survival suits. Significant improvements of the survival suits have been implemented with regards to thermal characteristics. This increases the probability of surviving in cold water. On the other hand, the suits are regarded as being more complicated to use ([33] p. 46).

2.3.7.4 OPERATIONAL LIMITS OF HELICOPTERS

Recommended guidelines for helicopter operations on the Norwegian Continental Shelf can be found in the Norwegian Oil and Gas guidelines number 066 and 095, in addition to the Helideck Manual. [28, 29] The regulations for offshore helicopter operations in Norway can be found through the N-CAA, BSL D 5-1 [30].

Speed, fuel consumption, payload and amount of fuel are keywords deciding the operational range limit and time window for a helicopter. This is particularly important for rescue missions as they are not planned. The requirement for operational range in offshore operations is to be able to fly to the destination, approach, and be able to return to the point of origin, still having 30 minutes of additional fuel [36]. The reason for this is simple; if you go out and can't land, you have to be able to get back [37]. Point 6.6 in [28] says "The helicopters must always carry enough fuel to reach land with the required reserves. The use of an 'offshore alternate' is not permitted."

Not allowing for "offshore alternates" presents a great limitation for operational range. Alternative solutions for additional fuel storage and refuelling are possible, either by landing on offshore refuelling stations or using helicopter in-flight refuelling, HIFR. [37] HIFR is however not a normal operation for civil helicopter operations. Table 2 displays speed and range limits for the most common SAR helicopters[17].

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[16] Modified-Automatic Dependent Surveillance. For a simple brief, see 35. International, F. *Norway Implements M-ADS*. 1999 [cited 2013 February 26th]; Available from: http://www.flightglobal.com/news/articles/norway-implements-m-ads-49863/.

[17] Various sources provide slightly different range limits for the helicopters. The general limit used in this report is 200 nm

TABLE 2 - HELICOPTER RANGE

Type	Speed [kts]	Maximum Range [nm]	Operational Range Limit[18] [nm]
Sikorsky S-92A	151	539	232
Super Puma EC225	141	454	192
Sea King	110	450	198

The Sea King helicopters have been in service from the very beginning, and are now due for replacement. The planned replacement will take place by 2015. Norway is planning to acquire 10 – 12 new all-weather search and rescue helicopters, through the Norwegian All Weather Search and Rescue Helicopter, NAWSARH, project. [39]

Regulations concerning weather minima for flying in Norwegian airspace can be found in BSL D 1-11 [40], and again in BSL D 5-1 [30]. Reduced visibility is often a direct cause for helicopter accidents. Fog and precipitation are often found as root causes in accident investigations.

2.3.8 COMMUNICATION AND NAVIGATION

Communication via radio and satellite has proven unreliable and there are clear gaps in the coverage in the areas north of 70 degrees latitude. The northern areas are particularly affected by geomagnetic storms, which may render impossible communication in multiple frequency levels and also provide major deviations or total loss of GPS signals [41]. Regular compasses and gyro are also unreliable at such latitudes [42]. In many parts of the Arctic the lack of proper sea maps are also of great concern. These issues do however not seem to be the case for the area of interest in this thesis.

Automatic Identification System (AIS) and Maritime Communications and Traffic Services are established along the Norwegian Coast. Vessel Traffic Service (VTS) was established in Vardø in January 2007, Operated by the Norwegian Coastal Administration. This service is designed to guide and monitor vessels, protecting against undesired events in the Norwegian Barents Sea, by promoting safe and efficient navigation. The Norwegian Economic Zone (NEZ) outside the baseline, the area around Svalbard and also outside Tromsø and Finnmark constitute the area of operation for the Vardø VTS Center. The Center cooperates with vessels, other government agencies, the NCA duty team in charge of national response and the Norwegian SAR. The administration also coordinates tugboat preparedness in northern Norway, in union with Regional Headquarters North-Norway[19] and the NCA duty team.

[18] The operational range limit is an approximation based on the requirement to be able to fly at cruise speed for 30 minutes after return to the point of origin. This does then not include the time needed to e.g. pick up people from the water. Including this, the operational range limit is closer to 174 nm 38.
Røsok, A. *Flyging i Barentshavet*. in *Beredskapskonferansen*. 2011. Stavanger.

[19] Norwegian Armed Forces

For communication, VHF, MF and HF[20] in addition to satellite are generally sufficient for the lower Arctic areas (including the Norwegian Barents Sea), however, voice and data transmission in the high Arctic become problematic.

Modern ships are usually equipped with digital satellite communications equipment, not simply due to safety reasons, but also for management and navigation of the ship. This relies on geostationary INMARSAT satellites that do not provide service from approximately 80° north. IRIDIUM is another option. A constellation of 66 polar orbiting satellites provide coverage of the Arctic (see figure below). IRIDIUM has a very low data transfer rate[21] (less than 9,6 kb/s) and communications are limited and often interrupted, despite that the system's ability to communicate ice charts and satellite images have been proven. Several projects are underway, and as activity in the Arctic region increases, the requirement for improved voice and data transmission coverage proves vital.

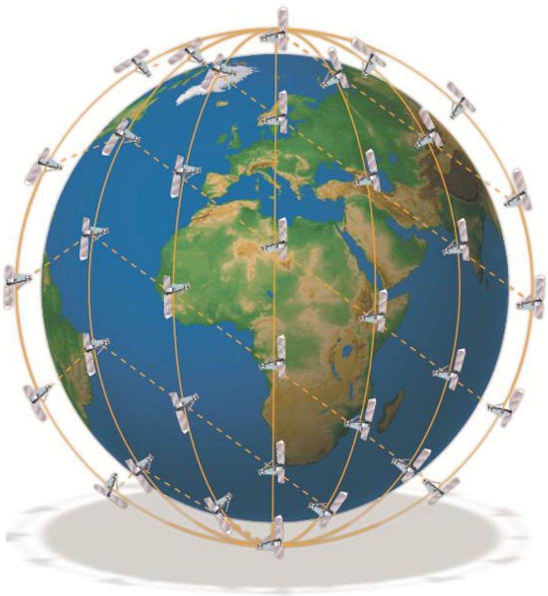


FIGURE 11 - IRIDIUM ORBITS

[20] Very High, High and Medium respectively

[21] These types of systems originally designed for defence and military purposes often have low bandwidth capacities due to security and minimum effect levels. Messaging systems using codes and numbers are transmitted and then reconstructed by the receiver. This way, large amounts of data can be transferred with low bandwidth.

2.4 HUMAN FACTORS

Occurrences in this domain are beyond the reach of exact prediction because of the variety of factors in operation, not because of any lack of order in nature.

Albert Einstein

Humans are an important issue for operating in the high north. It is not the purpose of this report to investigate human error probabilities as such, it is however important to highlight some factors that affect human performance in the high north.

2.4.1 COLD

For optimal and effective performance, the human body needs to be kept within a narrow temperature range, for central parts of the body 37 °C ± 1-2 °C. Other than climate, factors affecting the body's ability to regulate temperature are; activity level, clothing and technical protective measures. The critical climatic factors are air temperature, radiation temperature, wind and humidity [4]. Individual factors include age, nutrition, psychic disorders and mental health, diabetes, experience and fatigue [43].

When exposed to cold, the body responds with a variety of physiological reactions in order to maintain the body temperature. Both physical and behavioural measures assist in this process. Heat transport between the central and outer body parts happen via the blood circulation. An early stage response to reduce heat loss is to reduce the blood flow to the outer parts of the body with up to 99%. Blood supply to the head is not reduced, and a person at rest may lose up to 50% of all heat through the head.

Heat loss is determined from the difference between body temperature and the surroundings, and can occur in four ways (see figure in appendix I);

1. Convection
2. Radiation
3. Conduction
4. Evaporation

Exposure to cold temperatures in combination with wind is very limiting to human performance as well as dangerous. The cold is a great risk to bare skin, and table 3 illustrates the effects of low temperatures [6]:

TABLE 3 - HUMAN LIMITATIONS IN COLD CONDITIONS

Wind Chill	Wind Chill Risk Class		Recommended Limits
less than -10°C	0		Normal Work; emergency work; planned maintenance
-10°C to -24°C	1	Uncomfortably cold	Normal work (reduced work periods); emergency work
-25°C to -34°C	2	Very cold, risk of skin freezing	Normal work (reduced work periods); emergency work
-35°C to -59°C	3	Bitterly cold, exposed skin may freeze in 10 min	Emergency work only
-60°C and lower temperatures	4	Extremely cold, exposed skin may freeze in 2 min	Emergency work only

A table displaying the Wind Chill Index (WCI), used to estimate risk for cold-related injuries, can be found in appendix H. In 2001, a new WCI was introduced, using a formula based on testing of heat loss from exposed skin on humans [8].

Humans are designed to work within a very narrow temperature range. When pushed outside this range-limitation, the effects will influence the physical, emotional, cognitive and stress on people. Cold affects every single element in human muscular performance such as persistence, speed, power and coordination [8]. An important issue with the cold is that when humans are pushed beyond their limits, they are subject to an increase in psychological stress. The body consumes more energy as it attempts to function normally and thus it tires more rapidly. The cold increases fatigue; affects the ability to think clearly and even has effects on short-term memory.[44]

2.4.1.1 COLD RELATED INJURIES AND DISEASE

Frost action damage (FAD) or frostbite, hypothermia and other injuries caused by cooling of the human body are among the cold related injuries personnel may experience.

FAD is most common in the outer parts of the body (arms, legs, head, hands and feet). FAD show a strong increase under conditions with below -10 °C [4]. Frostbite develops through stages;

- The skin surface loose blood flow and becomes white. No permanent damage.
- Continued exposure to cold will cause the skin to freeze and become hard. This type of damage can cause blisters. Second degree FAD usually heals within 3-4 weeks.
- Deeper FAD causes damage to muscles, tendons, blood vessels and nerves in the exposed area. A blue/violet colour will appear with blisters, usually filled with blood. Can lead to permanent disablement and in extreme cases amputation.

Hypothermia is defined as cooling of the body’s core temperature to below 35 °C. Initiated by fatigue and confusion, followed by un-controlled shaking, lack of coordination and poor judgement. The shaking occurs because the body attempts to create heat and is energy demanding. As the cold worsens, the shakings will increase, and may cause death due to exhaustion. A person suffering from hypothermia must be reheated using external heat sources.

For a list of cold-related injuries, see appendix I.

Cold can cause disease either directly or indirectly. The body's cooling rate is affected by several individual factors; cardiovascular disease, blood circulation disturbances, respiratory diseases and muscle and skeleton diseases, skin diseases and allergies.

In addition to this list, Reynaud Syndrome, also known as "white fingers", is important. A strong contraction of the outer blood vessels as a response to exposure to cold leads to considerable reduction in blood supply for fingers and toes. Persons with RS are more prone to having FAD. Symptoms include migraine, head aces, chest pain and possible distorted vision. This can cause up to 100 % reduction in real work capacity.

Man over board accidents will be covered in chapter 4, and immersion will also be covered there.

2.4.1.2 COLD AND PERFORMANCE

Human performance affects both work efficiency and safety. Exposure to extreme situations affects cognitive, emotional and physical stress. In addition to reduced capacity of the individual, the risk of having an accident increases.

PHYSICAL PERFORMANCE

Cooling affects all aspects of muscular performance; endurance, strength, power, speed and coordination. Studies show that there is a connection between skin temperature and motor control [4].

TABLE 4 - EFFECT OF COLD ON MOTOR CONTROL (TABLE ADAPTED FROM [4])

Skin temperature (°C)	Effect on motor control
32-36	Optimal temperature
27-32	Reduced sensitiveness, precision and muscle force in fingers
20-27	Reduced accuracy and endurance
15-20	Reduced motor abilities
10-15	Pain, reduced muscle power and coordination in hand
<10	Numbness

More recently the effect of the WCI and reduction in finger technique has been examined. [45]investigated the subject with wind chill equivalent temperatures (WCET) basing the results on subjects exposed to cold wearing mittens until the finger temperature of 14 °C was reached. This indicates for how long manual work can be performed. The results are presented in table 5.

TABLE 5 - COMBINATIONS OF WCET AND EXPOSURE DURATION CORRESPONDING TO AN ESTIMATED FINGER SKIN TEMPERATURE OF 14 °C. (TABLE ADOPTED FROM [45])

WCET (°C)	Exposure duration (min)
-10	>60
-20	37
-30	16
-40	9
-50	5

Cooling will reduce physical performance by 2-10 % per °C reduction in muscle temperature [4].

COGNITIVE PERFORMANCE

The term *cognitive* involves the ability to receive and process information, memory, judgment, reason and the ability to solve problems. There are many studies that show a reduction in cognitive performance when exposed to extreme conditions, cold amongst others. There are however many factors playing a part, and proper preparation, motivation and acclimatisation may reduce the negative effects [8]. According to [8], there are no concluding studies showing clear reduction in cognitive performance in cold conditions. Light exposure to cold has even shown increased cognitive performance, however, exposure to extreme cold over some time shows a sharp decline in cognitive performance. Exhaustion and longer recovery times for personnel is a risk [4].

ADDITIONAL CHALLENGES

In addition to the cold, darkness is an important factor. Poor lighting will increase the risk for accidents, and also present issues for transport, search and rescue.

The constant presence or absence of light may affect sleep patterns and mood.

Nutrition is more important when working in extremely cold environments, both in calories and composition.

VISION

In darkness and in foggy conditions, the human eye is very limited and this will reduce performance during operations and increase the risk.

2.4.2 MAJOR ACCIDENTS

Several major accidents such as; Deepwater Horizon, Piper Alpha and Alexander Kielland particularly for Norway, propelled health and safety issues into being a major topic on the agendas of policy-makers, oil and gas companies including operators and employees. The *traditional* way of reducing the likelihood of such events has been to focus on technology and operations. Today it seems to be consensus that understanding human factors (HF) is the greatest challenge facing safety experts in the offshore industry. Various studies have shown that about 80 – 90 % of all accidents are caused to some degree by human failures [46].

Human Reliability Analysis (HRA) is a popular topic. In January 2012, a survey conducted by Oil & Gas iQ [47] found that;

- 48.6% see human factors as the biggest challenge offshore has to face today and in the future
- 10.8% see problems with technology and equipment as the key issue, with a similar number for having right processes in place and reacting to new legislation.

In the *Presidents Report* after the Deepwater Horizon accident it was suggested that the petroleum industry should learn from the nuclear industry [48]. A problem with HRA is modelling a human. Humans are not perfect and modelling the fitness of a worker, how the worker will respond to a given scenario and so forth is not a straight forward task. Accident scenarios that directly involve human action will often state assumptions such as “operator detects alarm and responds accordingly within a time frame.” The reliability of this action has to a very limited extent been standardised. With the effects work in the Barents Sea will inflict on workers, it is also possible that HRA models will need to be modified.

Over the years a variety of HRA methods have been developed:

- THERP – Technique for Human Error Rate Prediction
- ASEP – Accident Sequence Evaluation Programme
- HEART – Human Error Assessment and Reduction Technique
- SPAR-H – Simplified Plant Analysis Risk Human Reliability Assessment
- ATHEANA – A Technique for Human Error Analysis
- CREAM – Cognitive Reliability and Error Analysis Method
- ++

The HSE report *Review of human reliability assessment methods* [49] found a total of 72 potential HRA tools and acronyms within the project timeframe. Of these, 17 were found to be useful to major hazards directorates. This study showed that all HRA methods in the review had their (recognized) limitations; however, they found no significant objections to any of the tools, and concluded that they could all provide useful insight to risk assessment.

Compared to modelling a human, a machine becomes relatively straight forward. A machine has no feelings, never complains, does not get bored or possesses any other human “weaknesses”. Without any experience in the Barents Sea it is hard to say anything conclusive about how HRA analysis will be different. It is however appropriate to assume that personnel working in the Norwegian Barents Sea will experience more negative than positive effects regarding human psyche and overall performance.

2.4.3 IMMERSION ACCIDENTS IN COLD WATER

Drowning has traditionally been named as the main cause of death in fatal accidents in water. And while drowning is certainly an important direct cause of fatalities, other factors may be equally important for survival in water. The risk of drowning is reflected in the production of life saving equipment, mainly providing flotation, however accidents such as the sinking of the Titanic is a well-known example of how flotation is not enough [50].

Immersion accidents are divided into four life-threatening phases, each potentially fatal:

- Initial immersion responses, or cold shock (0-3 min)
- Short-term immersion or swimming failure. Due to rapid muscle and nerve cooling. (3-30 min)
- Hypothermia (usually after approximately 30 min)
- Post-rescue collapse or circum rescue collapse. Basic cause of death is due to collapse of blood pressure when a victim is pulled from the water.

2.4.3.1 COLD SHOCK

The first responses mainly affecting blood circulation and lungs are termed cold shock. The sudden drop in skin temperature as a consequence of immersion may cause a wide range of physiological reactions, greatly reducing the chances for survival. There is no difference between skinny persons and persons with lots of subcutaneous fat. The temperature causing these reactions may however vary. People not used to exposure to cold may experience these responses in water temperatures as high as 25 °C.

Immersion in cold water will lead to an immediate contraction of the blood vessels in the skin, pushing blood back towards the heart, adding resistance. At the same time, increased heart rate and a dramatic rise in blood pressure will occur as the heart is trying to pump blood back towards the skin. Hyperventilation is also an issue with cold water immersion. Rapid, uncontrolled hyperventilation is common in immersion colder than 15 °C. This can result in a panic-like sensation with great risk of inhaling water. Companies operating in the Norwegian sector have a requirement that passengers in helicopter flights over water shall have emergency breathing equipment, so that they may escape a water filled cabin without breathing in water. On the British side of the North Sea, many operators have a special work-suit meant to reduce the cold shock effects in case of immersion.

2.4.3.2 SHORT-TERM IMMERSION OR SWIMMING FAILURE

Deeper cooling affects nerves, muscles and joints. Cold impairs nerve-reaction speed, chemical reactions and muscle mechanics. The cooling of periphery nerves and muscles may quickly develop into functional disablement, equivalent to paralysation [8]. Swimming abilities in warm water has no relationship to swimming in cold water. The angle of attack will increase, drag will increase, stroke rate will increase and stroke length will decrease, creating an exhausted human, vertical in the water, crying for help. The combination of crying out (releasing approximately four litres of air) and the raising of arms signalling for help remove buoyancy. [51]

Survival after the initial cold shock is largely depending on what flotation device the person has available. Experience has shown that even good swimmers will have trouble swimming in cold water, even for as far as two to three metres. Coordination of arms and legs, in addition to breathing becomes very difficult as the senses cool down, impairing feedback to the brain. The reduction of blood flow to the arms and legs means less oxygen for the working muscle, and soon the person will be working on an anaerobe metabolism [8].

2.4.3.3 HYPOTHERMIA

A person having survived the initial cold shock with an appropriate flotation device will enter a third critical phase where general cooling of the body is the risk. Hypothermia is defined as a condition where the core body temperature is below 35 °C. The lowest ever accidental hypothermia body temperature reached with survival was 13,7 °C , by Anna Bågenholm, in 1999. Hypothermia is often set as a limit for survival because a reaction to the low core temperature is unconsciousness, greatly increasing the risk of drowning.

An interesting effect on core temperature after immersion in cold water is that it actually rises for the first few minutes. Shaking is one of the body's defence mechanisms against cold, in addition to removing blood from the arms and legs in order to keep the core heated. This will happen even before hypothermia is reached. At 33 °C, the mental capacity will be greatly reduced. A very dangerous stage of hypothermia is when the core temperature reaches 31-32 °C, and the shaking ceases. The body's heat production will then be greatly reduced, causing further cooling to accelerate. Below 30 °C a state of unconsciousness is common, and at 28 °C it is probable to experience auricular fibrillation. 25 °C is the general limit, where most people will die, even though there are several examples of success in reviving persons from lower core body temperatures than that. These are however exceptions. [8]

BEFORE RESCUE

A sudden negative physiological change in the condition of the survivor when rescue seems imminent is experienced, and is assumed to be located in the heart- and circulatory mechanisms. The heart works slowly for a person suffering from hypothermia and the increased blood viscosity gives a reduction in the bloodstream supplying the heart muscle with necessary nutrition and oxygen. The increased heart rate that may follow expectations of rescue (e.g. hope) may thus result in lack of oxygen for the heart.

Catecholamine (particularly noradrenaline) provides protection during hypothermia because it increases the blood pressure. It is considered plausible that when a person considers rescue to be imminent, the sensation of relief may cause a sudden reduction in noradrenalin. This causes the blood pressure to drop and further the hearts blood supply, which may cause cardiac arrest.

DURING RESCUE

It is debated what actually causes the deaths recorded during the rescue. Some studies suggest that thermal response is the main cause. "Afterdrop" is blamed by some because as the blood from arms and legs return to the blood circulation they may provide a thermal shock to the heart. A different theory is that the hydrostatic pressure in the water to some degree supports the blood circulation. Thus, if a person is in a vertical position right after being picked up, the blood may drop to the legs, causing a reduced blood flow for the heart and brain. If the person has to assist in the rescue it may trigger some of the before-mentioned effects and cause cardiac arrest.

AFTER RESCUE

Rescue statistics show that a significant number of fatalities occur just before, during, or shortly after rescue. The percentage vary between incidents, however the average is close to 20 % [8]. This includes survivors from rescue rafts or life-boats who have not been immerged. Matthes noted during the Second World War how a ditched German aircrew, who had been conscious in the water and even aided in their own rescue, became unconscious and died shortly afterwards [51].

The survivors will at the time of rescue be affected one or more of the following conditions:

- Close to drowning
- Impaired muscular function
- Hypothermia
- Trauma

Physiological change is also important, as the blood volume and distribution may affect cardiovascular functions.

The most common cause of fatalities after rescue is hypoxia basically causing drowning because of the water already in the lungs. A delayed effect may also be the before-mentioned drops in blood pressure. Intensive warming of the body may also cause the blood vessels near the skin to expand, reducing the flow back to the heart, causing a drop in blood pressure.

2.4.4 SURVIVAL TIME IN COLD WATER

Survival in cold water is highly dependent on clothing and also training. [52] estimated in their report that; even when wearing thermally insulated garments (TIG) in addition to regular work clothes, under a waterproof membrane type survival suit, the survival time would drop by as much as 67% if your suit was leaking[22]. [53] presents three scenarios where the *standard man* is immersed in cold water with a temperature of 5° C. Time until the body reaches a core temperature of 34° C is made the survival time. When the body reaches this temperature, unconsciousness often follows, highly increasing the risk of drowning in calm seas. If the weather worsens and turbulent seas (Beaufort 5 or greater) is encountered, and estimated 50% reduction in survival time is used, due to the need to assist in staying in an upright position and leakage. In addition, a 10% reduction due to water inertia when suit is leaking is added.

[22] From an approximate 3 hours survival time down to approximately 1 hour.

TABLE 6 - PREDICTED SURVIVAL TIME ACCORDING TO [53]

Scenario	Clothing	Beaufort Scale	Survival Time
1	Membrane suits and lifejackets, over regular clothes. No leaks.	0-2 >3	2 hours 1 hour
2	Membrane suits and lifejackets, over regular clothes. Leakage.	0-2 >3	80 minutes 36 minutes

This report was issued in 1996 and improvement to survival equipment has no doubt been made. The OLF requirement to survival suits is six hours in 2°C water, based on ISO requirements [54].

As pointed out by Færevik [55]; there is no conclusive model that is absolutely correct when it comes to survival time in cold water. The model presented above is one of many recognised models[23]. The industry standard for operations on the Norwegian Continental Shelf is 120 min from accident is reported until rescue from water. This requires proper survival suits and locating devices. The new survival suits fulfil this requirement. The figure below displays the effect of various clothing and insulation options in different water temperatures.

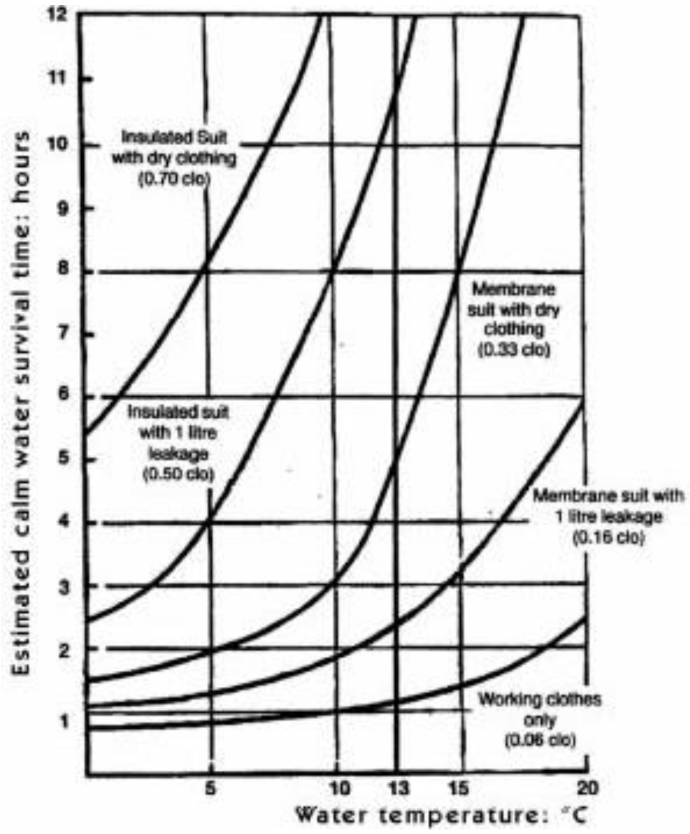


FIGURE 12 - PREDICTED SURVIVAL TIME AGAINST SEA TEMPERATURE FOR DIFFERENT LEVELS OF IMMERSED CLOTHING INSULATION. AS DERIVED FROM THE WISSLER MODEL, MODIFIED BY HAYES, 1987 [56].

[23] For more details see Wissler, Tikuisis and the book “Survival at Sea (Golden and Tipton)

2.4.4.1 PREVENTING FATALITIES

The cooling rate for a person in cold water is depending on many factors such as water temperature, currents and waves. Isolation against heat-loss is extremely important. Subcutaneous fat is very effective, and “survival of the fattest” is to some degree true [8].

The protective system between the human and the water is important. Air is a particularly good insulator, and maintaining a layer of air between the human and the water is very effective.

Survival suit is the primary mean for protection of an individual. On appendix R, a discussion on survival suits is included.

2.5 PETROLEUM ACTIVITIES IN THE BARENTS SEA; PAST, PRESENT AND FUTURE.

In 1980, the Norwegian government allowed for petroleum exploration north of 62 degrees latitude. The exploration-debate was a political conflict through the 1970's. The Arbeiderparti-government[24] wanted to begin exploration drilling in 1977 and was supported by Høyre[25], in addition to the three northernmost provinces. The fishery organisations, environmentalists and the middle parties feared the environmental and economic consequences of moving further north. Lack of oil spill preparedness first postponed exploration by one year before the blowout on the Bravo-installation at the Ekofisk-field postponed it by another two years.

In the Nordland shelf, some large fields are in production; Åsgard, Heidrun, Norne and Skarv, in addition to some smaller fields. The southern Barents Sea was opened in 1988 [23], although the story of petroleum activities began earlier. In 1984, the Snøhvit-field was discovered in the Barents Sea. Snøhvit is the world's northernmost field in production and the well stream is the longest in the world with multiphase flow[26]. It started production in 2007.

At first, exploration in the Norwegian Barents Sea was a summer activity. In the years from 1980 until 1986, there were normally two or more exploration rigs in the region. The full winter programme commenced in 1987/88, when Ross Rig and Polar Pioneer first spent the winter. From that point, exploration became an all-year activity. Between 1994 and 2004 there was little or no activity, before picking up slightly. Using the fact pages on the Norwegian Petroleum Directorate (NPD) homepage, a total of 98 explorations have been made in the Norwegian Barents Sea.

Goliat, the first manned production installation is set to begin producing in 2014 [25]. In addition, new developments around the Skrugard and Havis fields should be expected in the near future.

The expectations for the future indicate more findings in the north. According to the Norwegian Petroleum Directorate (2009) (NPD), 13,5 billion Sm^3 o.e.[27] is the estimated amount of petroleum resources in the Norwegian and southern Barents Sea. 5,1 billion Sm^3 o.e. is produced, remaining proved resources are 5,0 Sm^3 o.e., while undiscovered resources are estimated at 3,4 billion Sm^3o.e. New estimates for the Norwegian Barents Sea indicate 960 million Sm^3 o.e. [57, 58] of undiscovered resources.

There is also great optimism after the agreement on the partition line between Norway and Russia was reached on September 15th 2010. There is expected to be a large amount of gas in the partition line area, and exploration activity is expected to be high in order to secure the interests of the two countries [23].

[24] The Norwegian Labour Party
[25] The Conservative Party
[26] Gas, water and lighter petroleum fluids
[27] Oil equivalent. When talking about energy, tonne of oil equivalent is also used and at approximately 42 GJ.

3. THEORY AND METHOD

In theory there is no difference between theory and practice. In practice there is.

Lawrence Peter «Yogi» Berra

This chapter will give an overview of risk management and the risk picture in the Norwegian Barents Sea. In addition, the methods used in the analysis will be elaborated.

3.1 RESEARCH AND METHODS

This thesis has been based on the following:

- Examination of literature on; operations, emergency preparedness, cold climates, survival in cold climates, remote areas and development of the Norwegian Barents Sea.
- Risk management theory: Risk Analysis, Safety Barriers, Defined Situations of Hazard and Accident (DSHA).
- Examination of information gathered from relevant databases and accident investigation reports related to maritime as well as aviation accidents.
- Analysis of barriers using event trees and bow tie analysis in order to identify critical aspects of both operational and emergency preparedness scenarios.
- Performing interviews with relevant personnel in order to gather experience and hands on information. This information was used to support analysis and evaluations.
- Some example calculations have been performed in order to illustrate issues. These are simple calculations and comments regarding their accuracy can be found in the respective sections.

The analysis can be split in two parts: operational and emergency preparedness analysis.

The main method used for analysing the scenarios has been bow tie analysis; and bow tie analysis was used to examine the effects of findings in literature and interviews. The analysis have for a large part been qualitative due to lack of data, and the main focus has been on identifying the differences between the Norwegian Barents Sea and the rest of the Norwegian Continental Shelf, and how they may be dealt with.

For the emergency preparedness scenarios, it was assumed that the accident had already occurred. Therefore, the analysis performed for these focus on mitigation of effects.

3.2 THE RISK PICTURE

Any offshore activities in the Barents Sea will need to consider the additional challenges that arctic climate and remoteness presents. Several challenges add risk to the risk picture from the North Sea, and in order to maintain the same safety level for offshore activities in the Barents Sea, all of these factors must be taken into consideration in technical solutions and operational best practices. The Barents 2020 phase 1 [7] presents additional challenges in a summarised table. An extract of that table is presented below:

TABLE 7 - ADDITIONAL METOCEAN CONDITIONS (FROM [69]). GREEN: NO NEED FOR CHANGE; YELLOW: STANDARDS OK BUT MORE DATA NEEDED TO REDUCE UNCERTAINTIES; RED: NEEDS UPDATING IN STANDARDS AS WELL AS MORE KNOWLEDGE

Hazard	Additional Challenge in the Barents Sea	Implications	Mitigation
Metocean			
Wind	No	None, except when combined with low temperature	None, but better spatial data coverage needed
Waves	No	None, except when combined with ice and glacial features	
Current	No	None	
Weather Forecast	Yes, more demanding due to less data and smaller scale	Few observations from open ocean give less reliable forecasts. Particularly relevant for polar lows	Increased observation network, automated stations at sea, higher resolution models
Visibility (not including darkness)	No, but somewhat worse conditions	Hamper operations including ice management	Procedures, more data
Temperature	Yes	Wind chill, tougher working conditions, icing	Limit exposure, enclosures, procedures, ventilation, choice of materials
Icing	Yes	Change dimensions, freezing valves and other process equipment, block escape routes, slippery gangways, falling loads, reduced gas detection, reduced effectiveness of radar and communication	Ice removal manually, by chemical de-icing, choice of coating and materials heat tracing (electric heating cables), steam and salt

Table 8 displays a summary of the risks that may encountered in the arctic based on [59-61]. Some of these, such as sea-ice, are not amongst of the big issues for operations in the Southern Norwegian Barents Sea.

TABLE 8 - SUMMARY OF RISK FACTORS IN THE BARENTS SEA.

Identified Risk Factors	Mitigation Measure
Low Temperatures have major impacts on the working environment and affect the structural materials used on ships and platforms; however there exists substantial experience from onshore operations.	• Personnel have to be protected by enclosing working areas. The enclosure should be properly designed to avoid introducing additional risk (e.g. confined gas). • Correct material selection ensures proper material ductility.
Ice will be present for large parts of the year (depending on location), in terms of drifting sea ice and icing on equipment.	• Additional strengthening and special designs to account for the loads from the ice. • Ice monitoring systems.
Weather conditions in the Artic are not well understood and long-term developments are uncertain due to lack of data and proper forecasting. Quick shifts and little or no forecast makes weather windows a crucial part of the risk picture in Arctic operations.	• Special design considerations if the long-term development leads to more severe conditions (e.g. waves.) • Weather service and data collection. Creation of weather forecast models to predict polar lows.
Long-term human performance might be affected due to low temperatures, lengthy periods of darkness and light, noise and vibration from ice, and psychosocial aspects of living in remote areas.	• Selection and training of personnel in addition to adequate rehabilitation between working periods can help ensure a suitable workforce. • Appropriately designed living quarters give necessary relief during working periods.
A more vulnerable environment with unknown effects	• More safety barriers should be introduced; narrow operational windows or seasonal operations can be considered. • Probability of other risk factors should be reduced, to account for the possible increased consequence of incidents.
Oil spills in ice represents a major challenge, since no technology exists for oil spill recovery in ice. Detecting oil spills during polar nights is also demanding.[28]	• Appropriate technology for detecting and recovering oil spill in ice is lacking, and should be developed.
Escape, evacuation and rescue of personnel is more challenging due to long distances, darkness and sea ice. No single solution exists today that is suitable for all conditions. Also, enclosed areas reduce ventilation and escape routes.	• Several alternatives for escape, evacuation and rescue should be implemented to ensure appropriate safety of personnel until a single solution can be developed.
Indigenous interests can be perceived as a risk for industrial activity in the Arctic due to the operator's lack of knowledge.	• A serious study of rights and cultures, including consultation process. • Early involvement of indigenous peoples and other stakeholders.

[28] Extensive research is currently being performed in order to develop methods for detecting and removing oil in ice and darkness.

3.3 RISK MANAGEMENT

"It's impossible that the improbable will never happen."

Emil Gumbel

All activities of an organisation involve risk at some level, and there are many theories on how to approach risk, and they range from the Normal Accident Theory (NAT[29]) to High Reliability Organisations (HRO) to Resilience Engineering and many more. This chapter will focus on more traditional risk management (as proposed in ISO 31000); however, a brief comment on resilience engineering will be included.

The way organisations manage risk is by identifying it, analysing it and then evaluating it; should the risk be modified by risk treatment in order to satisfy the criteria [62]? For the Barents Sea, the risks are not necessarily new; they are however to some degree different.

This thesis uses as a base the concepts of risk management and barriers for the analysis. This chapter will give a foundation for understanding risk management and further the concept of barrier management. Risk management coordinate activities to direct and control an organisation with regard to risk [62]. In the second part of this chapter, principles for barrier management, with focus on the Norwegian petroleum industry, will be described. After investigations and mapping of the risk level in the Norwegian petroleum industry, relatively large differences considering understanding of, and thus compliance with the regulations considering especially barrier management, were found.

First, it is important to define the term *risk* and some constituents properly for the purpose of the thesis.

3.3.1 WHAT IS RISK?

As pointed out by Sklet [63], the use of risk-informed principles necessitates an understanding of the word risk.

Risk is a term used often and with different meaning. In fact, there is no commonly agreed definition of the word. There is an abundance of definitions of the word in literature, and several views exist, and are perhaps best illustrated by the following history [64];

"One of the first initiatives from the Society for Risk Analysis was to establish a committee to define the word risk. The committee laboured for 4 years and then gave up, saying in its final report, that maybe it is better not to define risk and let each author define it in his own way, emphasizing that each should explain clearly what way that is".

There are however some definitions that are being used more frequently than others [65]

[29] Because there are so many (infinite) ways that something can go wrong, accidents are considered normal.

- Risk equals the expected loss
- Risk equals the expected disutility
- Risk is the probability of an adverse outcome
- Risk is a measure of the probability and severity of adverse effects
- Risk is the combination of probability and extent of consequences
- Risk is equal to the triplet (s_i, p_i, c_i), where s_i is the ith scenario, p_i is the probability of the ith scenario, and c_i is the consequence of the ith scenario, i ¼ 1, 2, . . ., N,
- Risk is equal to the two-dimensional combination of events/consequences and associated uncertainties (will the events occur, what will be the consequences)
- Risk refers to uncertainty of outcome, of actions and events

These can roughly be divided into three categories [66]

- A. Risk is an event or a consequence
- B. Risk is a combination of probability and expected loss.
- C. Risk is expressed through events/consequences and uncertainties.

For engineering purposes (and others) it is common to use category B, defining risk as a function of probability and consequence [67].

$$Risk = f(Pr, C)$$

Kaplan and Garrick stated that the question "What is risk?" is actually three questions [68]:

1. What can happen?
2. How likely is it that it will happen?
3. If it does happen, what are the consequences?

In this way, risk may be modelled using a set of triplets (S_i, L_i, X_i), where S_i is the i-th scenario, L_i is the likelihood of scenario *i*, and X_i the consequences of scenario *i*.

3.3.1 RISK FACTORS

In engineering terms the most common way of looking at risk is as a function of probability and consequence, or the effect of uncertainty on objectives [62]. The perception of risk is also important because it involves how people see the risk subjectively. This section briefly describes the two main constituents of risk: probability and consequence.

3.3.1.1 PROBABILITY

There are basically two definitions of probability. First, the *classical* way, is to look at probability as the long term (relative) frequency of an event, i.e. if you roll a dice a sufficient number of times the probability of rolling a six will be one sixth. Second, the *Bayesian* way, is a subjective measure of belief of the situation, about the occurrence of an event, or about the truth of a statement, i.e. what is the probability of New York lying south of Rome?[30] To a classical statistician this gives no meaning. However, with the lack

[30] New York is in fact south of Rome.

of data for many areas in the Barents Sea, it would seem as though Bayesian reliability may be the governing way of looking at probability for some years to come, or a combination of the two. For the North Sea, an exceptional amount of data has been collected over the years, and some of it could indeed be transferred to the Barents Sea.

3.3.1.2 CONSEQUENCE

The Oxford Dictionaries define consequence as: a result or effect, typically one that is unwelcome or unpleasant, or the importance or relevance of an event or an action.

The consequences of an accident may be classified in different categories [69]. The common ones are:

- Personnel consequences
    - Fatalities
    - Impairment
- Environmental damage
- Economic loss
    - Damage to material assets
    - Production/service loss
- Information "loss"
- Image (i.e. reputation damage)

3.3.2 RISK ACCEPTANCE CRITERIA AND EVALUATION

The term risk acceptance criteria are, in most standards, specified in a way that compares the matter of either accepting or rejecting future risk. The NORSOK Z-013N [70] defines risk acceptance criteria as:

Criteria that are applied in order to express the acceptable level of risk for the activity at hand.

Which is supported by NS 5814:2008 [71] where risk acceptance criteria are defined as *criteria which form the base for decisions regarding acceptable risk.* Risk acceptance criteria can be based on government requirements, standards, experience, theoretical knowledge and norms. There is not necessarily a quantitative requirement.

Common qualitative criteria are [66]:

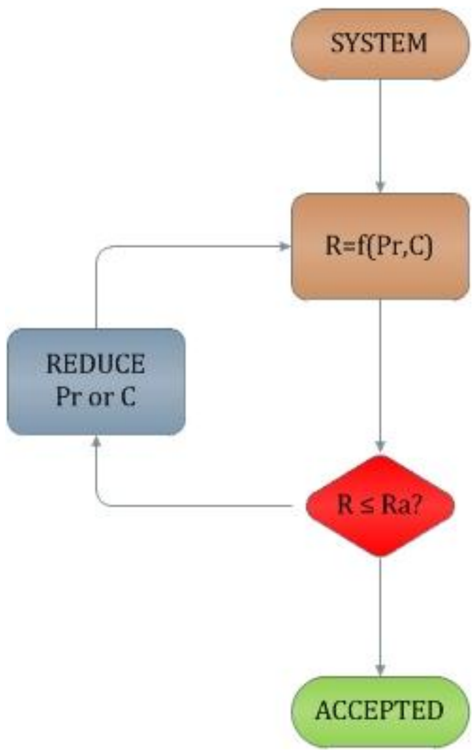


FIGURE 13 - RISK REDUCTION

- All avoidable risks shall be avoided
- Risks shall be reduced wherever practicable
- The effects of events shall be contained within the site boundary
- Further development shall not pose any incremental risk

In [71] acceptable risk is defined as: *Risk which is accepted in a given context based on the current values of society and in the enterprise.* However, as pointed out by Johansen, those searching for a generally agreed definition of acceptable risk *are likely to be disappointed.*

There are some desired qualities that risk acceptance criteria should fulfil. According to [70], risk acceptance criteria should:

- Be suitable for decision making
- Be suitable for communication
- Be unambiguous in their formulation
- Be concept independent (i.e. not favour any particular solution)

There are many more discussions that could be included here as to the point of acceptable risk. Do we accept options or risks? Is acceptable equivalent to tolerable? The combination of risk and reward is also important for what society is willing to accept. Risk perception is therefore an important topic in risk management.

3.3.2.1 PERCEPTION

Risk perception simply represents the subjective assessment of the probability and the consequences of a particular unwanted event, and further how concerned people are. Common risks, risks that we know and see often, often lead to a higher tolerance for that particular risk, even though the objective risk is lower. If you are concerned with the probability of having a blow-out in the Arctic, you should definitely reconsider driving a car to work.

Risk in the Arctic zone is not always greater than for example the North Sea. In many parts of the Barents Sea it was concluded that the probability of an accidental oil spill was no greater than in other parts of Norway's Continental Shelf [65].

The goal must be to attain sufficient knowledge so that society at large as well those directly involved are able to make their decisions, weighting the downside risk against the benefit of the activities in question.

This will also be needed when evaluating the need, benefits and cost of measures available for achieving optimal risk reduction. [61]

Peoples willingness to accept risk may depend on; the *benefits* from taking the risk, the *control* we have over the risk and the *type of consequence* arising from the risk. The control aspect may for most purposes be redefined as *the control we believe others have over the risk*. [72]

Communicating risk is a challenge on many levels in all industries. It is of fundamental importance because describing the level of risk is of utmost importance in order for risk acceptance criteria to be operational. It is extremely important to choose an adequate expression for risk acceptance. This is emphasised by [73], warning that improper metrics produce anomalous results.

The fundamentals of commonly used risk metrics are included in appendix L. In the next section, the concept of ALARP and risk acceptance in the Barents will be discussed.

3.3.2.2 EQUIVALENT RISK – BARENTS SEA COMPARED TO THE REST OF THE NORWEGIAN CONTINENTAL SHELF

One of the common models is shown in figure 14, the ALARP (As Low as Reasonably Practicable) principle. ALARP is the British risk acceptability framework, however it is widely recognised in many other countries, including Norway. The ALARP-principle was introduced in the British TOR framework for tolerability of risk from UK nuclear stations [74]. HSE have also provided a series of guidance documents regarding the principle. The principle is based on limiting or mitigating risk to a point where it is reasonably practicable. But what is reasonably practicable? A problem with ALARP pointed out by [75] is that it is often interpreted as: as *little* as reasonably *possible.* Another model that has been proposed for the Barents Sea is a version of ALARP called ALAP (As Low As Possible).

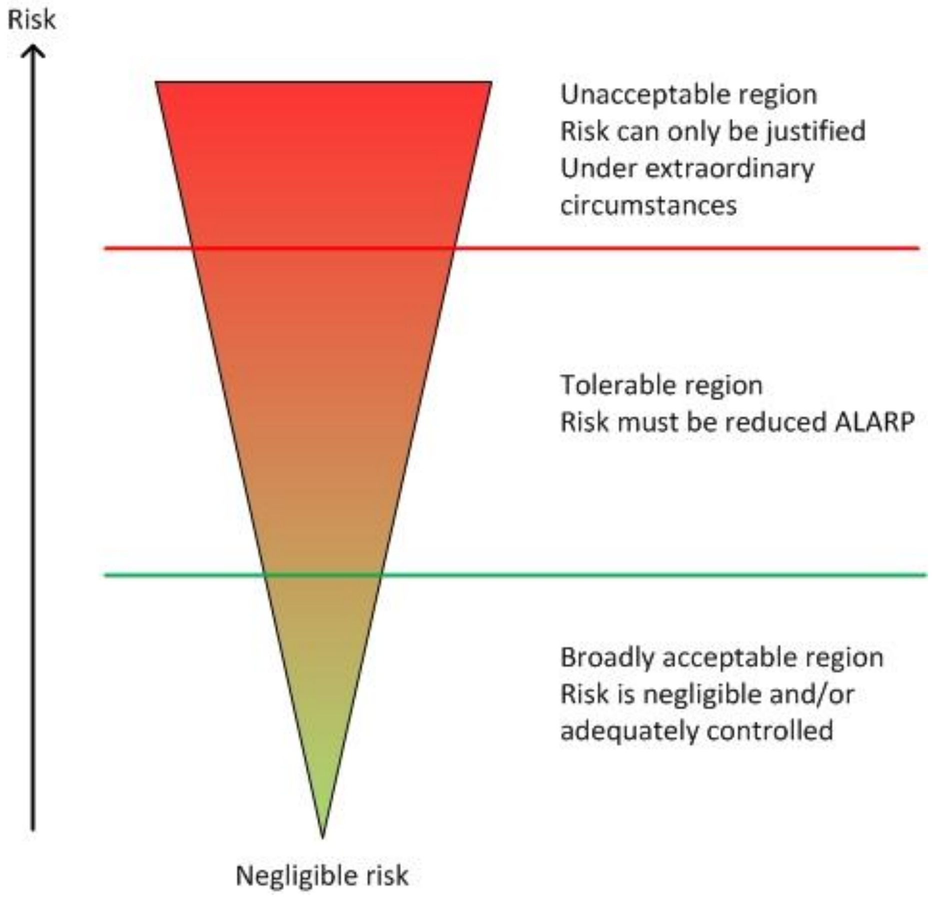


FIGURE 14 - THE ALARP PRINCIPLE. ADAPTED FROM [74]

In the Norwegian Barents Sea the risk acceptance policy is *equivalent risk* as the rest of the Norwegian Continental Shelf. Risk is defined as a function of probability and consequence ($Risk_i = P_i \times_i$). The general opinion is that the consequences are increased in the Norwegian Barents Sea; partly due to unknown factors and partly due to remoteness, available resources and a challenging operating environment. This means that in order to keep risk at the same level, the probability of unwanted events must be lowered. This is illustrated in the figure below.

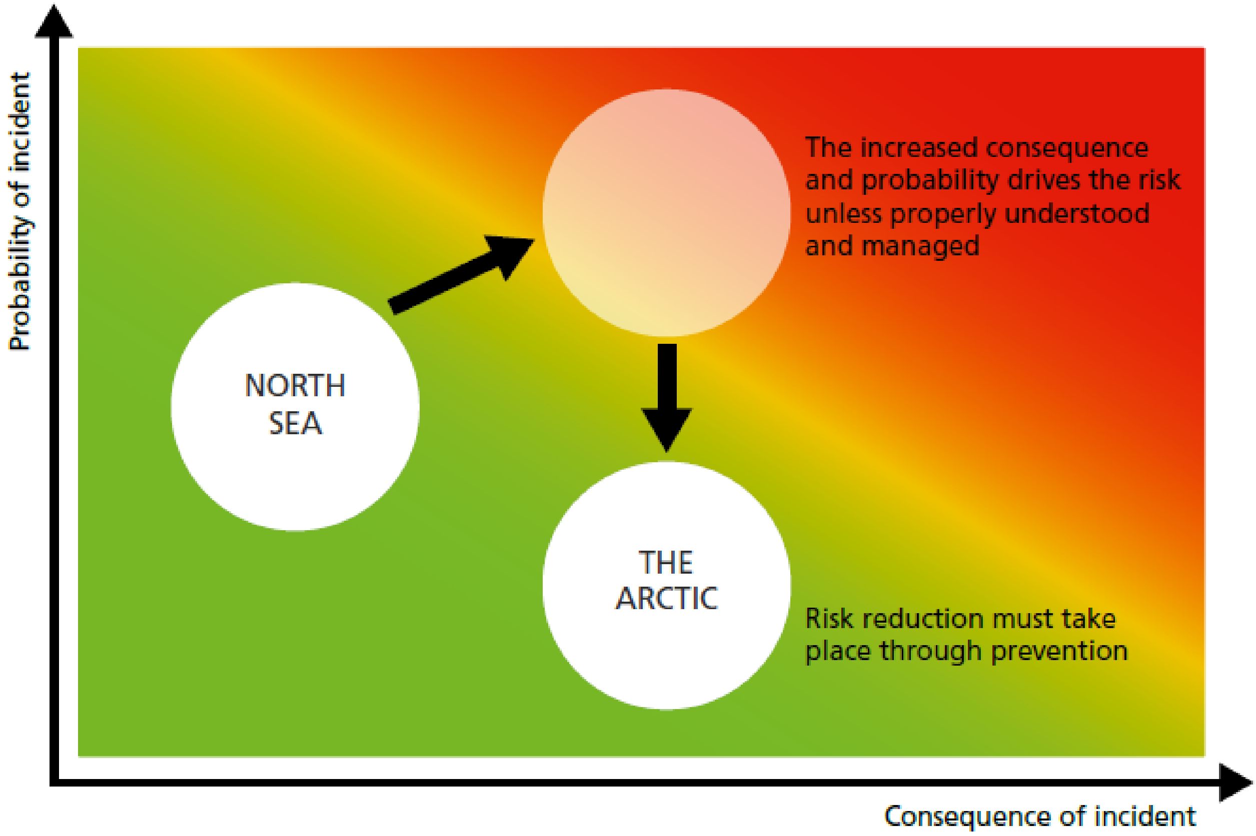


FIGURE 15 - PRINCIPLE OF RISK MANAGEMENT BY REDUCING PROBABILITY OF A HAZARDOUS EVENT [7]

A relatively new way of looking at safety efforts that might be applicable for the Norwegian Barents Sea is *resilience engineering*. A brief comment is included below.

The focus of risk management and safety efforts are usually the unwanted events and outcomes, corresponding with the traditional interpretation of safety as "freedom from unacceptable risk". Resilience engineering defines safety as "the ability to succeed under varying conditions". This could be of interest in high north development, due to the lack of information and untested solutions. Resilience can be broken down into four main abilities; the ability to respond to events, to monitor on-going developments, anticipate future threats and opportunities, and to learn from past failures and successes alike. This means also taking into account that operations usually are successful, even so; they should be expected to be. The theory of resilience engineering propose a new dimension in the traditional risk matrix; positive. The figure below illustrates the principle.

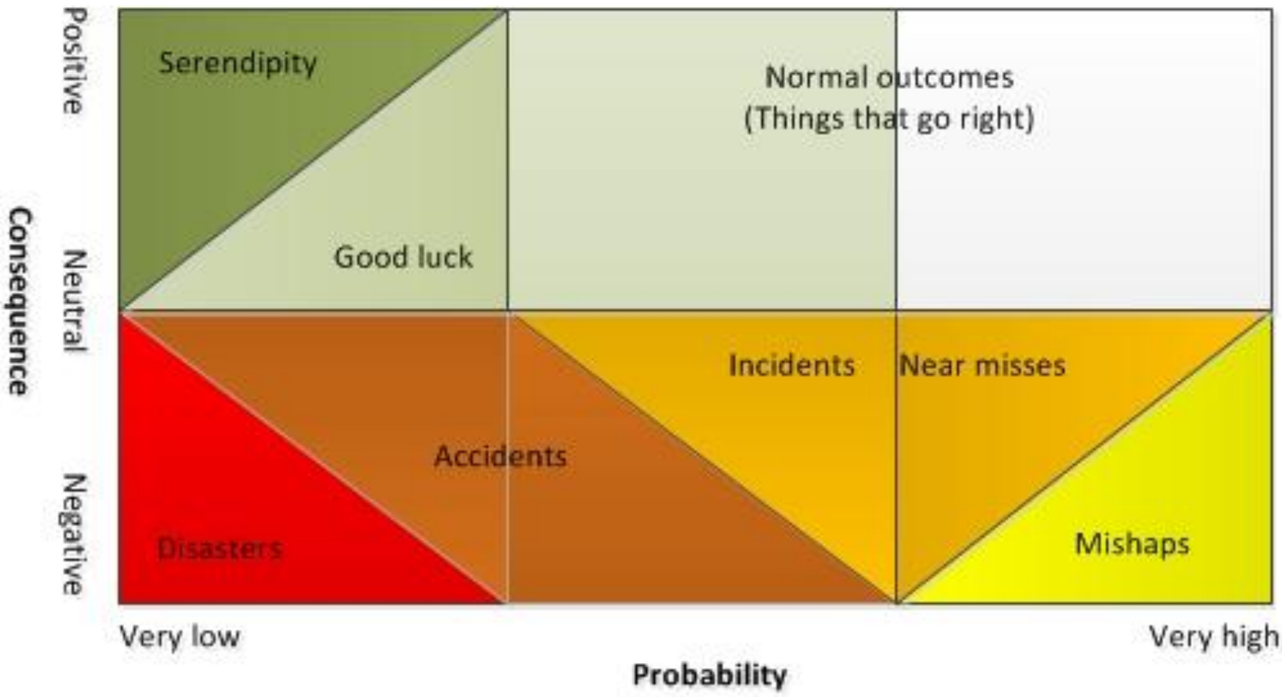


FIGURE 16 - RESILIENCE ENGINEERING, RANGE OF OUTCOMES [76]

By having a resilient solution, unexpected situations and events could be handled better, and equivalent risk in the Barents Sea could be achieved.

3.4 BARRIERS AND BARRIER MANAGEMENT

The functions of barriers can be illustrated through the two figures 17 and 18. These are simple representations that are very common in literature and most barrier analysis methods are based on these simple figures.

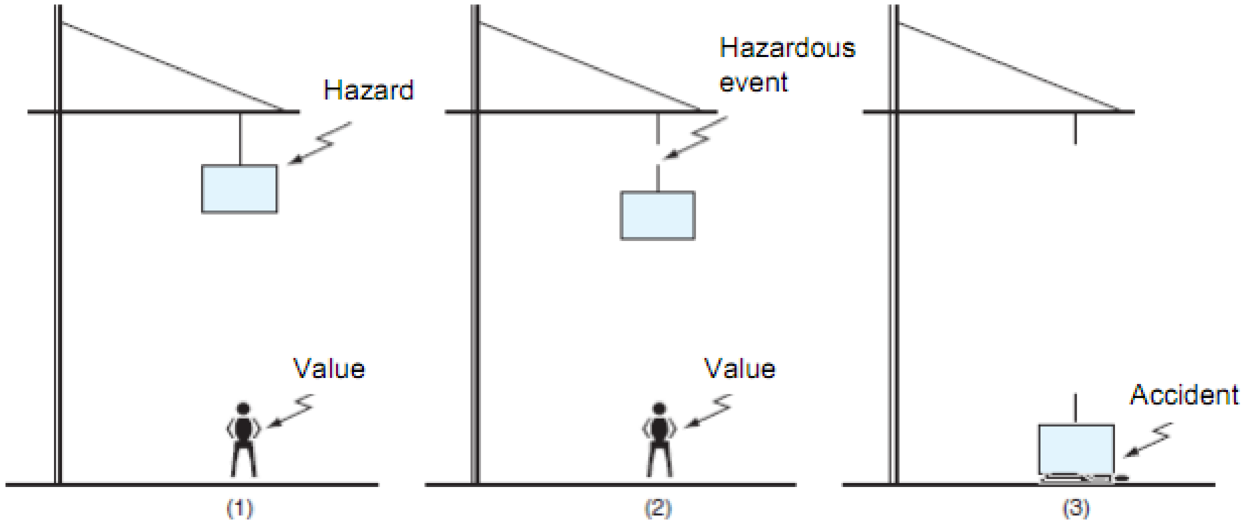


FIGURE 17 – HAZARD, HAZARDOUS EVENT AND ACCIDENT (FIGURE ADOPTED FROM [77])

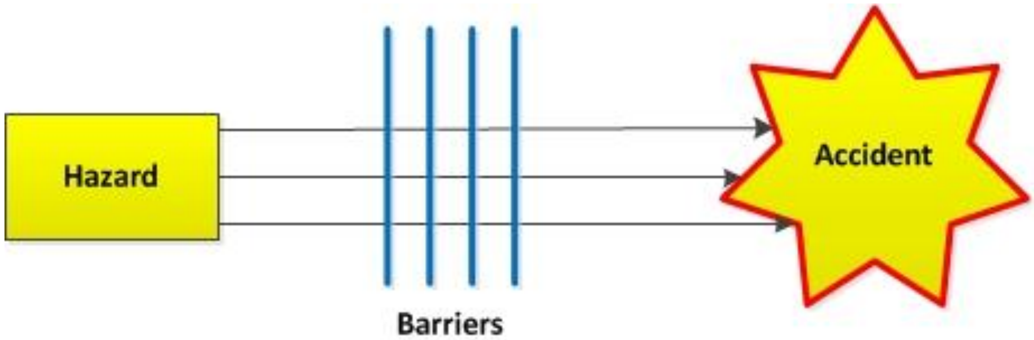


FIGURE 18 - BARRIER CONCEPT

It is important to distinguish between risk and hazard. Even though risk covers a wide range of phenomena, the terms risk, hazard and also threats are often mixed. A hazard is a source of physical damage, that could ultimately be converted into actual delivery of loss or damage. It can only exist as a source. Risk involves the possibility of this conversion.

The concept of barriers was introduced by Gibson in 1961, when he introduced the energy-barrier model. The basic concept was to separate a *value* from a hazard by placing a *barrier* between them. This was later further developed in 1970 by Haddon when the idea that accidents occur when, in the absence of barriers, harmful energy is allowed to have an effect on a *value.* This chapter looks into the concept of safety barriers, barrier management and methods for analysing them.

3.4.1 SAFETY BARRIERS

In the petroleum industry and the general society, the term *barrier* is often used with different meanings. Safety barriers are required in legislation and standards, discussed frequently in literature and also applied in practice. There are many different definitions of safety barriers and the related terms. The definitions used in this thesis are the same as presented in the paper *Safety barriers: Definition, classification, and performance* [63, 78].

Safety barriers: "physical or non-physical means planned to prevent, control or mitigate undesired events or accidents."

Barrier function: a function planned to prevent, control or mitigate undesired events or accidents

Barrier system: *a system that has been designed and implemented to perform one or more barrier functions.*

DNV defines barrier functions, elements and performance shaping factors, illustrated in figure 21, as follows [79]:

- *Barrier functions* – The intended role of a barrier (prevent, control, or mitigate undesired events)
- *The barrier elements* – Can be either operational, human or technical
- *Performance shaping factors* – factors that are influencing the performance of the barrier[31]

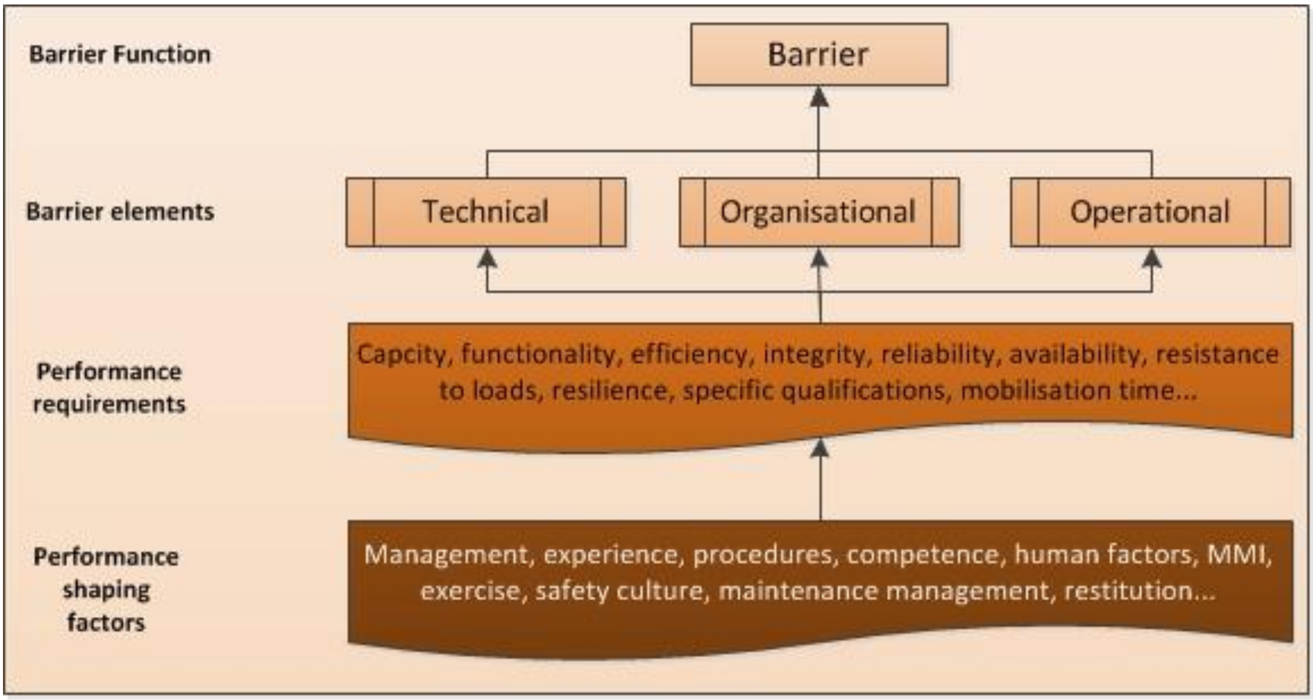


FIGURE 19 - BARRIER DEFINITIONS [80].[32]

[31] A better definition would be: factors of importance for barrier functions and barrier elements ability to perform as intended.

The means may range from a single element, such as human action or a physical element, to complex systems involving many different elements for example socio-technical systems. That safety barriers are *planned* suggests that at least one of the purposes of the means is to reduce the risk. As Sklet points out; ISO:13702 defines prevention as the reduction of the likelihood of a hazardous event; control means limiting the extent and/or duration of the hazardous event in order to prevent escalation; while mitigation means reduction of the effects of the hazardous event.

The functions describe the purpose of the safety barriers or what they shall do in order to perform their assigned task. If a barrier function is performed successfully, it should have a direct and significant effect on the occurrence and/or the consequences of an undesired event or accident. The functions are often and should be defined by a verb such as: close, stop, avoid or prevent [63, 78].

A barrier system designates how a barrier function is realised or executed. One barrier system may consist of several barrier functions. In some cases, there may be several barrier systems that carry out a barrier function [78]. In a barrier system, a barrier element is a component or a subsystem that by itself is not sufficient to perform a barrier function. The system may be built up from many different types of elements ranging from computer software to operational activities performed by humans [81]. Barriers can be online (functioning continuously), offline (in need of activation), temporary and permanent.

Sklet [78] presents a recommended way of classifying barrier systems, shown in figure 20.

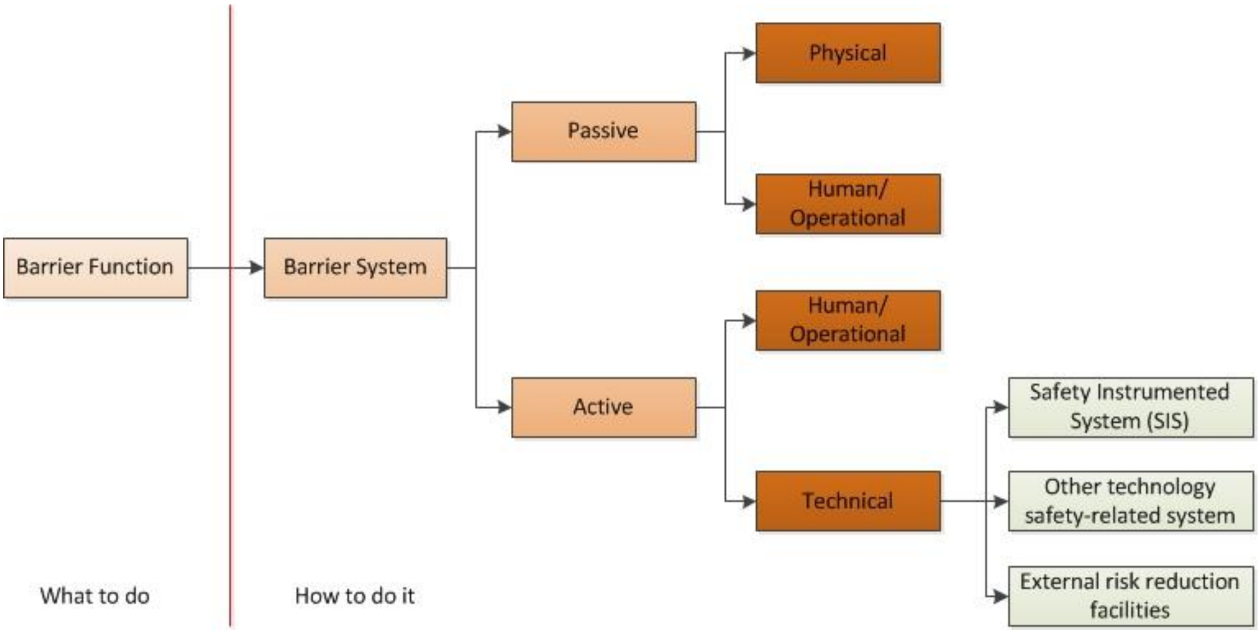


FIGURE 20 - CLASSIFICATION OF SAFETY BARRIERS, ADOPTED FROM [65]

[32] Further developed from a presentation of the article 80. Petroleum Safety Authority Norway. *Clearing up the confusion*. 2013 [cited 2013 March 25]; Available from: http://www.ptil.no/safety-status-and-signals-2012-2013/clearing-up-the-confusion-article9150-686.html.

Whenever barrier functions are related to a process model or phases in an accident sequence, it is common to classify the barrier functions as *prevention, control* or *mitigation [78].* There are however many different versions of this classification. A summary of the different views on this classification can be found in Sklet's article and is presented below.

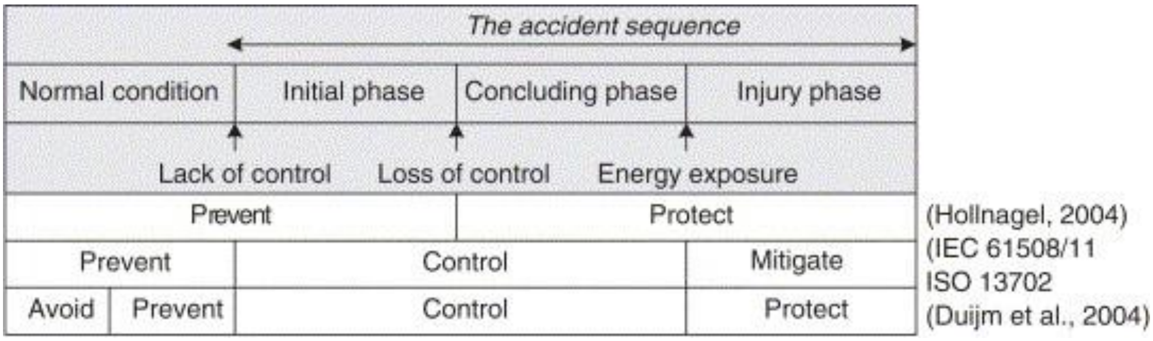


FIGURE 21 - GENERIC SAFETY FUNCTIONS RELATED TO A PROCESS MODEL [65]

Identifying failed, missing or functioning barriers is an important part of barrier analysis. The analysis of barriers in an accident investigation will typically include:

- Barriers that were in place and how they performed.
- Barriers that were in place but not used.
- Barriers that were not in place but were required.

The barrier functionality or effectiveness is the ability to perform a specified function under given technical, environmental, and operational conditions.

3.4.2 ANALYSING BARRIERS – BOW TIE

There are a variety of methods that can be used to analyse barriers in a system. The bow tie method will be used to investigate the scenarios and the barriers involved in this thesis. After recommendation from [82], BowTieXP from CGE Risk Management Solutions was used for creating bow ties for the report. A free student trial version was used. This section will give a brief overview of the bow tie method. Bow tie analysis is closely linked with fault tree-, and event tree analysis and was originally developed combining the two and including the barrier concept. An illustration of the bow tie model and its relation to risk analysis is shown in figure 24 below.

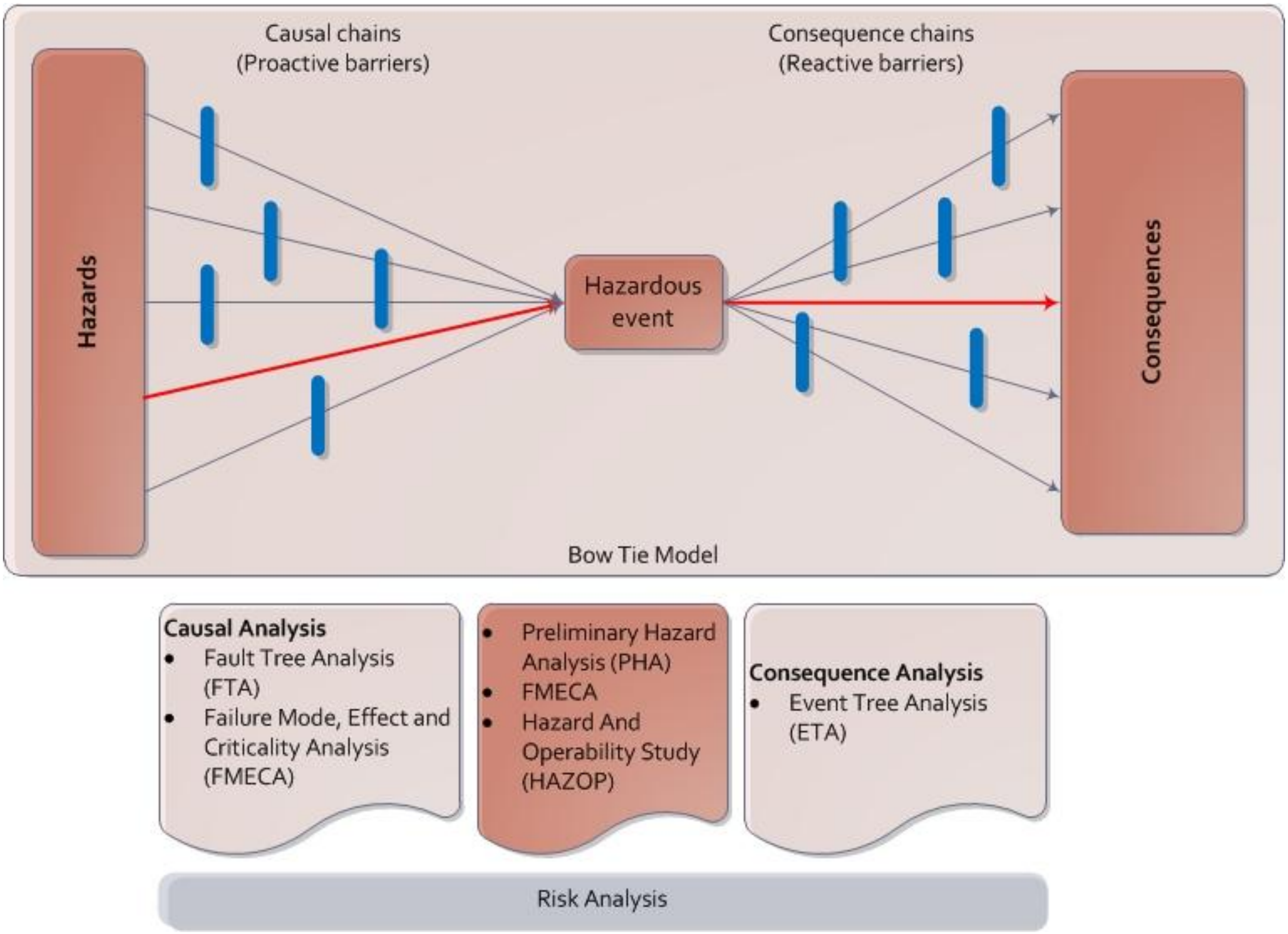


FIGURE 22 - BOWTIE AND RISK ANALYSIS, FIGURE ADOPTED FROM [77]

James Reason proposed a model known as the Swiss cheese model for illustrating how barriers can be compromised. Here, the holes in the cheese represent failure of the planned defence, possibly resulting in an accident, illustrated with the red arrow in the figure above.

The basic concept of a bow tie analysis is thus; what hazards can trigger an unwanted event (e.g. losing control of the ship) and what may be the consequences of that event (e.g. collision). When these questions are answered, barriers may be introduced in order to avoid hazards evolving into unwanted events, and further to mitigate the consequences in the case of an unwanted event.

In any complex system, barriers may cover one or more roles of protection, and "holes" in the defence might occur. Any barrier analysis should thus address the following:

- What is the barrier?
- What shall the barrier eliminate or prevent? (Left hand side)
- What shall the barrier reduce or mitigate? (Right hand side)
- What are the barrier weaknesses? (Escalation factors)
- How can the weaknesses be eliminated or prevented?
- What is the performance requirement of the barrier?
- How can the barrier and performance requirements be tested?
- Are there dependencies between barriers in the system?

The elements in a bow tie analysis are shown in the figure below. Analysing a bow tie can be straight forward in many cases; however, complex sequences may require multi-level (tiered) analysis. This can be performed down to any satisfactory level of sophistication.

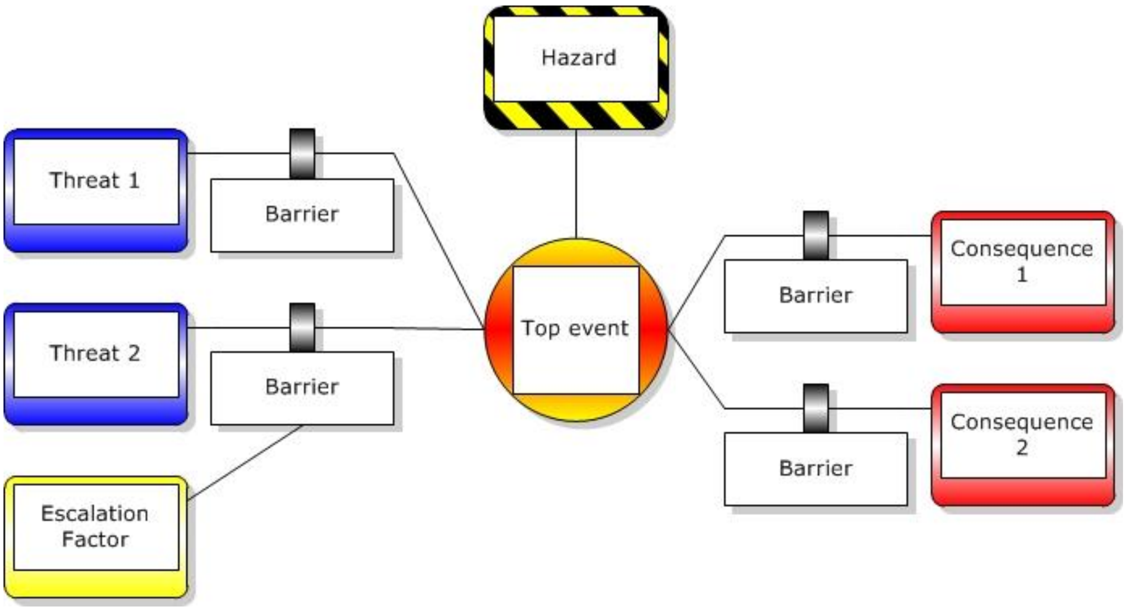


FIGURE 23 - ELEMENTS IN A BOW TIE ANALYSIS, ADOPTED FROM [17]

The elements in the figure above is defined in [83]:

- Hazard: things that are a part of your organisation and could have negative impact if control over that aspect is lost.
- Top event: the moment when control is lost over the Hazard.
- Threat: whatever will cause the Top Event.
- Consequences: potential outcomes of the Top Event.
- Escalation Factor: Anything that will make a Barrier fail.
- Control: Barriers

3.4.2.1 FAULT TREE ANALYSIS (FTA)

FTA is a top-down approach to failure analysis, beginning with a potential undesirable event called a *TOP event*, and then determining all possible ways this TOP event may occur. The causes of the TOP event are connected using logic gates. FTA is used to determine causes and also the probability (or frequency) of an unwanted event. It may also be used to analyse the reliability of pro,- and re-active barriers installed. FTA is the most applied method within causal analysis and was developed by Bell Telephone Laboratories in 1962[33]. A FTA can provide results such as:

- What combinations of failures and events that can lead to a TOP event.
- What is the probability/frequency of having the TOP event?
- What faults and/or events are of greatest importance for the occurrence of the TOP event?

The main question in a FTA is "what caused it?" This can then be investigated until the wanted level of detail is obtained. A fault tree (FT) example is included in the figure below.

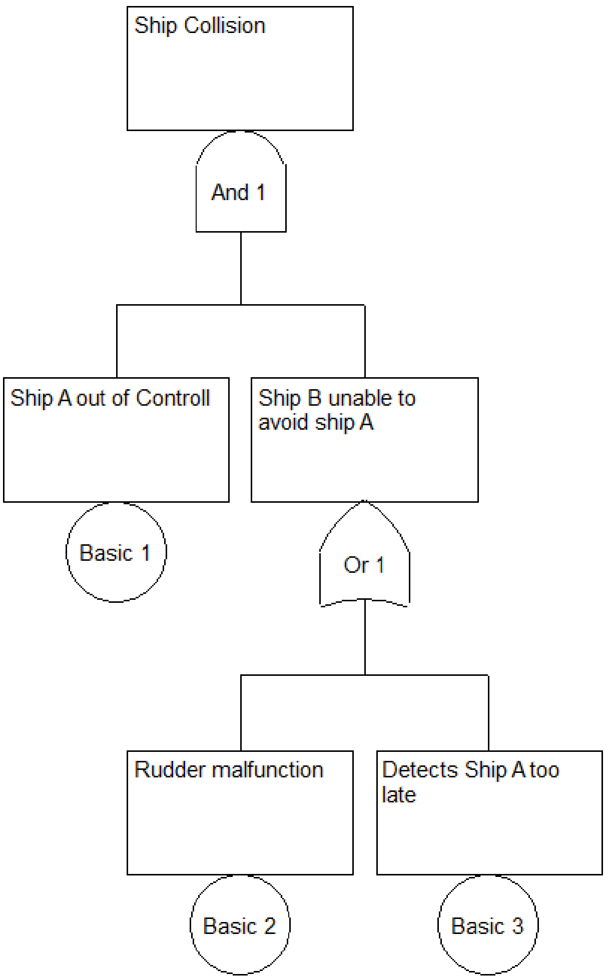


FIGURE 24 - FAULT TREE EXAMPLE

[33] Bell Telephone Laboratories performed a safety assessment of the launch system on board the nuclear Minuteman-missile.

When analysing a FT it is common to use minimal cuts (or cut sets) as a starting point. A minimal cut set is defined as: a set of basic events whose simultaneous occurrence ensures that the TOP event occurs. The cut set is said to be minimal if the set cannot be reduced without losing its status as a cut set. [69]

3.4.2.2 EVENT TREE ANALYSIS (ETA)

An event tree analysis (ETA) is an *inductive* procedure that displays all possible outcomes of an accidental (initiating) event, taking into account whether installed safety barriers are functioning or not, and additional events and factors. [69]

A generic event tree (ET) is shown in figure 25. An *accidental event* is defined as the first significant deviation from a normal situation that may lead to unwanted consequences (e.g. drive off for a shuttle tanker). This accidental event may lead to a variety of consequences. [69] These consequences can be illustrated with a consequence spectrum, as shown in figure 28.

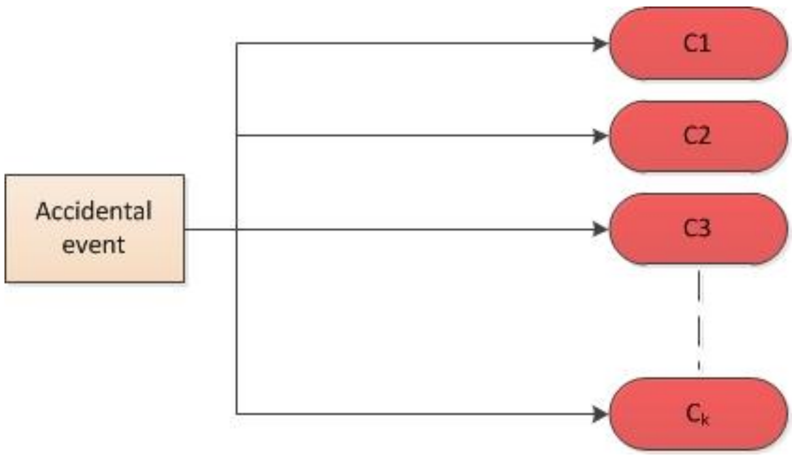


FIGURE 25 - GENERIC EVENT TREE

When this figure is established, barriers are implemented to prevent or mitigate the potential consequences. The probability of an accidental event causing any of the consequences is thus dependant on whether the implemented barriers are functioning as intended. This can then be used to detect design and procedural weaknesses, and evaluate the probabilities of various outcomes, as shown below.

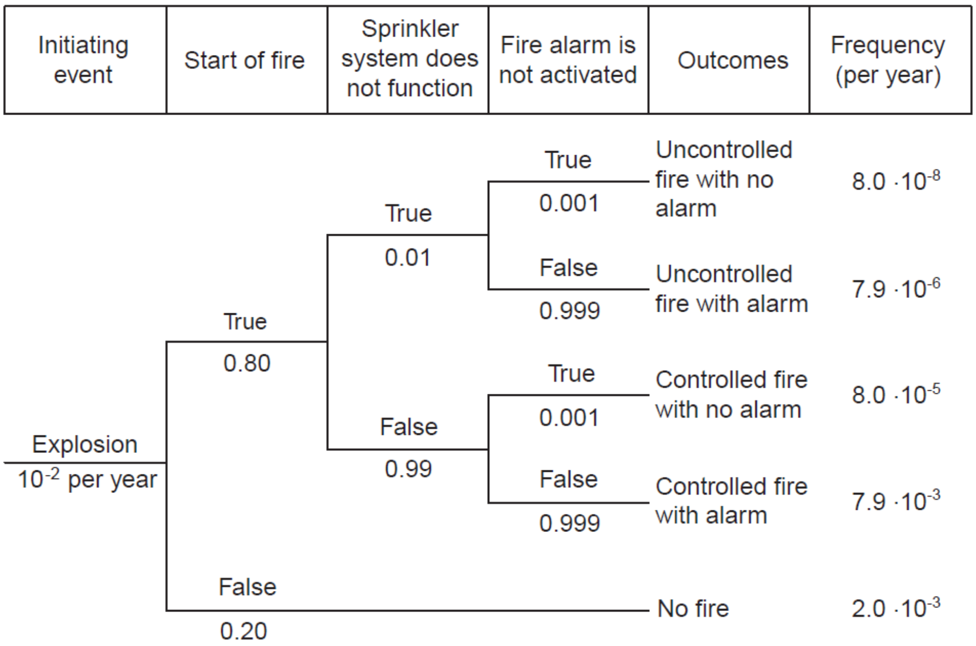


FIGURE 26 - EVENT TREE EXAMPLE, FIGURE ADOPTED FROM [69]

3.4.2.3 BARRIER BLOCK DIAGRAM

Analysing barriers can be done in several ways. The use of barrier block diagrams is common when analysing the quality of a barrier. Barrier block diagrams can be analysed using the same methods as for an event tree. An illustration is presented in figure 27. For the analysis in this thesis a regular bow tie analysis will be performed.

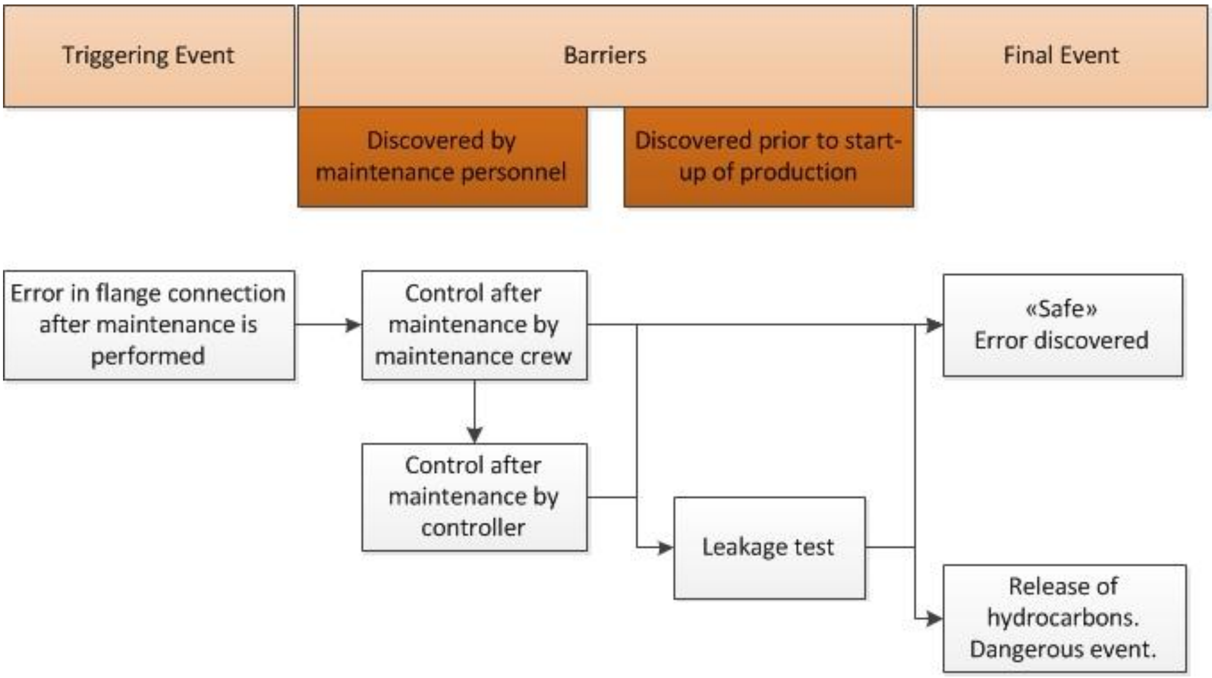


FIGURE 27 - BARRIER BLOCK DIAGRAM, ADOPTED FROM [67]

3.4.3 BARRIER MANAGEMENT

The purpose of barrier management is to establish and maintain barriers able to handle the risk encountered at any time through the prevention of unwanted events or mitigation of consequences should the situation arise. Barrier management includes the processes, systems, solutions and efforts necessary to ensure needed risk reduction through implementing and follow-up of barriers. These topics are covered in standards such as ISO:31000 and ISO:9000 in addition to [84] and [78].

Risk management assumes a systematic use of expedient analysis and reviews in order to support decisions of importance to risk associated with the business.

The risk evaluation contributes to establishing the risk picture, which is in turn used to evaluate the need for barriers, ensuring risk reduction to an acceptable level and meeting the requirements.

Barrier management is an integrated part of the companies HSE-management and further the company's performance management. [84] illustrates the role of barrier management with figure 28:

FIGURE 28 - ROLE OF BARRIER MANAGEMENT, ADOPTED FROM [84]

In order to handle risk in proper way, barrier functions and barrier elements must be identified, grounded on the risk picture. Using [62], the PSA [84] describe a barrier management model. The model is based on the process for risk management, shown in figure below.

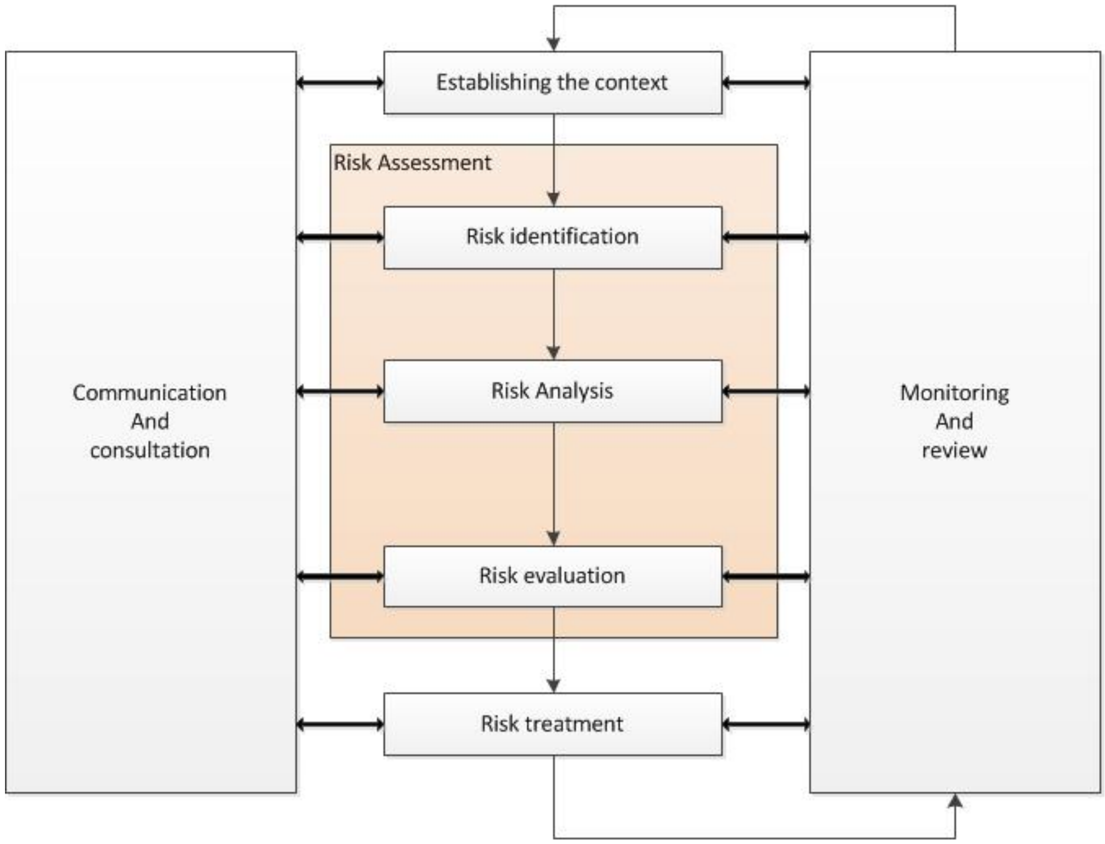


FIGURE 29 - ISO:31000 RISK MANAGEMENT PROCESS, ADOPTED FROM [62, 84]

PSA use, as a basis, the process for establishing the risk picture and barriers in a planning-, design-, or build phase (see figure 33).

The essence of barrier management is to have systematic and continuous control to make sure that the barriers are relevant, effective and robust. This means:

- Having a systematic process for selecting and developing the barriers. The starting point is the need to protect something of value.
- Selecting and dimensioning robust barriers. Taking into account uncertainty: one can never be sure that all possible future events have been identified nor that the barriers will have the desired effect on future events.
- Having a continuous process. [84]

Proper barrier management does not only consider the selection of technical and operational solutions in the design phase, it also involves making sure that the solutions maintain their desired qualities over time, and that those who directly or indirectly (through decisions or actions) affect the risk picture and/or the barrier characteristics have a good understanding of the consequences of their choices and actions.

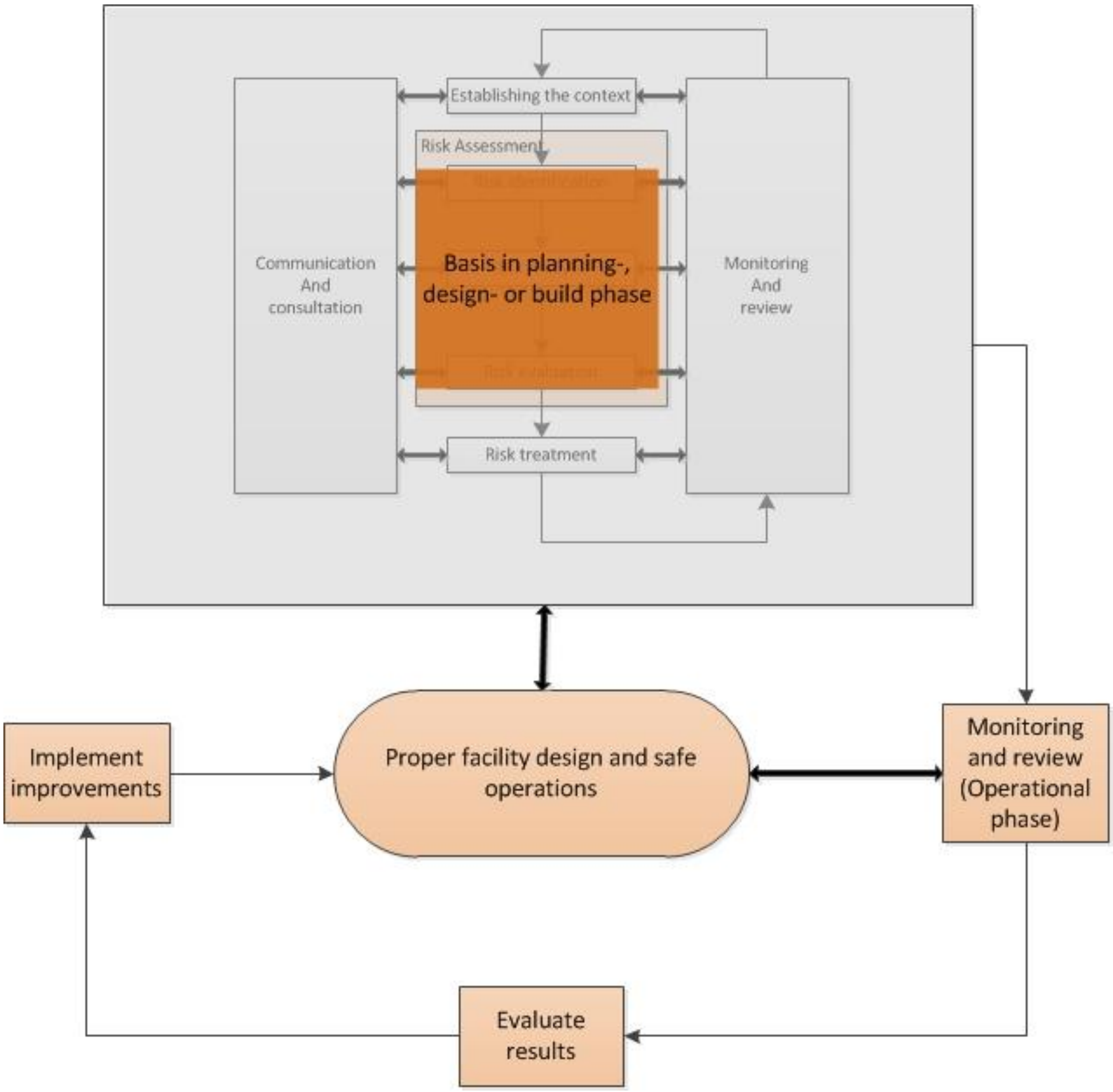


FIGURE 30 - PSA BARRIER MANAGEMENT PROCESS [84]

As pointed out in this chapter; barriers are important solutions for risk reduction (through reducing the probability of occurrence) and for limiting the consequences. This will be discussed further in chapter 4.

4. MAIN ANALYSIS

The operations selected for this thesis were based on important risk factors in the Barents Sea. For example in [59] (page 66-67), offloading from an offshore installation to a shuttle tanker was identified as the single most vulnerable operation with regards to large oil spills. In addition to the large masses, and thus large impact energies could potentially be catastrophic.

The operational and emergency preparedness scenarios selected for investigation in this thesis were:

1. Off-loading by shuttle tanker
2. Flotel in connection to a rig
3. Helicopter emergency landing on water (ditching)
4. Man overboard (MOB)

The scenarios were selected in order to present more concrete information about risk in the Barents Sea. The selection process was conducted through conversations with supervisors Professor II Jan Erik Vinnem (NTNU) and Børre J. Paaske (DNV). Further basis and motivation for the selection was found in reports such as the Barents 2020 project reports.

The scenarios have been created with the purpose of being realistic. For the emergency preparedness scenarios, close to worst case scenarios have been created. The reason for this is that in the absolute worst case scenarios it will not be possible to rescue the person(s) in the water.

It was regarded as outside the scope of this thesis to reproduce general risks for these operations such as DP drift off and helicopter ditching probabilities, the task was to look into Barents Sea specific risk.

The analysis can then be divided in two sections; regular operations and emergencies. For the emergency preparedness scenarios the right hand side of the bow tie was given more attention due to the assumption that the accident had already occurred.

4.1 OFFLOADING BY SHUTTLE TANKER

With the increasing number of FPSOs in use, the number of shuttle tanker (ST) offloading operations should also be expected to increase. This may be especially true for the high north, where possible great distances may prove pipelines unfeasible. FPSOs may offload to oil shuttle tankers indirectly via remote loading buoys; however the majority currently rely on direct offloading. There are in general two ways that direct offloading is performed; tandem and side-by-side offloading. Side-by-side offloading is less adopted in harsh environments [85]. Therefore, the focus of this thesis will be on tandem offloading operations.

This chapter will focus on the specific operation and not take into consideration the transportation of oil, as it was considered to be outside the scope of this thesis. The procedures and standards will be of greater importance.

4.1.1 DESCRIPTION OF OPERATION

Tandem offloading means that the shuttle tanker is positioned behind the FPSO (typically 50 – 80 m behind). The physical connection is through a mooring hawser and a loading hose. The two ways a shuttle tanker positions itself is by using its own dynamic positioning system (running in DP-mode) such that the hawser is not tensioned, or by applying a small amount of astern trust and maintain a small tension on the hawser (Taut Hawser Mode). DP is considered to be more probable for use in the Barents Sea, due to greater uptime in harsh environments [85, 86].

The FPSO – shuttle tanker tandem offloading operation can be summarized in the following five steps [85]:

1. Approach: tanker approaches the FPSO sterns and halts at the wanted distance.
2. Connection: messenger line, hawser and loading hose are connected.
3. Loading: oil is transferred from FPSO to tanker.
4. Disconnection: manifold is flushed and loading hose and hawser are disconnected.
5. Departure: tanker reverses away from FPSO stern while sending back hawser messenger line before sailing away from the field.

This is a frequent and both complex and difficult marine operation. The frequency depends on production rate and storage capacity of the FPSO and shuttle tanker size, and every 3-5 days is common [85]. The duration of the operation may be in the order of 24 hours, again based on storage and transfer rate. In his doctoral thesis, H. Chen included a detailed description of a North Sea tandem offloading operation. For illustrative purpose, this has been included in appendix J. Shuttle tankers performing offloading operations are recommended by DNV to have DP Class 2 or higher on the Norwegian Continental Shelf (A brief description of the DP classes can be found in Appendix N) [87]. This means that a backup system shall be available, limiting the possibility of having a drift- or drive off.

In 2011, OLF released a 10 year operability survey of Norwegian FPSOs [88]. FPSO offloading has been very successful with high regularity, with offloading proceeding routinely in 4-5 m significant wave heights. Although the DP2 ST have shown good performance, both ST and FPSO vessels and crews, several near misses due to ST drive offs linked to position errors and one contact incident. This is of particular concern in the Norwegian Barents Sea where a polar low could develop fast and put the ST off position.

One important factor that significantly impacts offloading costs is crude storage capacity. The time taken to hook up a ST, offload the cargo and transit is similar for large and larger volumes. Out of the six FPSOs included in the OLF survey, only one (900k) can fill a ST in a single offloading. The other FPSOs are progressively smaller (800k, 580k, 420k, 380k, 190k). Also due to operating restrictions the full storage volume cannot be fully utilized [88].

4.1.2 INCIDENTS

Losing control of the ST is the most probable issue in offloading scenarios. The figure below displays ST incidents and accidents from 2000 until 2011.

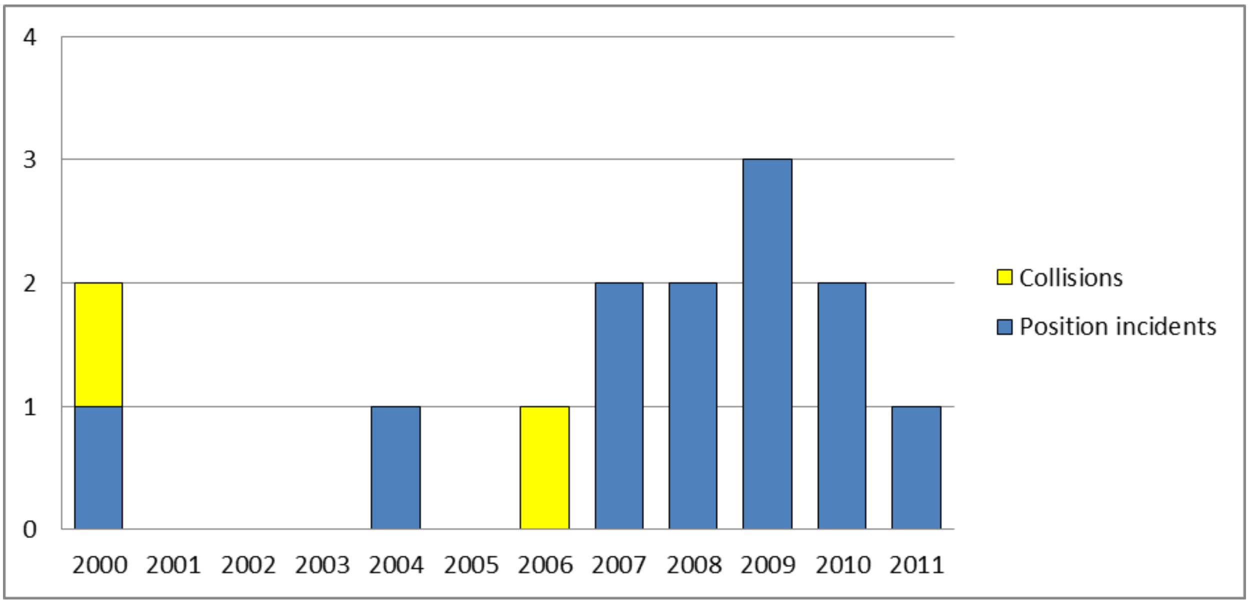


FIGURE 31 - COLLISION AND POSITION INCIDENTS FOR SHUTTLE TANKERS. [89]

The increase over the last five years in the figure is being closely watched by the PSA. The two collisions in the Norwegian sector in this period were [90]:

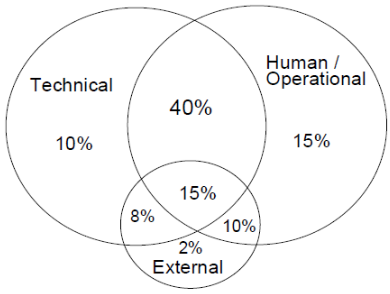
- Knock Sallie collision with Norne FPSO in 2000
- Navion Hispania collision with Njord B FSU on November 13th 2006

Chen [85] has listed five collision incidents between FPSO/FSU and DP ST in the North Sea (not just the Norwegian sector) in the period 1996 to 2000. DP ST offloading in tandem is, as mentioned, per today the preferred way of offloading in the Barents Sea. DP is used more and more, and fewer manual operations are conducted. A large part of the incidents between ships and installations have been caused by technical failures or erroneous use of the DP-system.

In the HSE report *Operational safety of FPSOs shuttle tanker collision risk* [91] a comparison between the risk influencing factors (RIFs) that cause collision (based on 19 incidents) is presented, as shown in the table below:

TABLE 9 - RANKING OF RIF GROUP COMBINATIONS (EXPERT JUDGEMENTS)[91]

RIF group / RIF group combination	*Ranking*	*Contribution*
1. Technical dep. alone	4	10 %
2. Human/Operational dep. alone	2	15 %
3. External conditions alone	7	2 %
4. Technical *and* Human/-Operational (in combination)	1	40 %
5. Technical *and* External (in combination)	6	8 %
6. Human/Operational *and* External (in combination)	5	10 %
7. Technical *and* Human/-Operational *and* External (in combination)	3	15 %



As can be observed, the external conditions alone are only accountable for 2 % of the incidents.

4.1.3 RISKS

In the Norwegian Barents Sea, south of Bjørnøya, the conditions are, except for lower temperatures, very comparable to the North Sea. In Barents 2020 Ph.3 [59] the probability of incidents is therefore assumed to be the same for both locations. The following are considered general risks with tandem offloading operations:

- Impact energy
    - Empty ship
    - Fully loaded ship
    - Other ship
- Hose fracture/leakage
- Grounding in transit when fully loaded

The greatest concern that differs from the North Sea is the environmental aspect. Parts of the Barents Sea include more environmentally sensitive areas, and the consequences of a major oil spill could be more severe. The consequence severity varies with the operational phases (1-5 in previous section). Transit fully loaded and during cargo transfer are the two phases (3 and 5, see section 4.1.1) considered most vulnerable. The Barents 2020 report suggests that the frequency of events will be the same in the Barents Sea as in the North Sea.

Disconnection in itself should in general not present any additional difficulties. In the case of an emergency disconnection, some spill may occur. With the "zero discharge" goal, this should however be kept at a minimum. The goal of zero discharge was first presented in Report no 58 (1996-97) to the Norwegian Parliament (Stortinget) [92]. ISO 19904-1:2006 specifically states that a dripless valve should be included in the system [86] (p. 150). Special rules apply for hydrocarbon release in the Barents Sea due to uncertain effects.

4.1.3.1 DRIVE-, AND DRIFT-OFF

For some years, drive and drift-off have been considered to be the greatest dangers in offshore oil and gas operations. With two large masses in close proximity, any form of direct contact can potentially be harmful to people, environment and assets.

This thesis focuses on Barents Sea specific issues. Drive off may not be a specific issue; it is however of such importance that it was deemed fitting to include a short description of how it may occur and what is done to prevent it. Drift off (or force off) may have a greater frequency in the Norwegian Barents Sea. The last comment contradicts the conclusion in [59]; the probability of incidents should be expected to go slightly up.

The collision model[34] has two conditions for a collision to occur:

- Tanker has uncontrolled forward movement (UFM) (Left hand side of Bow Tie)
- Recovery actions initiated fail (from both tanker and FPSO) (Right hand side of Bow Tie)

The collision frequency can thus be given as:

$$P(Collision) = P(UFM_i) \times P(Failure\ of\ recovery \mid UFM_i)$$

In the years from 1996-2000 [85] estimated that each shuttle tanker would experience one collision every ten years. However, with updated and improved procedures and a continuous evolution the frequency will arguably have dropped further.

There are two ways a tanker can move forward;

- Powered condition (Powered forward movement, PFM)
- Drift condition in case of lost power (Drift forward movement, DFM)

DFM is considered to be a low frequency and low consequence event [85]. Tanker blackout is not a frequent event, and the shuttle tanker is required to position itself downstream of the FPSO and thus drift *away*. There are scenarios where the tanker will drift towards the FPSO, however, the speed it can pick up during a 50-80 m distance is limited.

Recovery actions are also usually performed by the tanker, more specifically the DP operator. Time is often too short for the FPSO to do much effort.

Combining the frequency with the above arguments, the collision equation can be rewritten as:

[34] As presented on p.8 in 85. Chen, H., *Probabilistic Evaluation of FPSO-Tanker Collision in Tandem Offloading Operation*, in *Department of Marine Technology*2003, Norwegian University of Science and Technology: Tapir.

$$P(Collision) = P(PFM) \times P(Failure\ of\ tanker\ initiated\ recovery \mid PFM)$$

When looking at this particular risk in a bow tie perspective, there are two stages to the event:

1. Initiation (Left hand side).
    a. How can drift/drive-off forward be prevented?
2. Recovery (Right hand side).
    a. Recovery actions initiated for avoiding collision.

4.1.3.2 POLAR LOWS AND OPERATIONS

Sudden weather changes such as polar lows may occur and force a suspension of the operation. While this may not necessarily cause any particular danger to personnel or equipment; it may cause unwanted downtime, small spills in the disconnection and worst case; drift off.

Polar lows may necessitate disconnection, and another challenge could be incorrect forecasts; causing an unnecessary precautionary disconnection.

4.1.3.3 VISIBILITY

With the operation metocean limitations (see chapter 4.1.5), visibility may fall below the requirements. This could be dangerous for the operation, and in rare cases it could lead to collision.

4.1.3.4 ICING

Icing may be an issue for these types of operations, as mentioned in chapter 2.2.1. Particularly atmospheric icing is interesting as it may affect antenna and communications equipment. Sea spray icing should not be a big problem for vessels of this size (when stability is the only issue); however, the amount of ice accumulated could lead to a situation where the ST must disconnect before it is fully loaded. Ships that will operate in the area are required to have de-icing systems. The effectiveness of these systems was not made available at the time of writing.

4.1.4 BOW TIE ANALYSIS – OFFLOADING

In the HSE report *Operational safety of FPSOs shuttle tanker collision risk* [91], a influence diagram of collision risk between shuttle tanker and FPSO is presented. This diagram is an extended version of the bow tie shown in this section. [91] is a thorough analysis of all aspects regarding collision risk and is one of the main sources for this chapter. The focus in this thesis will be limited to the Barents Sea specific factors. The main influencing factors that may cause a collision are the same in this thesis as in [91]. Two of the branches will not be investigated in much detail in this thesis, unless related to the third; external conditions.

The main undesired event selected for this analysis was losing control of the shuttle tanker, a *drift/drive-off event*. An additional fault tree was made for the event *undesirable disconnection.* This was included because a disconnection during offloading may cause one or more of the following:

- Small oil spill
- Lost time incidents
- Increased risk due to large mass moving in close proximity to the FPSO
- Increased risk to workers performing manual labour

The bow tie will as mentioned focus on preventing a loss of control of the ST due to metocean conditions, and discuss what needs to be in place in order the avoid a collision in the event of a loss of control incident. This will also include some general aspects regarding DP systems. As stated; rapid changes in weather or currents and waves may move the vessel sufficiently for the ship to drift off its position. In addition DP systems are the number one cause for alarm in most articles regarding the subject.

4.1.4.1 DRIVE/DRIFT-OFF SCENARIO

The main differences between the Norwegian Barents Sea and the rest of the Norwegian Continental Shelf are of concern. General issues are thus related to weather and light. Manual work will also be necessary to some degree and human/operational error are accordingly of importance. The left hand side of the bow tie shown in figure 35 is a simple representation of the factors that may result in a drift/drive-off and further; a possible collision.

Weather and ice are the main differences from the rest of the Norwegian Continental Shelf. Sea ice and ice bergs are not considered to be a threat in this thesis, as there is no occurring ice in the area of interest; icing is however an issue.

An overview of the bow tie that was developed is shown below:

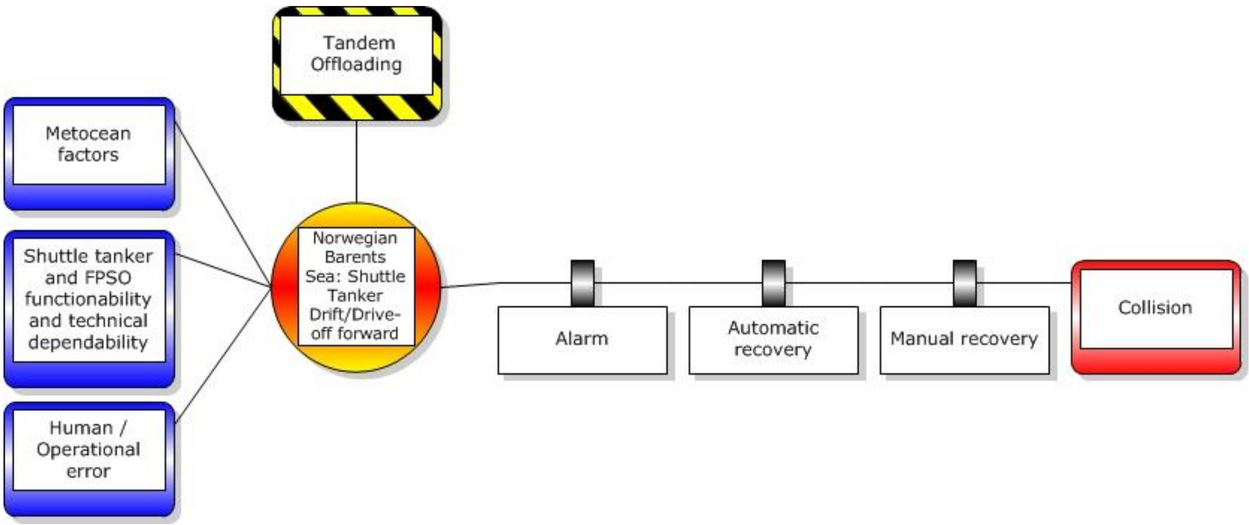


FIGURE 32 - BOW TIE OFFLOADING, DRIFT/DRIVE-OFF OVERVIEW

The unwanted event was collision, and in order to avoid a collision, three barrier systems were included:

1. Alarm
2. Automatic recovery
3. Manual recovery

There are two elements necessary for avoiding a collision; knowing you are out of position and to be able to recover. To be able to recover was split in two, due to the technical and human/operational aspects.

The threats that could cause a drive-off are not discussed in detail here. There is nothing indicating an increased risk for drive off in the Norwegian Barents Sea compared to the rest of the Norwegian Continental Shelf. For drift-off, the metocean factors are important. Some of the main sources used in this thesis were [85, 91, 93].

4.1.4.1.1 ALARM

Alarm represents a technical response to an out of position situation. There was one main performance shaping factor this barrier system:

- No alarm

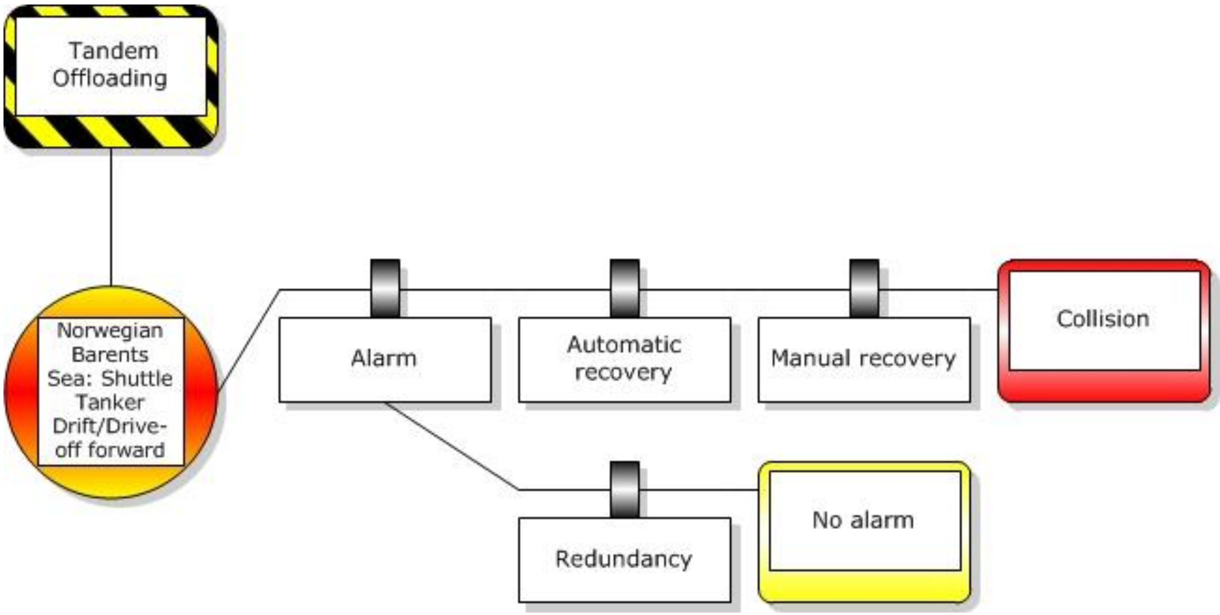


FIGURE 33 - BOW TIE OFFLOADING, ALARM

It was seen as outside the scope of this thesis to discuss in detail the technical systems used. If the alarm malfunctions in some way it will take longer for the DP operator and crew to realise what is going on. Having redundancy in a 1oo2 system, or perhaps even better; 2oo3 would be desirable. 1oo2 simply means that *one out of two* alarms must go off for the actual alarm to go off. The 2oo3 system eliminates the number of false alarms by requiring at least two out of three alarms to go off.

4.1.4.1.2 AUTOMATIC RECOVERY

Once the alarm goes off, an automatic recovery process should commence. Automatic recovery involves the DP system making corrections to the shuttle tankers position. The main performance shaping factor here was:

- Failure of the DP system.

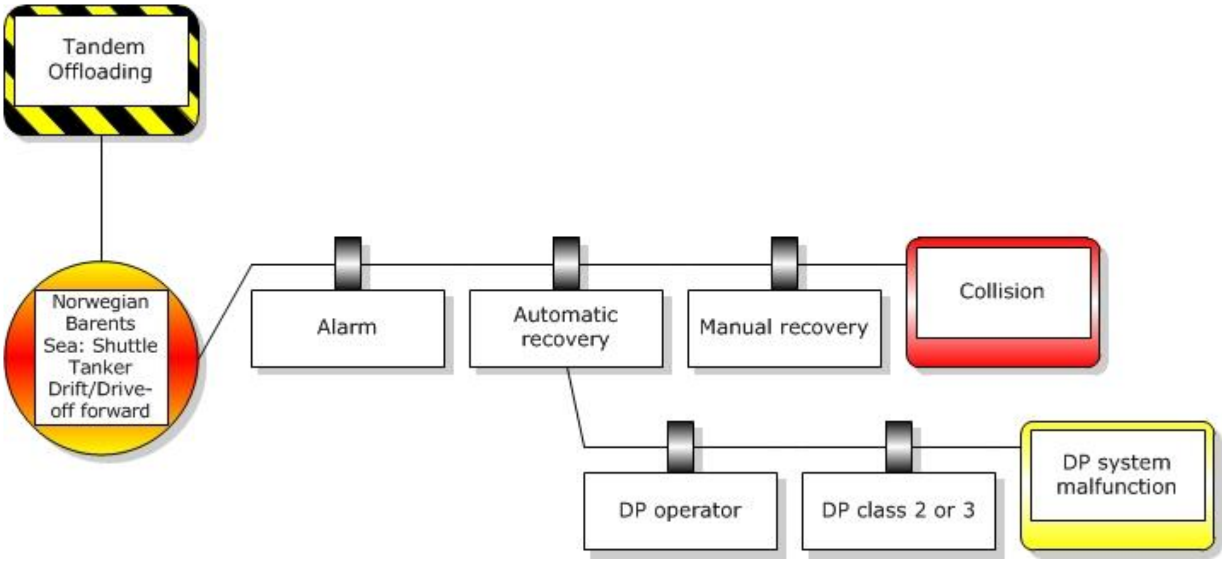


FIGURE 34 - BOW TIE OFFLOADING, AUTOMATIC RECOVERY

The two barrier elements selected were having a DP class 2 or 3 and the DP operator. DP class 2 or higher is a requirement. The automatic systems (if functioning) are assumed to respond immediately, and for this option there is no particular need for a heading off set from the FPSO or increasing distance between the ST and the FPSO. Should the DP system fail, manual recovery is the next option.

4.1.4.1.3 MANUAL RECOVERY

Manual recovery is the final barrier between a drift/drive-off and a collision. The three main performance shaping factors for manual recovery were:

- DP operator performance
- Heading towards FPSO
- Damage hose

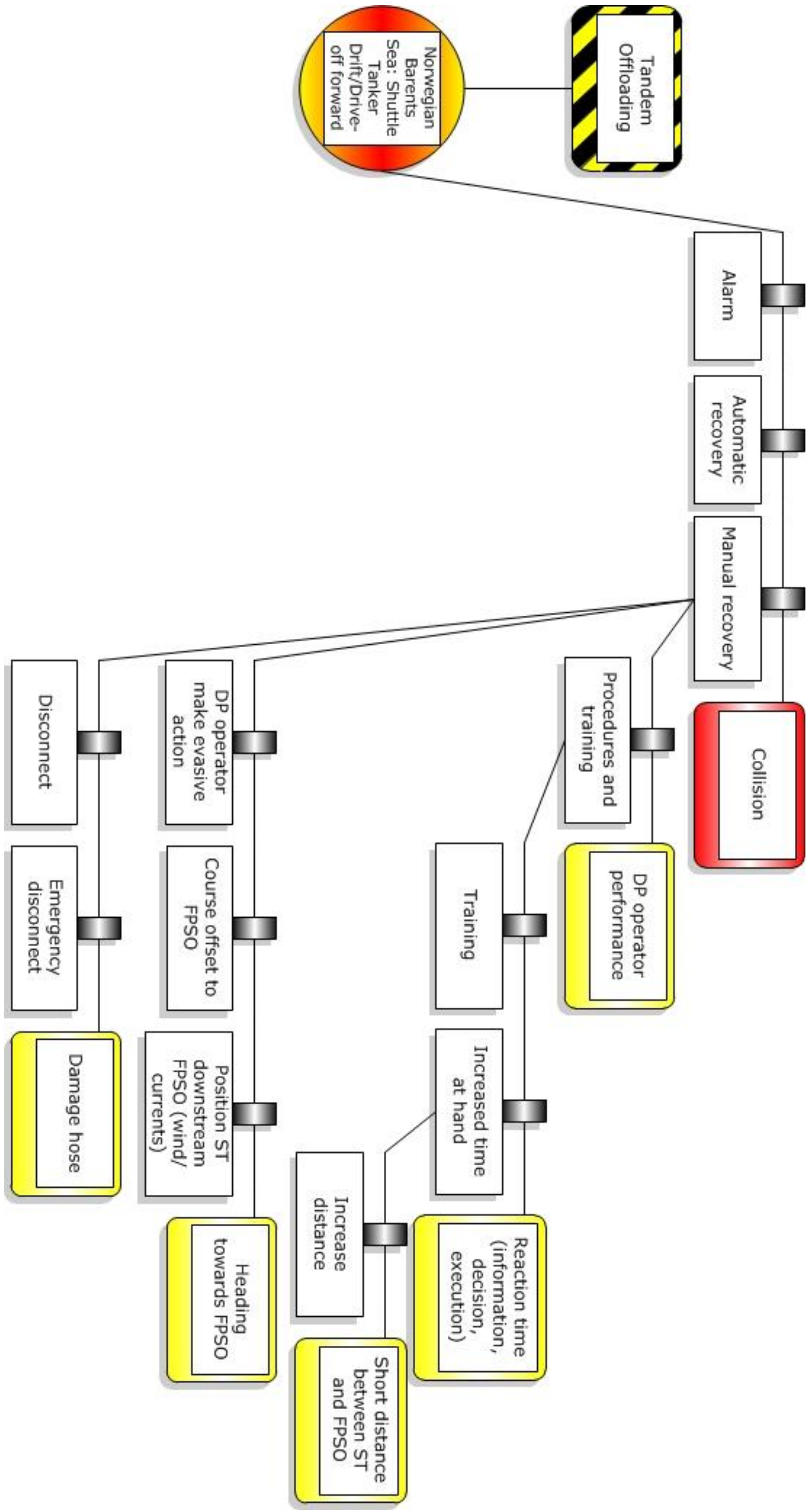


FIGURE 35 - MANUAL RECOVERY

Some of these elements are not Barents Sea specific, however due to the increased risk in the Barents Sea they will be discussed briefly.

DP operator performance

Procedures and training are the two main influencing barrier elements. Being familiar with the situation and knowing what to do will greatly increase the chance of a successful recovery. An issue here is the reaction time. The reaction time can be divided into three stages; information, decision and action. Knowing what and how to do it will greatly assist here.

Another option is to increase the time the DP operator has to react. The most efficient way to do this would be to increase the distance between the ST and the FPSO.

Heading towards FPSO

Heading towards the FPSO is a requirement for having a collision risk. There were three main barrier elements:

- Course offset to FPSO
- Position ST downstream FPSO (wind/currents)
- DP operator make evasive action

Having a course offset to the FPSO is looking to gradually become the standard for tandem offloading operations [94].

Damage Hose

Damage to the hose is a risk when the conditions deteriorate. This risk has not been looked into in particular in this thesis. It will be of importance regarding environmental issues, where small spills may occur if a disconnection is unsuccessful. Disconnection or an emergency disconnect will handle the threat of breaking the hose, however small spills may occur in emergency disconnection situations. The breaking of the hose in itself should not be a great safety issue, but will cause downtime for the FPSO and cause minor spills, violating the “zero discharge” policy. Any further spill should be handled by valves on both the FPSO and the ST.

4.1.4.2 UNDESIRABLE DISCONNECTION SCENARIO

With the rapid weather changes that occur in the Barents Sea, undesirable disconnections may be required. An undesirable disconnection is not necessarily a dangerous operation, but it will represent an added cost for the operation as a result of time spent not offloading. Also, leaks and minor spills are closely linked to the number of connections and disconnections. Due to the many uncertainty factors involved, precautionary disconnections may occur. Although it is rational to be safe rather than sorry; unnecessary disconnections should be kept to a minimum. An overview of the threats and potential consequences is given below.

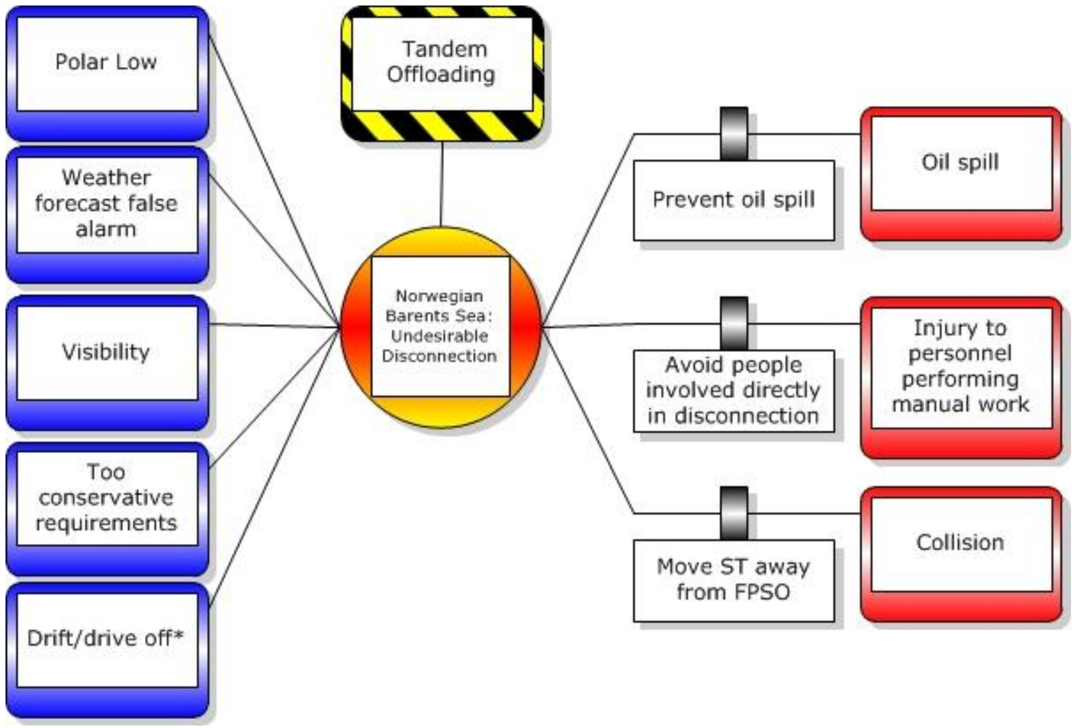


FIGURE 36 - BOW TIE OFFLOADING, UNDESRIBALE DISCONNECTION, OVERVIEW

There were three unwanted consequences selected for this scenario, in addition to the overall negative impact of a lost time incident.

- Oil spill
- Injury to personnel performing manual work
- Collision

4.1.4.2.1 OIL SPILL

Oil spill may occur in a disconnection. There was one main performance shaping factor here, as shown in the figure below, in addition to a sub-performance shaping factor:

- Small oil spill possible
- Emergency Quick Disconnect (EQD)

Oil spills in the high north are considered more serious events than in the south, and the Norwegian government has, as discussed in previous chapters, established a "zero" spill tolerance level.

The first barrier element is to empty the hose. In the case where an EQD will be necessary, no spill valves are needed in order to avoid or limit any spill.

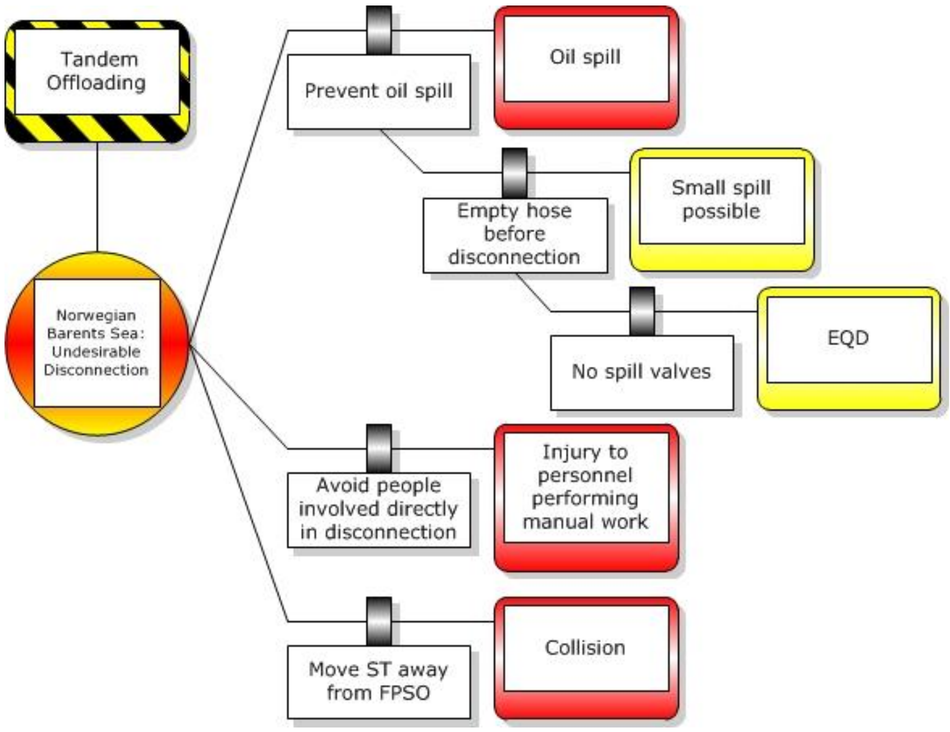


FIGURE 37 - BOW TIE OFFLOADING, UNDESIRABLE DISCONNECTION, OIL SPILL

4.1.4.2.2 INJURY TO PERSONNEL PERFORMING MANUAL WORK

As presented in the figure below, the personnel performing manual work will be vulnerable, especially in an emergency. A simple solution to this is to make the disconnection fully automatic, and thus avoiding people involved directly in the disconnection. Manual work should only be required if the automatic system is not functioning as intended.

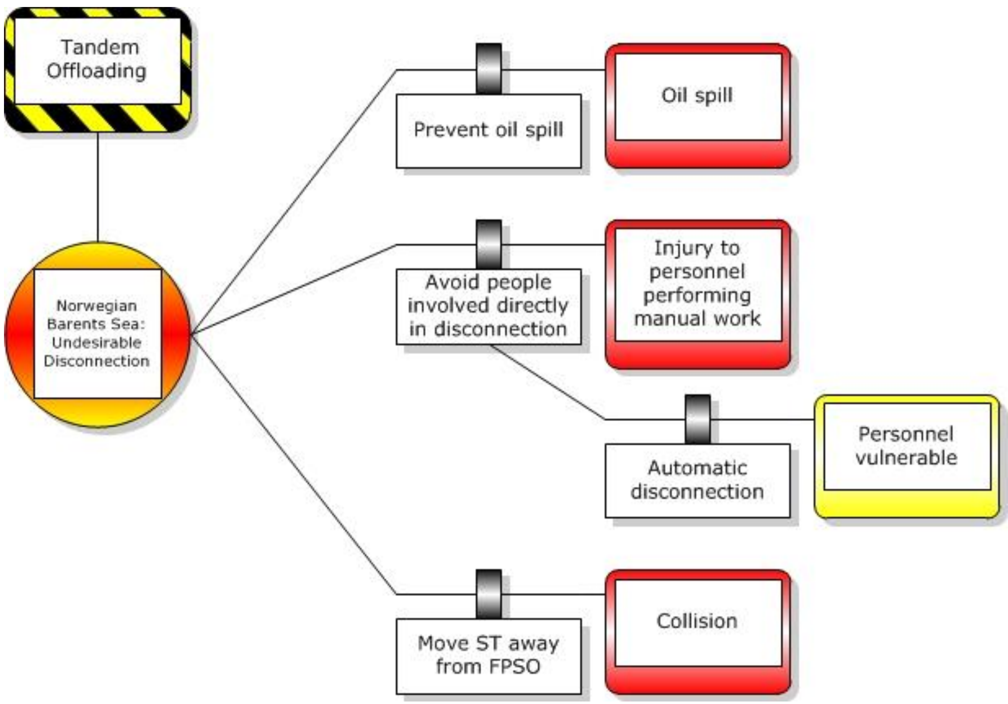


FIGURE 38 - BOW TIE OFFLOADING, UNDESIRABLE DISCONNECTION, INJURY TO PERSONNEL PERFORMING MANUAL WORK

4.1.4.2.3 COLLISION

After disconnecting, two large masses are operating very close to each other. The possibility of having a collision is plausible; however not very probable.

4.1.4.3 THREATS

The threats that may lead to an undesired disconnection are, as displayed in figure 39:

- Polar low
- Weather forecast false alarm
- Visibility
- Too conservative requirements
- Drift/drive off*

Polar lows are discussed in detail in chapter 2.2.3 and will only be briefly discussed here. For drift/drive off, see chapter 4.1.3.1.

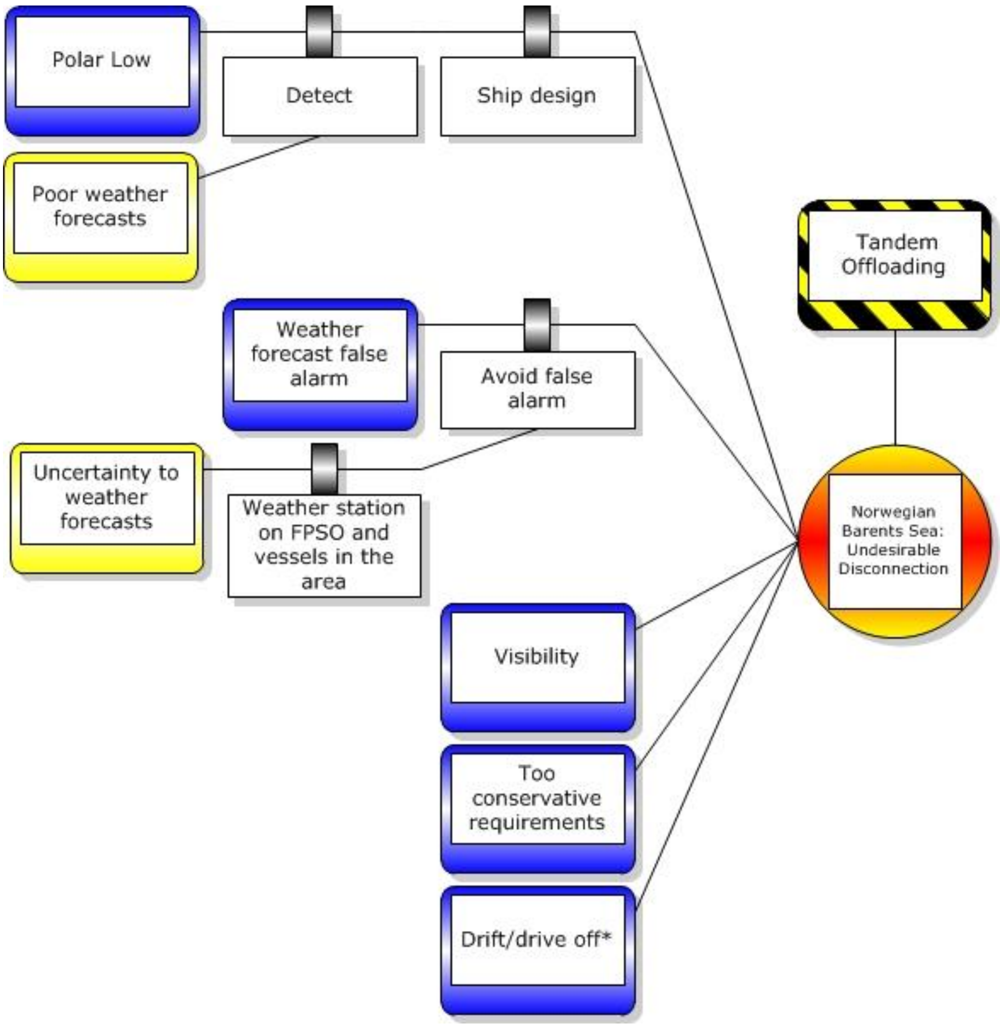


FIGURE 39 - THREATS THAT MAY CAUSE AN UNDESIRABLE DISCONNECTION

4.1.4.3.1 POLAR LOW

Polar lows were discussed in detail in previous chapters. The main barrier functions dealing with this threat were

- Detection
- Ship design

Detection has been discussed in the same chapters as polar lows; ship design has not been discussed in detail. STs and FPSOs have vessel specific limitations. Using vessels that can handle the conditions the best is favourable.

4.1.4.3.2 WEATHER FORECAST FALSE ALARM

As has been discussed, weather forecasts are uncertain. If a polar low is predicted, the ST cannot commence offloading, or should abort operation. This threat is also relevant for the case of *not* predicting a polar low.

4.1.4.3.3 VISIBILITY

Visibility is an issue, as will be discussed in chapter 4.1.5. If fog is forming or heavy snow is falling, visibility may fall below the minimum (see table in chapter 4.1.5). It has not been the aim of this thesis to suggest solutions to this problem; however, the use of radar, laser measurements and other equipment will assist in "blind" conditions; however it is not permitted at this point. In the aviation industry transponder based systems are used in blind conditions and provide the option of triangulating the position of the aircraft and thus accurate positioning. This is in use in the offshore industry as well, but the requirements for offloading require visual contact. Developing such a system in the area may positively affect positioning close to installations.

4.1.4.3.4 TOO CONSERVATIVE REQUIREMENTS

Too conservative requirements illustrate the issue with making the requirements. This is more of a comment than a complete discussion. The requirements must be strict enough, yet not strangle the industry. In the case of the Norwegian Barents Sea, uncertainty may cause regulators to set the bar too high. This may in turn make safe operations unfeasible.

4.1.5 METOCEAN LIMITATIONS

Tandem offloading is a weather critical operation. The operation can last up to 24 hours depending on the equipment being used, and polar lows may develop during this period. A key aspect for tandem offloading is thus how often it will be necessary to postpone or abort the operation for an unknown period of time due to sudden changes in the conditions?

ISO 19904-1:2006 provide the UKOOA Tandem Loading Guidelines [93] for guidance on tandem loading operations. The weather limits presented are as follows[35]:

[35] These values are typical maximums. Limits may be installation-, and vessel specific.

TABLE 10 - METOCEAN LIMITATIONS, TANDEM OFFLOADING

Safe Tanker Approach Limits	The offtake tanker should normally only approach within 3 nm provided the wind speed, H_S, visibility, and FPSO/FSU motions and yaw are within safe limits. Typical values for DP tankers are: • 10 min mean wind < 40 knots • H_S < 4,5 m • Visibility > 500 m • FPSO/FSU heading stable (±5°)
Safe Tanker Offtake Limits	The tanker should normally only continue offtake provided the wind speed, H_S, visibility, and FPSO/FSU motions are within safe limits. Typical values for DP tankers are: • 10 min mean wind < 50 knots • H_S < 5,5 m • Visibility > 100 m

Rapid changes in weather along with more conservative forecasts may be one of the greatest differences between the Barents Sea and the North Sea. Should the forecast predict weather worse than the limits, the shuttle tanker will be required to disconnect. False alarms may be frequent due to the limited weather data available.

Also the rapid development of polar lows may present problems for the operation, as it will probably be necessary to abort the operation for an unknown period of time. The information that was available during the writing of this thesis has not indicated that the development of polar lows will be a problem with regards to disconnection, unless grossly misjudged by the involved parties. The main issue found was again that the operation must be postponed.

4.1.5.1 METOECAN DATA

After researching several reports from the Norwegian Meteorological Institute (NMI) and through discussions with members of NMI, some weather features relevant for the operation was obtained.

Using wave charts from [95] and plotting trend lines it was found that the approximate area of interest would have the following percentage of H_S as follows:

TABLE 11 - PERCENTAGE OF TIME WITH SIGNIFICANT WAVE HEIGHTS GREATER THAN; 2, 3, 4 AND 4,5 M.

H_S [m]	2	3	4	4,5[36]
January	75	45	25	11,1
July	14	2	1	0,1

4,5 m was selected because it represents the general limit for connection in a tandem offloading scenario.

[36] Calculated values using exponential trend lines in excel. For January; $H_s(\%) = 131.58e^{-0.549Hs}$, and for July; $42.512e^{-1.32Hs}$.

Using visibility data, also from [95], relevant for Bjørnøya, and thus not necessarily applicable for the whole area of interest, the following data was obtained.

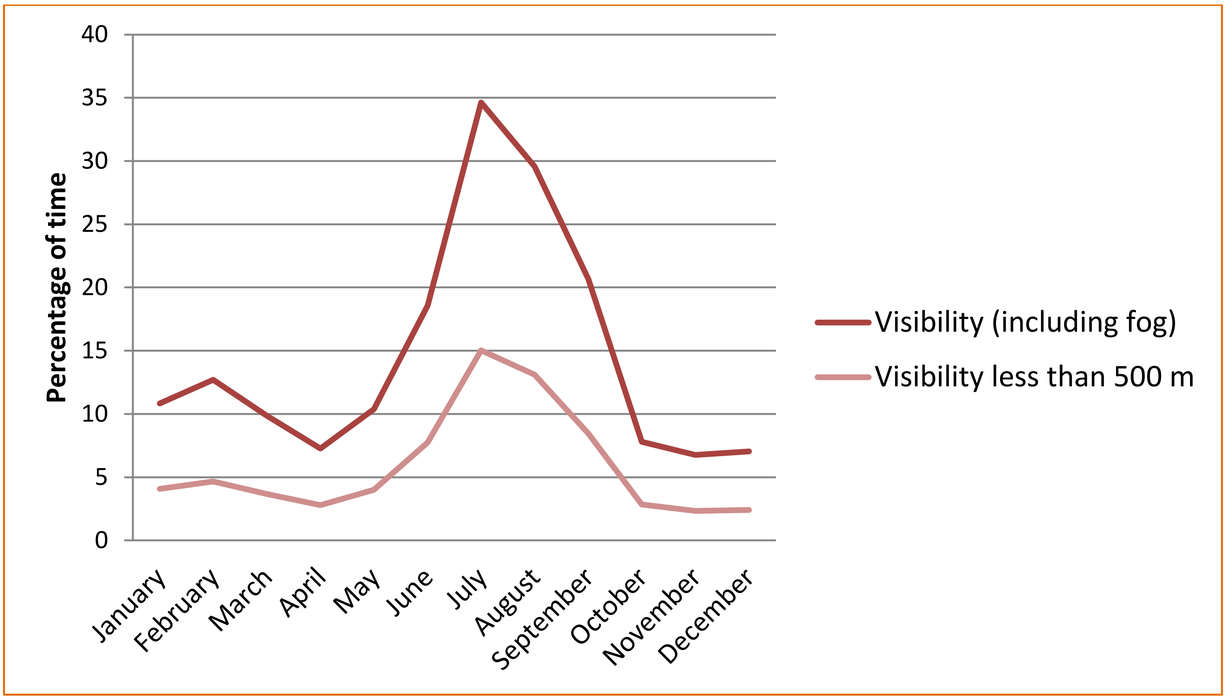


FIGURE 40 - VISIBILITY DATA FOR BJØRNØYA

This chart shows the visibility average in the period 1958 – 2010. Fog is defined in [95] to reduce visibility to less than 1000 m. This chart indicates that for approximately 15 % of the time in July, offloading cannot commence.

As mentioned earlier, there is no reason to believe that weather forecasts will be more conservative in the Barents Sea due to uncertainty. The same models are applied; however, the number of observations may provide inaccurate forecasts. Greater activity in the area will no doubt increase accuracy of forecasts.

Wind is also a limiting factor for offloading operations. For the winter of 2012/13, there were a total of 21 forecasts predicting winds of over 40 knots, however none above 50 knots. The observed numbers where three and zero respectively [16].

Darkness in itself has, with the information that was provided, not been recognised as a problem. An FPSO will have sufficient lighting equipment, and even in zero vision conditions, the DP-system will not be affected[37]. The main concern for the offloading operation itself in poor visibility conditions is, as pointed out by [96], the transfer of the messenger line.

[37] It is however still not permitted to approach the FPSO under these conditions.

4.1.6 SUMMARY OF IDENTIFIED BARRIERS

The barriers and barrier elements identified in this chapter are summarised below. The efforts listed below are risk reduction measures, aimed at reducing the frequency of events.

The three main barrier functions for the drive and drift off scenario were:

- Alarm
- Automatic recovery
- Manual recovery

For the case of having an undesirable disconnection, the main undesired consequences were:

- Oil spill
- Injury to personnel performing manual work
- Collision

DP operator performance

Procedures and training are the two main influencing barrier elements. Increase the time the DP operator has to react. The most efficient way to do this would be to increase the distance between the ST and the FPSO.

Heading towards FPSO

Heading and moving towards the FPSO can be avoided in the following three ways:

- Course offset to FPSO
- Position ST downstream FPSO (wind/currents)
- DP operator make evasive action

Oil spill

- Empty the hose
- No spill valves

Injury to personnel performing manual work

It should be a requirement to make the disconnection fully automatic, and thus avoiding people involved directly in the disconnection.

Collision

See heading towards FPSO.

4.1.7 RECOMMENDATIONS – OFFLOADING

The ability to offload quickly is a key issue for offloading operations in the Barents Sea. There are two main reasons for this:

1. Time is money.
2. More importantly; avoiding long operations that may need to abort due to weather deterioration.

Rapid changes in weather can occur in the Barents Sea. Polar lows, currents and other factors may change rapidly. This may both affect the DP-positioning of the ST and cause unwanted delays. Considering new computer systems and computing capacity, DP-systems can only be expected to become better. Rapid changes in weather are therefore not considered to be of great risk when considering DP-systems, except for the one scenario described for flotel in the next chapter.

A general problem with the Barents Sea is, as previously mentioned, shortage of local metocean forecasts. It was once proposed to have meteorologists stationed on installations in the North Sea. This may be appropriate for the Norwegian Barents Sea, until better weather service is available.

FPSO storage volumes vary significantly, and in order to avoid production cutbacks, offloading should be performed well before the tanks are full. This is of particular importance for Norwegian Barents Sea offloading, where winter drafts are a concern.

Typical North Sea ST cargo sizes are 850,000 bbls. Ideally the FPSO should be able to fill the ST in one loading.

In order to avoid any collision events, the ST must:

- Be downstream of FPSO
- Off-centred, avoiding collision course

The distance between the ST and the FPSO should also be increased, as is being done in the case of the Goliat FPSO.

4.1.8 BARENTS SEA REQUIREMENTS: CASE STUDY – GOLIAT

The Goliat FPSO will be the first using tandem offloading as oil off-take solution in the Norwegian Barents Sea. The offloading operation has been given the following requirements and limitations [1]:

- The ST shall during normal operation have a 50 m heading offset to the FPSO.
- Having a heading towards the FPSO is only allowed when the ST changes course from one side of the FPSO to the other.
- Normal operating distance between the ST bow and the FPSO is 250 m.
- Minimum distance between the ST and the FPSO is 150 m.
- Minimum distances between ST bow, manifold and the closest riser and mooring line are 50 and 20 m, respectively.

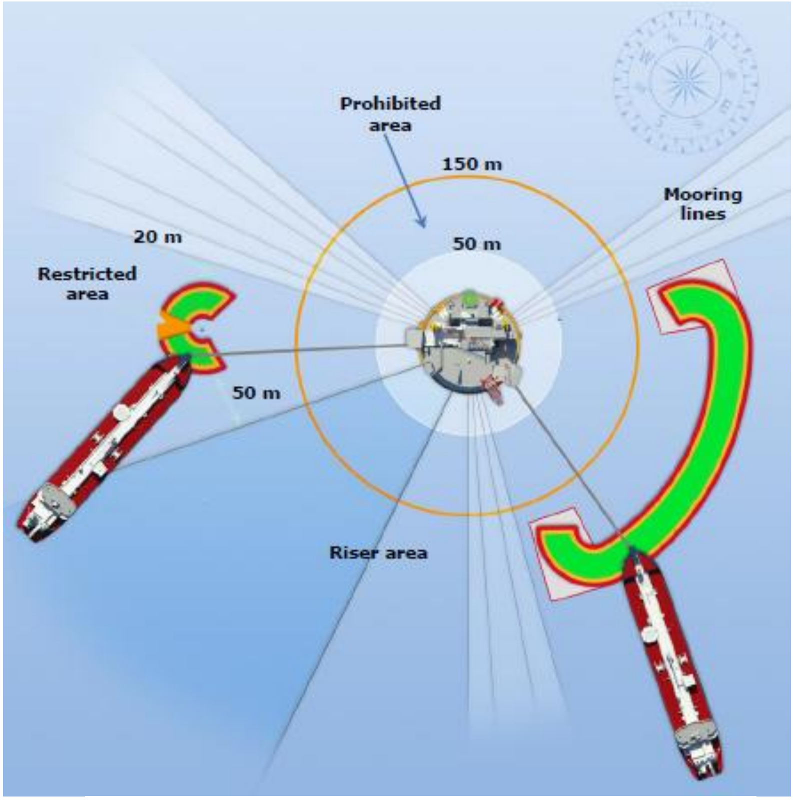


FIGURE 41 - GOLIAT, TANDEM OFFLOADING SET UP [1]

These efforts will, according to [97], reduce collision risk by a factor of 250 compared to traditional tandem offloading. In addition, the shape of the Goliat FPSO is favourable if a collision incident should occur. Unless there is a direct hit (a 0° hit, relative to the FPSO and ST position), the conic shape will cause a glancing hit, diverting much of the collision energy.

4.2 FLOTEL

Flotels (**Flo**ating Ho**tel**s, also written *floatel* or accommodation units[38]) are living quarters for personnel needed for exploration or general operations. In the Norwegian sector the fixed flotels are gradually being phased out due reduced workforce sizes. The flotels are not necessarily floating (for example jack-up flotels), however it is more or less the norm that they are. Today, flotels on the Norwegian Continental Shelf are usually in place when there is extra high activity in the area, typically during exploration or development. With the limited housing capacity in some areas in the high north it should therefore be expected that some use of flotels will be necessary.

The focus for this chapter was limited to drift off of a flotel on DP operation. Drive off could also have been considered, but it was seen as outside the scope of this thesis. No significant differences between the Barents Sea and the rest of the world that could cause a drive off were discovered, and thus drive off was omitted. A third type is known as force-off; which means no failures, but due to sudden change in environmental conditions, thruster capacity is insufficient and the flotel is forced off position. This has been included in drift off.

4.2.1 SCENARIO

A DP flotel is carrying out normal operation; operating on DP downstream from the installation, at a distance of 38,5 metres. A sudden 180° shift in wind direction and strength occurs (could be due to the sudden formation of a polar low).

Due to limited data on events involving flotels (see next section), this chapter will investigate the scenario above based on known performance of DP flotels.

It was also considered using a rapid change in current and wave direction as the scenario. The similarities between the scenarios lead to the choosing of one. It was seen as more probable to have such a rapid change in wind (also known as shear), in addition to wind being the dominating factor for flotel speed in a drift-off situation.

There are some similarities between the use of flotels and tandem offloading; the main one being station-keeping. Many if these issues where covered in the previous chapter on offloading operations.

4.2.2 DATA

It proved very difficult to find any useful data on flotel operations. In a study performed by DNV for HSE UK it was written on accident statistics regarding accommodation units that; *several potential sources for such information were consulted with no success. It was concluded that if such data was to be obtained, extensive manual work had to be performed. Hence no exposure data for accommodation units was obtained within the scope of this study. This implies that no accident and incident frequencies for these units are calculated in this report.*[98]

[38] There are many different names used, the main ones being; accommodation unit, flotel or floatel. Flotel is used in this thesis.

The metocean conditions are the main risk for this kind of drift of. A drift off can basically happen in two ways:

- DP malfunction or blackout. The thrusters are not delivering enough power to maintain position.
- Conditions change too fast or beyond thruster capacity, causing the DP system to be unable to compensate.

Given a drift off incident, collision risk is dependent on the flotel drift-direction. The shortest distance between the flotel and the installation will be along the gangway axis, approximately 38,5 meters. Should the direction deviate from the gangway axis, but still be within a sector leading to a collision, the distance will be greater. The flotel speed at a collision depends on wind and wave conditions. In a DNV analysis it was estimated that control after a drift off towards the installation would only be successful in approximately 10% of the incidents.

In order to perform some simple calculations, a flotel was selected as a model[39]. In the analysis, the flotel runs on DP mode.

A method provided by DNV regarding flotel drive and drift off has been used in this chapter. Using the method, DNV performed simulations in order to perform a quantitative analysis. They made the following remarks regarding some key aspects of the drift off:

- The probability of preventing a collision in the drift off scenario was found to be 0,1.
- Wind was the dominant factor for flotel speed in the drift off.

While this analysis was for a specific rig some interesting general points can be found. The relationship between wind speed and flotel speed was as follows:

TABLE 12 - RELATIONSHIP BETWEEN WIND SPEED AND FLOTEL SPEED

Wind [m/s]	Speed [m/s]
0-3	0,14
3-7	0,44
7-11	0,79
11-13	1,00
13-16	1,26
16-18	1,52
18-20	1,74

This relationship is almost linear, as shown in the figure below. A polar low with gale force winds may then cause a flotel speed of around 1,7 m/s (3,3 knots).

[39] The flotel used for general data here is the Prosafe newbuild *Safe Boreas.* http://www.prosafe.com/new-build-1-safe-boreas/category986.html

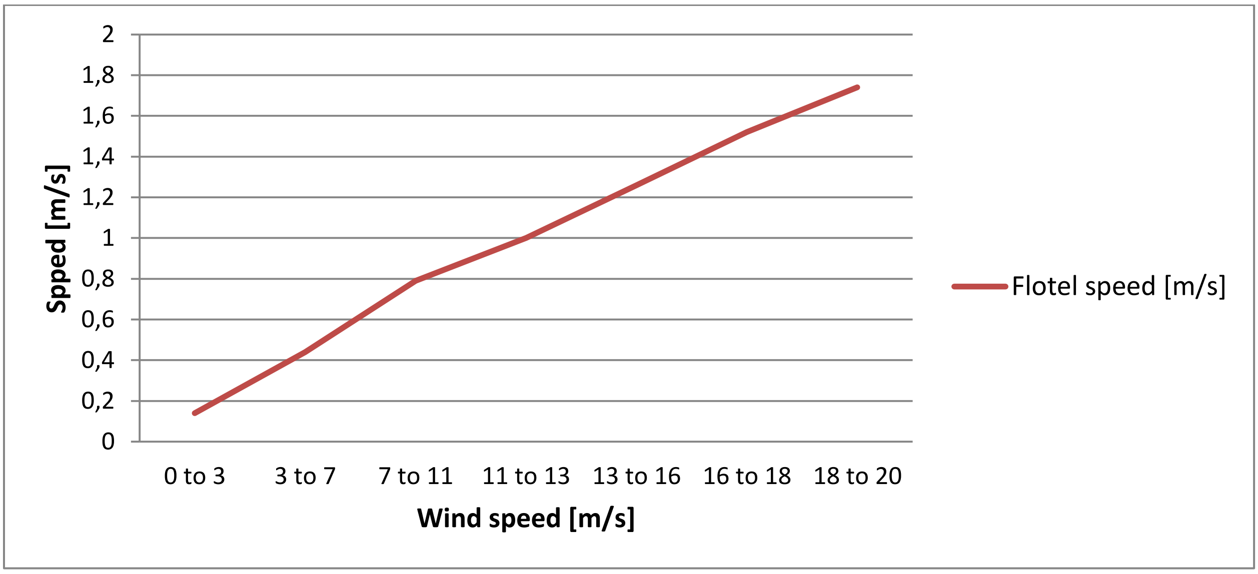


FIGURE 42 - RELATIONSHIP BETWEEN WIND SPEED AND DRIFT OFF SPEED FOR FLOTEL

Using these results it is possible to find a rough estimate for how much time it will take from the drift off begins until contact with the installation is made. Knowing the terminal velocity, the initial displacement and the total distance that must be travelled, the time available for evasive action can be calculated using the SUVAT-equations[40]. Using equation 4:

$$v^2 = u^2 + 2as$$

where *v* represents terminal velocity, *u* is the initial velocity, *a* is the acceleration and *s* the distance travelled, a can be found. Knowing all, except a, using v=1,7 m/s and s=40 metres, a can be found as:

$$v^2 = u^2 + 2as \rightarrow a = \frac{v^2}{2s} = \frac{1,7^2}{2*40} = 0,036\frac{m}{s^2}$$

Using this in

$$v = u + at$$

gives t=47 s. This rough estimate gives the DP operator 47 seconds to react and stop the flotel once it is moving. This calculation gives a too short time window than what can be expected to be realistic. It will take some time from the polar low strikes the flotel until it begins moving. Also, the acceleration will not be linear.

A case that was found was one from NPD. It identified an incident involving a dynamically-positioned flotel working in the Troll field and uncovered an issue with the DP-system and updating of information. The DP-system updated every 20 minutes; then a rapid change in current occurred, so that the flotel DP system was unable to maintain its position. The Flotel fortunately drifted away from the platform and no one was on the gangway at the time of the incident.

[40] These are all based on linear models and the numbers will therefore be of a conservative nature.

There was no data available to predict the probability of having a collision between a flotel and an installation. However, considering the necessary prerequisites and the event causing a drift off towards the installation, the probability of a collision occurring is expected to be very small.

4.2.2.1 PROBABILITY OF HAVING A COLLISION COURSE

Using the method provided by DNV the probability of having a collision can be calculated. Here, only the method will be described.

The probability of being on a collision course depends on the flotel position, in combination with wind and wave direction. Five alternative flotel positions relative to the installation are presented in the figure below.

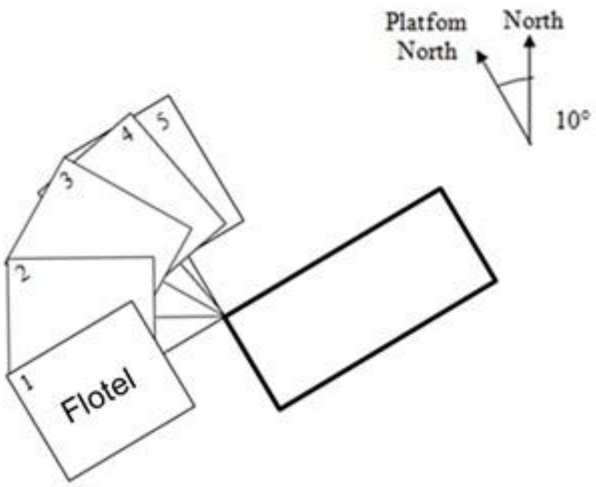


FIGURE 43 - FLOTEL POSITIONS RELATIVE TO INSTALLATION

The various positions have specific sea state limitations for when the flotel can remain connected to the installation. These are presented in figure 53. For significant wave heights over 7 meters, the flotel must move away from the installation regardless of position and wind direction.

Based on historical weather data for wind direction and wave height, the probability for having the flotel in a certain position can be calculated.

For each one of these positions the probability of the flotel drifting towards the installation can be evaluated. The DNV method uses the wind direction as a basis. Because the flotel position depends on wind direction, only certain wind directions are considered[41]. In the DNV method, each of the discrete wind directions are assumed to represent all wind directions within a sector of 30° (±15°). The probability within these circle sectors are assumed to be evenly distributed.

For each position, given the wind direction, the probability of having a collision is equal to the part of the circle sector that overlaps with the circle sector for possible collision in the figure below. The possible collision sector is also shown in figure 53.

[41] This does not completely satisfy the described scenario for this chapter, where the wind direction shifts 180°.

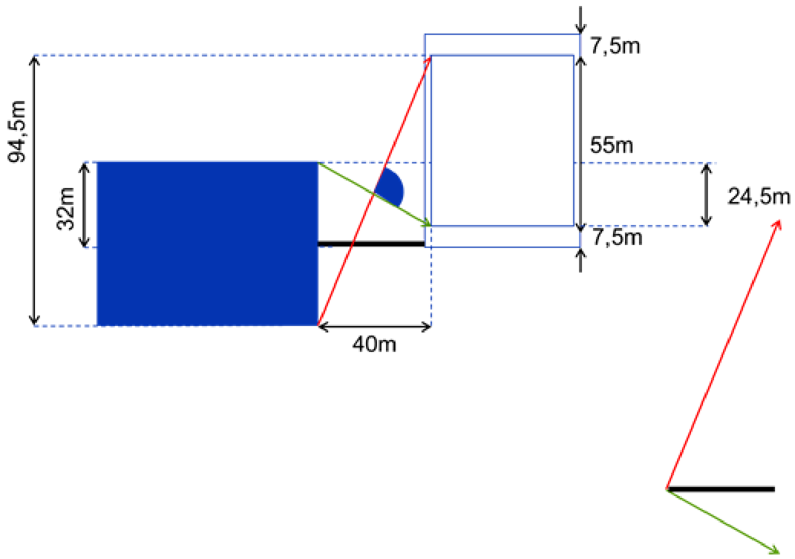


FIGURE 44 - FLOTEL POSSIBLE COLLISION SECTOR

4.2.2.2 PROBABILITY OF DP OPERATOR INTERVENTION

The probability for a DP operator intervention will increase with the duration of the drift off. This is logical because time available to make an intervention increases. In the model provided by DNV, the time to intervention was estimated using the SPAR-H method and a HRA workshop. The numbers used are uncertain, but they give a good foundation for understanding the intervention process. The results from the model are presented below.

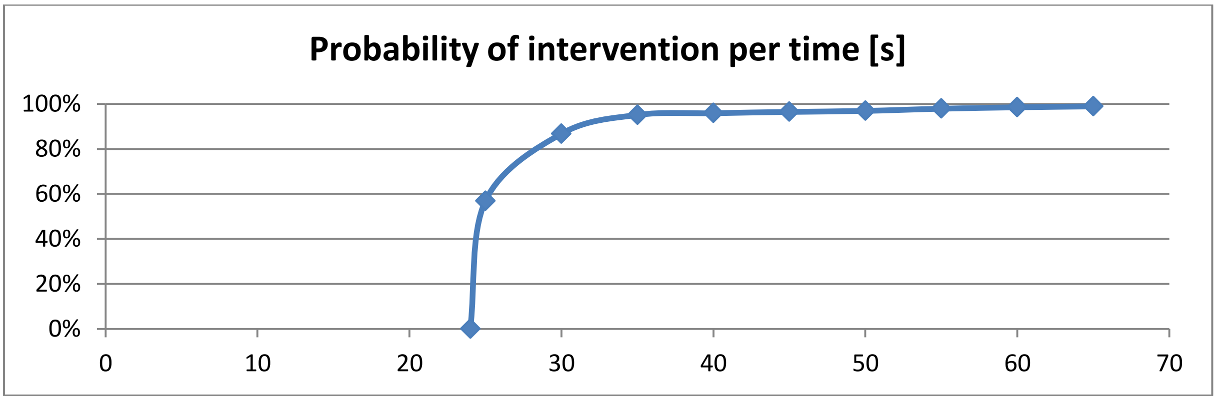


FIGURE 45 - FLOTEL DRIFT OFF, PROBABILITY OF INTERVENTION

This figure represents a specific case and is not necessarily representative for other cases. These figures may also be very optimistic. In [91] it was found that recovery actions in ST drive off situations that did not lead to contact occurred after approximately 40 seconds. In interviews with 10 captains and 7 DP officers, it was concluded that about 60 seconds would be necessary. The rapid rise in the graph above at around 25 seconds may therefore not hold.

This graph shape makes intuitive sense, because the probability of an intervention will be zero until a certain point. This point is considered the necessary time required to understand and intervene.

4.2.3 EVENT TREE DP FLOTELL

The main cause of drift-off events is loss of engine power. As mentioned in the introduction drift- and force-off have been included in drift-off. No indicators were found during the research indicating that moving north will cause an increase in engine failure. Therefore, only the case of weather change beyond the capacity of the flotel DP system has been considered here.

For the specific event of a DP flotel being in the path of a polar low, the event tree in figure 49 was established. For any sudden change in the environmental conditions, a DP system should be able to handle them[42]. However in the case of a polar low; the increase in wind and waves could be higher than the DP capability. In this case, a drift off towards the installation could occur. Also, a DP flotel often lie in position using reduced thruster capacity (e.g. 20% - 50%). This is a barrier that, in the case of a drive off, would limit the impact energy and also give the DP operator more time to handle the situation. It is possible that this may contribute negatively to station-keeping should a polar low occur.

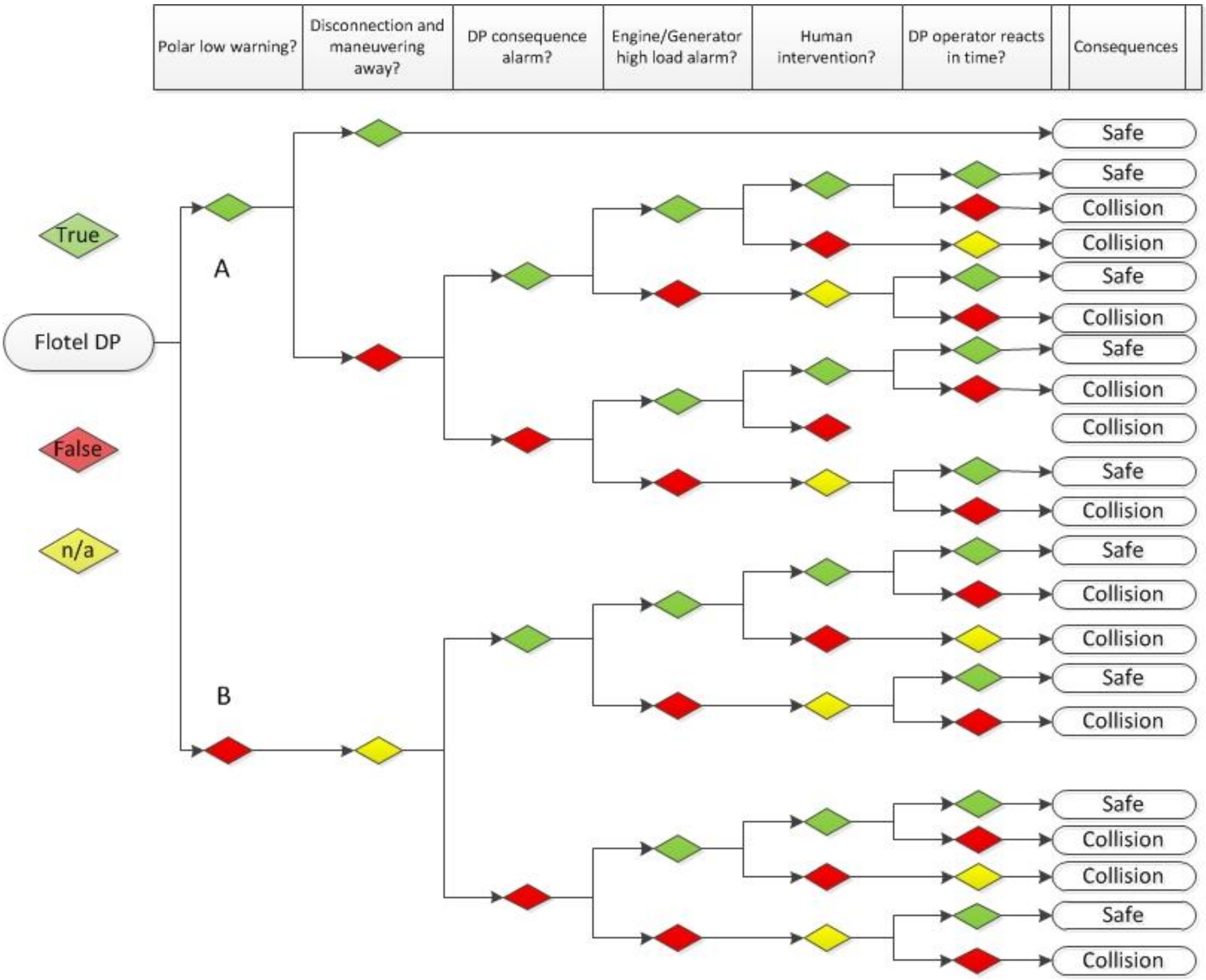


FIGURE 46 - EVENT TREE FLOTEL DRIFT OFF

42 DP3 seems to be the preferred set up on new builds.

The sequence in the event tree was developed after consulting [99]. There are two main consequences; collision or “safe”. Safe here means *no collision* and thus includes the option of near miss.

There are two main paths for this sequence of event;

A. Polar low warning
B. No polar low warning

The two branches have similar developments after this, the only big difference being the option of disconnecting.

If the flotel is disconnected and moved to a safe place, nothing further happens. If the flotel is not disconnected, the sequence of events is to a certain degree the same, with one exception that is not reflected in the qualitative event tree above; knowing that a polar low is developing. This should result in a higher probability for human intervention in time. If the polar low strikes practically without warning, this probability of successful intervention should presumably be lower.

DP consequence alarm should give an alarm once the environmental forces are either deemed or calculated to be over what the flotel can sustain. When this alarm rings, and various high load alarms from engines, generators and thrusters rings; human intervention is required. Human intervention could then simply be to steer the flotel away from the installation. All these elements could happen during the weather change phase as the polar low approaches. As mentioned in chapter 2.2.3, weather forecasting is now able to detect most polar lows 6-12 hours prior to occurrence. This means that it is highly unlikely that the flotel and the installation will be taken completely off guard.

Should the polar low for some reason remain undetected the DP operator’s ability to react in time is perhaps most critical element. If the DP operator did not detect this situation during build up, or reacts far too late, as in when polar low strikes the vessel in full force from the most unfavourable direction, the consequence will be a drift-off and collision.

4.2.4 EXAMPLE CALCULATION OF IMPACT ENERGY

Using a simple 1 DOF[43] model [100], the available energy and the energy to be absorbed can be calculated using basic formulas.

The available energy from the moving flotel can be expressed by:

$$E_{available} = \frac{1}{2} m v^2$$

Looking at the external dynamics of a 1 DOF system;

[43] DOF – Degrees Of Freedom

FIGURE 47 - EXTERNAL DYNAMICS, 1 DOF SYSTEM

This is a "perfect" impact and thus not very likely to occur; however it gives a conservative worst case figure. In water, added mass[44] and other factors will also play a part in these calculations.

The law of momentum conservation further states that:

$$M_A u_A = (M_A + M_B) v_{common}$$

$$v_{common} = \frac{M_A}{M_A + M_B} u_A$$

The energy that must be absorbed in the collision is thus:

$$E = \frac{M_A u_A^2}{2} - \frac{(M_A + M_B) v_{common}^2}{2} = \frac{1}{2} \frac{M_A M_B}{M_A + M_B} u_A^2$$

If we then use speed ranging from 0 to 2 m/s and the operation displacement of a SSAU 4000NG design flotel[45] of 26 800 Mt, and the Goliat FPSO operation displacement of 210 000 Mt, the available impact energy can be calculated.

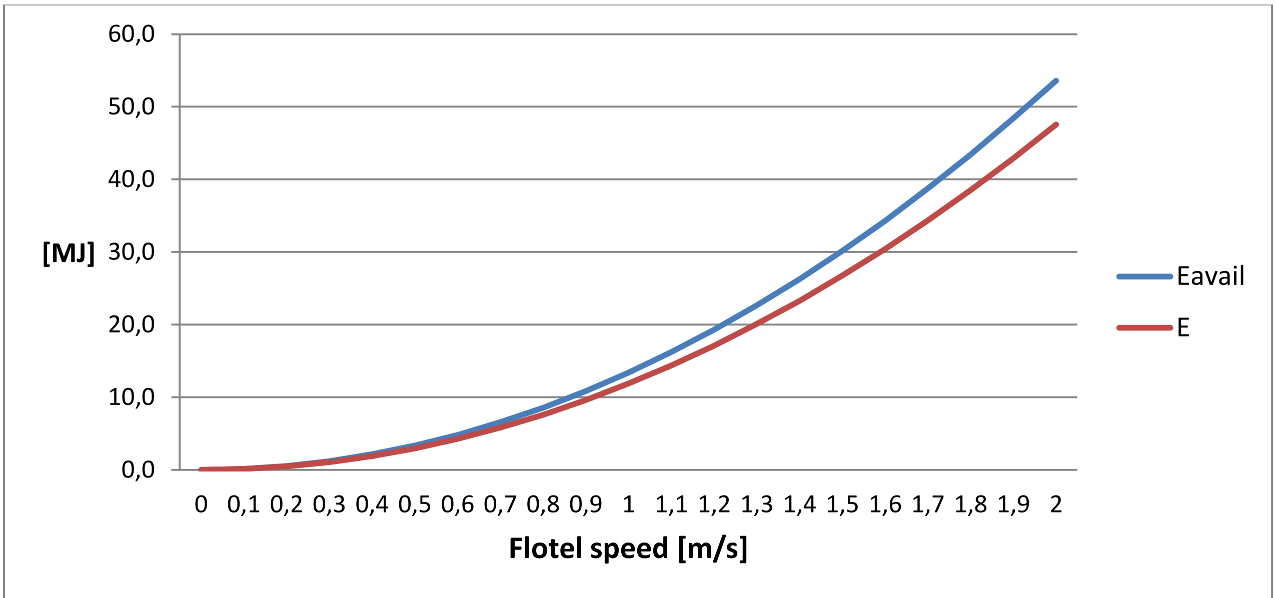


FIGURE 48 - ENERGY IN A FLOTEL DRIFT OFF (THEORETICAL). E IS THE ENERGY THAT MUST BE ABSORBED IN THE COLLISION, WHILE EAVAIL IS AVAILABLE ENERGY FROM THE FLOTELL ALONE.

[44] Added mass or virtual mass is the inertia added to a system due to the fact that an accelerating or decelerating body must move some volume of surrounding fluid as it moves through it.
[45] Which is the size of the under construction flotel "Victory", built by KeppelFELS Shipyard in Singapore for Floatel International. 101. Floatel International, *Floatel Victory*, 2012: www.floatel.se.

DNV provide guidelines for collision energy between ST and FPSO. While not directly comparable, the give an indication as to the amount of energy involved. Ships must resist rupture of the hull in 11 MJ collisions from the side and 14 MJ in collisions from the stern or bow. A flotel will have different characteristics than for example a ST colliding with a conventional FPSO, especially the lack of a bow and a bulb. 50 MJ may not cause critical damage to either the flotel or the installation, but should be considered.

4.2.5 BOW TIE ANALYSIS – FLOTEL

The bow tie analysis performed for this scenario is based on the event tree presented earlier in this chapter. An overview of the bow tie is presented below.

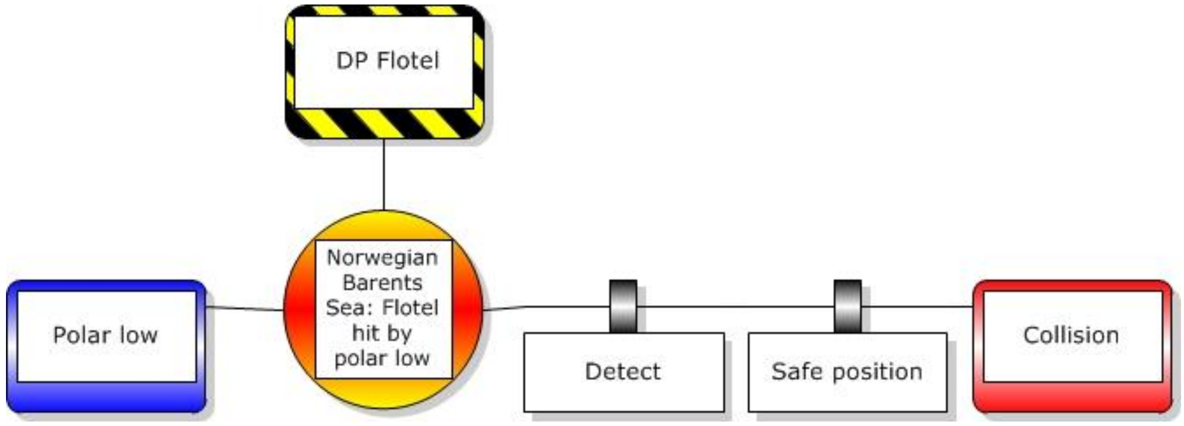


FIGURE 49 - BOW TIE FLOTEL

The threat is as discussed a polar low, and the unwanted event is the flotel being hit by the polar low. Added to this is *the flotel is hit from the worst possible direction*, as discussed previously.

At first, the flotel DP system will attempt to hold or regain position. If this is not achieved, it is only the DP operator who can avert the situation. The DP operator has several tools at hand, and will receive a number of signals indicating that the flotel is not behaving normally.

The time it takes from the drift off commences until operator intervention is the essential factor determining if the collision can be averted, or what the remaining speed, and thus collision energy, will be at the time of the collision.

4.2.5.1 BARRIERS - FLOTEL DRIFT DUE TO POLAR LOW

The two main barriers were:

- Detect
- Safe position

The two things needed in order to avoid a collision are; knowing that the polar low is developing, and having a safe position.

Polar lows were discussed earlier in this thesis.

4.2.5.1.1 DETECT

Detecting the polar low is the first barrier function. Detecting the polar low will enable the flotel to disconnect and move to a safe position before the polar low strikes, or at least the DP operator and crew can prepare for the polar low.

The main performance indicating factor here was:

- Unable to detect

The two main barriers dealing with this is:

- Weather forecast
- Weather monitoring

The figure below displays the barrier function *detect.*

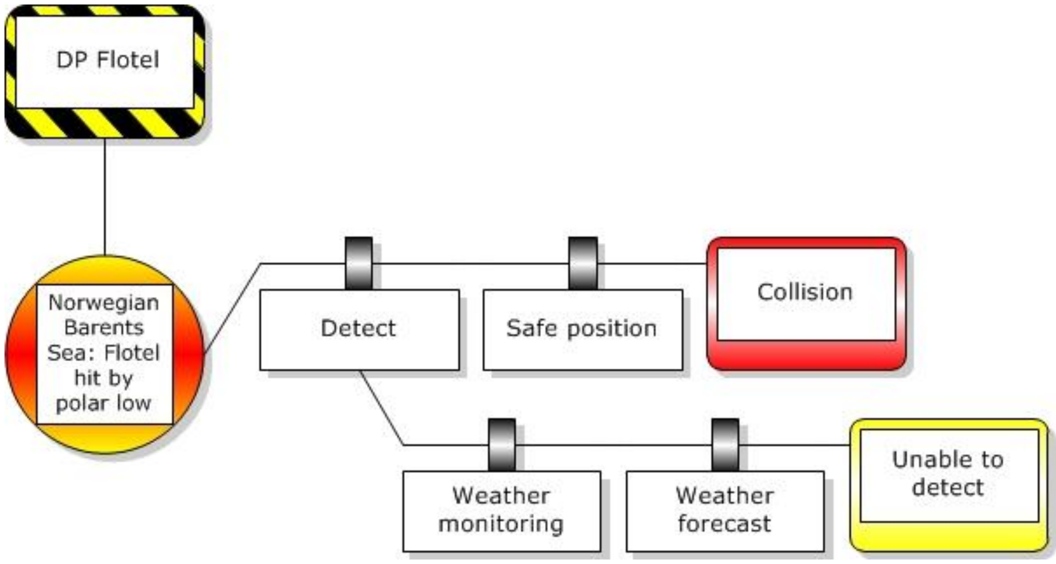


FIGURE 50 - BOW TIE FLOTEL, DETECT

The quality of weather forecasts and the ability to predict polar lows have been discussed in previous chapters. Weather monitoring will, at least until the forecasts are more accurate, be the most important barrier preventing a surprise hit by a polar low.

4.2.5.1.2 SAFE POSITION

Safe position incorporates any position avoiding collision. The main performance influencing factor is the DP systems ability to handle the change in conditions.

There were two main barriers preventing this:

- Disconnect and move to safe position
- Prevent critical loss of position

These two barriers cover two different parts of the event three; the first covers the option were the flotel is disconnected and moved away, and the second covers the option were the flotel remains in position by the installation. The barrier function is presented in figure 51.

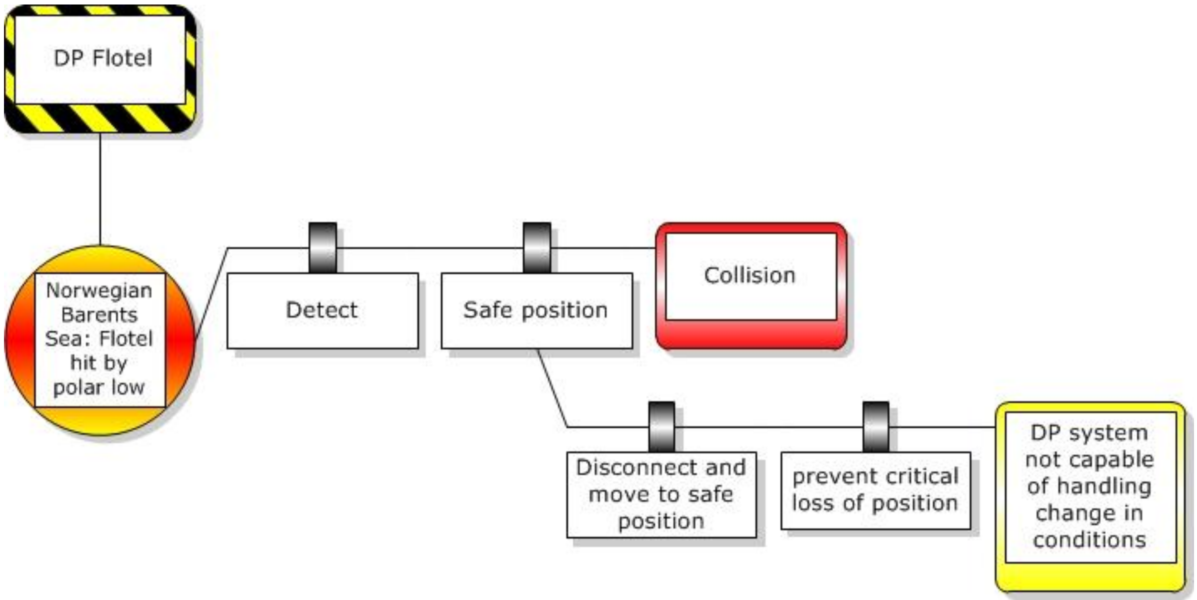


FIGURE 51 - BOW TIE FLOTEL, SAFE POSITION

Disconnect and move to safe position

This barrier simply means to move to a safe distance away from the installation. This option is only possible if the weather development is detected.

Prevent critical loss of position

This is a sub-barrier function. Should the flotel remain in position by the installation, the ability to avoid critical movement towards the installation is critical. Here there are two different scenarios; the first where the flotel DP operator and crew are aware of the development; second, where the flotel DP operator and crew are unaware of the development. There was one performance shaping factor here:

- DP operator reacts too late

There were three main barriers preventing this:

- DP consequence alarm
- Engine/Generator/thruster high load alarm
- Human intervention

The function is illustrated in figure 52.

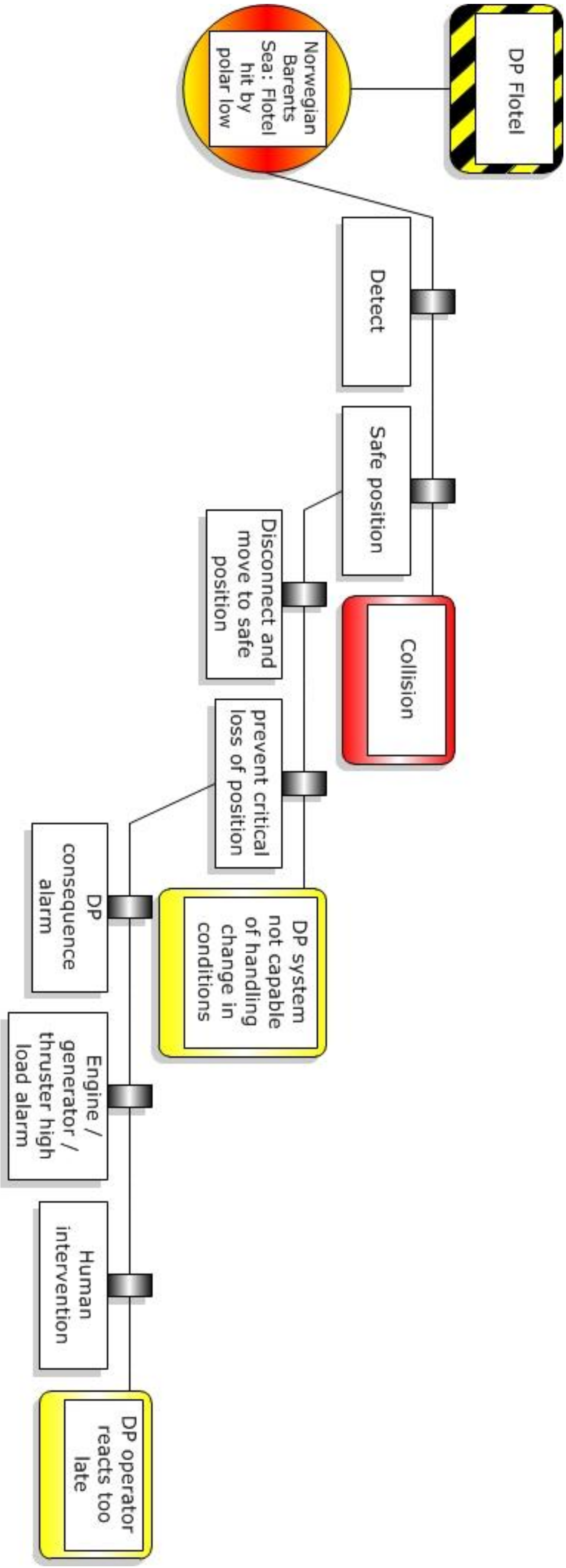


FIGURE 52 - BOW TIE FLOTEL, PREVENT CRITICAL LOSS OF POSITION

DP consequence alarm

This barrier was explained earlier in this chapter. This is one out of several indicators that the flotel is not able to handle the situation. This alarm tells the operator that the system will not be able to handle the situation.

Engine/Generator/thruster high load alarm

This barrier was explained earlier in this chapter. This alarm tells the DP operator that the flotel is struggling and unable to avoid drift off.

Human intervention

Human intervention is necessary in order to avoid a dangerous drift off. Human operation means DP operator performing evasive action, such as steering away from the installation. In order to avoid a collision the DP operator must detect, evaluate, make a decision and perform a manual intervention.

The flotel movement after the DP operator intervention has three phases:

a) A gradual decrease in acceleration until maximum speed is reached
b) A deceleration phase until flotel velocity is zero
c) Moving away from the installation

Phase a) and b) are the two phases where a collision can occur.

4.2.6 FLOTEL OPERATIONAL LIMITS

No general operational limits were found during the research for this thesis. Flotels have different operational limits depending on the design and DP configuration. For this section, an example from the method provided by DNV is presented.

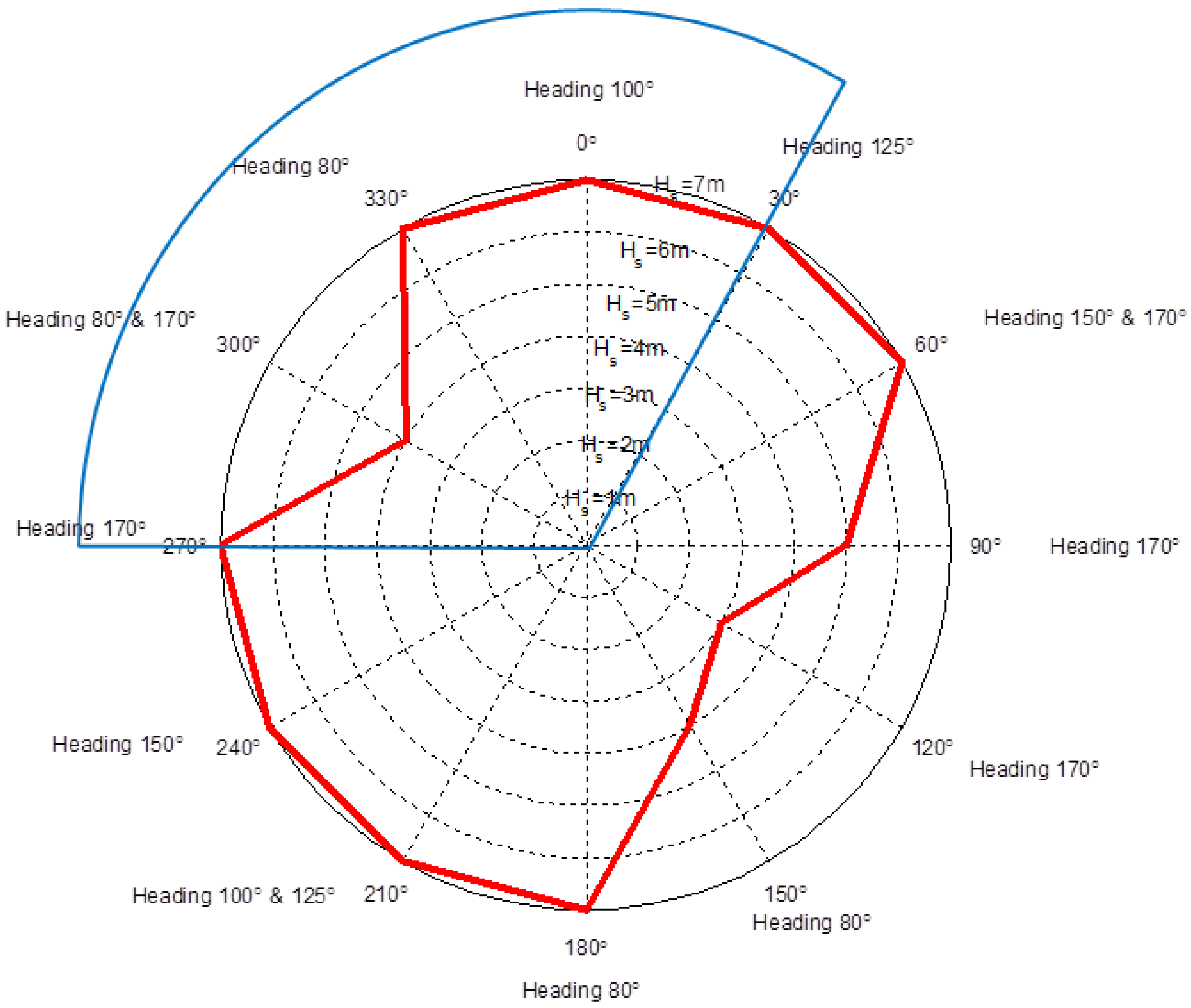


FIGURE 53 - FLOTEL LIMITATIONS, EXAMPLE FROM DNV

Figure 53 displays flotel headings for given wind directions. The figure also displays the limitations in sea state for the various wind speed directions. The red line represents the flotel limits. Wind direction and significant wave height, H_s, is indicated.

4.2.7 SUMMARY OF IDENTIFIED BARRIERS

This chapter has investigated the event of flotel drift off after being hit by a polar low.

The two main barriers were:

- Detect
- Safe position

Detect

- Weather forecast
- Weather monitoring

Safe position

- Disconnect and move to safe position
- Prevent critical loss of position

Prevent critical loss of position

- DP consequence alarm
- Engine/Generator/thruster high load alarm
- Human intervention

4.2.8 RECOMMENDATIONS – FLOTEL

According to the sources used in this chapter, the only way a collision could occur is if the DP operator fails to act, or if there is a blackout of the flotel, causing power failure to the thrusters. The latter was not considered in this analysis.

Should both the weather warning system and all alarms fail, the DP operator might respond too late. With computer power increasing, it should be possible in the near future to have a DP system that will automatically make a decision after a certain time.

The time at hand can be estimated for various scenarios, and if the flotel is moving towards the rig, the DP system could attempt to make evasive action when a certain time has passed, indicating that the DP operator will respond too late. The DP operator could then subsequently override the system

The weather forecast and monitoring have been discussed. Improved warning would limit the possibility of being in a collision course drift off situation.

All alarms should function properly at all times. The systems already have redundancy in their design today, and a 2oo3 configuration would limit the possibility of both false alarms and no alarm.

With very short time from drift off until impact, evasive action must occur immediately. Limiting necessary time to evaluate the situation and execute counteractions should therefore be of utmost importance.

Due to the nature of sudden weather changes, the bridge between the flotel and the installation should not be open at all times. A possible scenario that have occurred several times, but that has not been the focus of this chapter, is the failure of the bridge when flotel drifts slightly off position due to large waves or similar conditions.

The flotel and the installation should be able to handle collision energies of 50 MJ.

4.3 HELICOPTER EMERGENCY LANDING ON WATER – DITCHING

Also known as ditching (see figure below), an emergency landing on water may sometimes be necessary. Although no helicopter ditching has occurred on the Norwegian Continental Shelf since 1996[46] [103], data shows that new events must be expected. In the event of a helicopter ditching, people in the water should be expected.

In the Norwegian Barents Sea there are many factors that make this scenario different from the rest of the Norwegian Continental Shelf today. This chapter investigates the differences and if they can be handled.

Emergency landing on water is one of the most important scenarios for a SAR helicopter [104].

FIGURE 54 - BRITISH AIRWAYS HELICOPTER SIKORSKY S-61N, G-ASNL DITCHED IN THE NORTH SEA, 75 NM NORTH-EAST OF ABERDEEN ON 11 MARCH 1983. COURTESY OF P. MORRIS

4.3.1 SCENARIO

Surviving a helicopter ditching on water will initially depend upon the circumstances of the landing. For the purpose of this assessment it was assumed that the ditching was successful and all on-board the helicopter survived the landing. It was however assumed that the helicopter capsizes shortly after landing[47], necessitating immediate evacuation of the helicopter. Helicopters do not possess great sea-keeping abilities, although this is being looked into in new helicopter designs. Thus, the survivors will be in rafts (or worst case in water) from approximately T=0 hrs. The limitations for personnel in water will be used.

Further, the definition of a helicopter ditching from [105] is used in the assessment; *an emergency landing on water, deliberately executed, with the intent of abandoning the*

[46] The last accident was in 1997. 12 people were killed in a helicopter crash 102. Accident investigation board Norway, *Report on the air accident 8 September 1997 in the Norwegian sea approx. 100 NM west north west of Brønnøysund, involving Eurocopter AS 332L1 Super Puma, LN-OPG, operated by Helikopter Service AS*, 2001: www.aibn.no.

[47] In the last ditching episodes on the British continental shelf, the helicopters stayed afloat and were recovered before sinking. For the scenario in this thesis, the capsizing was chosen because it necessitates leaving the helicopter immediately.

helicopter as soon as practical. The helicopter is assumed to be intact prior to water entry, with all controls and essential systems[48], except engines, functioning properly.

The ditching is assumed to follow the procedures for emergency landing. Thus, a "MAYDAY" is sent immediately, meaning that SAR can begin as soon as possible. A figure describing the general process of ditching and survival is shown in appendix M.

From FAR/JAR 29.801, the term "reasonably probable weather conditions" is used; however, the FAR/JAR 29.801 is based on U.S. conditions and is not acceptable on the Norwegian Continental Shelf [106]. The Federal Aviation Administration (US) decided that sea state 4 (4 – 8 ft. waves, and a H/L-ratio of 1/12,5) satisfies "reasonably probable". For Norwegian waters this is however not satisfactory as operations are carried out in up to 60 knots wind[49], 10 m waves (33 ft.) and H/L-ratios of 1/10. A more general approach has been selected, and various aspects of helicopter ditching are investigated.

The ditching is assumed to take place outside of the safety zone. Act 29 November 1996 No. 72 relating to petroleum activities [107] dictates the requirements inside the safety zone, it is however obvious that people may be in need of rescue outside of this zone, and any changes must be made through the authorities. The 330 squadron has, in principle, the main responsibility for emergency preparedness outside of the safety zone.

4.3.2 GENEREAL ISSUES

In the event of a ditching, there is a great chance that the helicopter will capsize and sink. The people on board must unstrap, find an exit, operate necessary equipment in order to get out and exit. Upon leaving the helicopter, they must then enter a life raft and wait for rescue. The chance of survival thus depend heavily on being prepared [52].

A person involved in a ditching must be prepared for:

- Inversion, followed by a cold shock. Emergency breathing systems (EBS) are not uncommon, and could be of use in the event of inversion. However, in a study performed in 1997, three out of six subjects were unable to use the EBS in the cold water [108].
- Underwater escape, with a number of co-survivors.
- An unknown period of time spent in the sea.
- Entry into a life raft.
- An unknown period of time in the life raft.
- Transfer from life raft into a boat or aircraft.
- Transfer to safety.
- Full recovery.

[48] Particularly important are tracking and communication equipment.
[49] For landing/departure. There is no restriction for flying.

4.3.3 DATA

Helicopter accidents in the Norwegian sector are few, nevertheless they happen, and must be expected to happen again. On average, there were 16,85 person flight hours (that is; 16,85 passengers per flight) between 1999 – 2009. The number of passengers possible on the helicopters is at present 21 (2 pilots + 19 passengers), and it will be beneficial to limit the number of flights, because fewer flights means fewer possible accidents. If this is implemented, a slight increase in person flight hours should be expected for the Barents Sea.

Fixed installations remove the element of a moving landing area and could thus arguably reduce the risk. This "helicopter accident frequency" does not separate fatal accidents or crash landing-accidents from controlled emergency landings, and thus it is hard to say much about the actual frequency of ditching episodes. After combining DNV's numbers with the official number of flying hours (from [89]), [104] estimates a yearly frequency of 0,35 for the entire Norwegian sector.

Over the last 20 years, only three accidents have occurred. 0,35 is thus 2,33 times higher than the actual number of 0,15 events per year.

Finally, an accident frequency based on figures from [33] for the period of 2010 – 2019 gives:

- 0,45 per 100 000 flight hours.

This value holds for the Norwegian shelf only, and gives an estimated 2,3 accidents[50] on the entire Norwegian Continental Shelf for the period of 2011 – 2020, assuming that the number of flight hours develop similarly for the next ten years as it has for the previous ten. A figure displaying the accident rates and fatalities on the Norwegian Continental Shelf can be found in appendix K. This "helicopter accident frequency" does not separate fatal accidents or crash landing-accidents from controlled emergency landings, and thus it is hard to say much about the actual frequency of ditching episodes.

This thesis will focus on *controlled emergency landing* and as mentioned in the scenario, assume that an emergency landing is required, and not discuss the details as to *why* the helicopter must make an emergency landing beyond giving a probable reason for the emergency landing.

4.3.4 INCIDENTS

Two incidents will in brief be described here. Emphasis will be on what would have been different in the Norwegian Barents Sea. For full accounts of the incidents, please see the sources for section 4.3.4.1 and 4.3.4.2 respectively.

The two ditching cases selected were:

- The ditching of Eurocopter Super Puma 332L1 LN-OBP, 18. January 1996
- The ditching of G-TIGK (AS332L Super Puma helicopter), 19. January 1995

[50] Both fatal accidents and controlled emergency landings.

The first occurred on the Norwegian Continental Shelf, while the latter occurred on the British Continental Shelf.

4.3.4.1 18. JANUARY 1996 [103]

A Eurocopter Super Puma 332 performed a controlled ditching about 25 nm off coast (Egersund) at approximately 8:45 in the morning of January 18, 1996. Wind speeds were approximately 25-30 knots and H_S 3-4 metres. Water temperature was 5°-6° C and air temperature was 4°-5° C. There were 2 crewmembers and 16 passengers. The ditching in itself was performed in a controlled fashion. Significant events are listed below.

- Vibration in the helicopter at 08:42:33. Decision to ditch was made.
- MAYDAY was sent, and responded to, at 08:42:46.
- Emergency flotation gear (four flotation devices mounted the helicopter) was inflated at 400 ft and the helicopter was landed on water (controlled) at approximately 8:45.
- Upon landing:
    - Rescue life rafts released electronically from cockpit.
    - ELT (CPI) activated.
    - Passengers remained calm.

So far, everything happened as planned. A few remarks could be made regarding information prior to landing; however these are not relevant for operations today. Primarily the omission of life jacket information was mentioned in the accident report. Today, flotation is already included in the survival suit.

A helicopter (unable to perform rescue) was on site soon after the ditching.

When leaving the helicopter the raft on the right hand side (windward) had blown on top of the helicopter roof. The left hand side raft (leeward) was entered by all except one crewmember; however it swiftly drifted towards the back of the helicopter, and under the tail of the helicopter, which was moving up and down in the water, hitting the raft. The raft punctured and some passengers had to jump in the water in order to avoid the tail. All 17 eventually got back into the helicopter.

The right hand side raft was soon pulled from the roof and put on water. Only three passengers and one crew member managed to enter the raft before it drifted away.

Two helicopters from the 330 Squadron were on site about one hour after the ditching, and all were rescued.

What if it had happened in the Norwegian Barents Sea?

The life rafts were in reality not used. One was punctured by the helicopter and the other drifted away with only four out of 18 persons aboard. As mentioned, remaining in the helicopter is not considered a feasible option due to helicopter stability. In the Norwegian Barents Sea, the people on board would probably have to enter the water.

Due to limited resources in the high north, having a helicopter hovering over the scene soon after the ditching is not considered probable. This had a very positive psychological effect on the persons in the ditched helicopter.

The time to rescue might not be different if the ditching had occurred in the same distance from land. However, in the Norwegian Barents Sea the rescue would happen in darkness. Off the coast near Egersund, there would have been some daylight at the time of rescue.

Probable water and air temperature would be between 2°and 4° C, and -6° and -12°C respectively.

There were several issues with the survival suits; however these have been omitted from this discussion because the SeaAirBarrents suit covers all issues in the report.

4.3.4.2 19. JANUARY 1995 [109]

The Aerospatiale AS332L Super Puma helicopter G-TIGK ditched in the North Sea at a location 6nm South West of the Brae Alpha platform on January 19, 1995.

The sea conditions at the time were rough (sea-state 5[51]); however, the emergency flotation systems worked well, and the helicopter did not capsize. The crew and passengers were able to evacuate to the life rafts without injury. There were 16 passengers and two crew members.

Significant events:

- Helicopter “A” takes off at 11:38.
- Flight proceeds as normal, moves out of Aberdeen Radar coverage (80 nm).
- At about 12:36 there was a bang accompanied by a flash. The helicopter pilots assumed a lightning strike and further, an imminent need to ditch.
- A MAYDAY is transmitted and the pilot claims to have informed the passengers of the situation. Some of these messages could be heard on Radio Telephony; however none of the passengers remember hearing any messages on the PA system.
- During ascending, pilots notice that the helicopter behaves normally and decide to approach the Brae installation. They inform Brae of this.
- At the Brae B installation, another helicopter (“B”) has finished unloading passengers, and takes off in order to assist if necessary.
- At this point the first officer on “A” tests the tail rotor. A loud crack is heard, and ditching is imminent. New MAYDAY is sent to the Brae A installation.
- “B” relays the MAYDAY to Aberdeen FIS at 12:41 and sets course towards the assumed position of “A”.
- Passengers on “A” prepares for ditching as instructed in the pre-flight video. The pilot makes a new PA announcement (heard on the Radio Telephone), it was not heard by the passengers.
- Helicopter makes a gentle touchdown.

[51] Significant wave heights of 2,5 to 4 metres.

- The helirafts (life rafts) were deployed. Two passengers deployed the left hand side raft. They later stated that it had been blown over in such a state that it would be very difficult to utilize.
- The first officer decided that they should use the right hand side raft. All 18 entered the 14 man sized raft. Even though they punctured a buoyancy chamber below the boarding ramp, it remained satisfactory afloat.
- When "B" located "A" at 13:06, it remained in hover by the raft and assumed duties of on scene commander (OSC).

Three helicopters with winches and four without arrived on scene. In addition; two oil platform safety vessels and one RAF Nimrod aircraft assisted. All were rescued from the raft.

What if it had happened in the Norwegian Barents Sea?

Even though helicopter "A" was in radio contact with Brae A and helicopter "B", helicopter had to locate helicopter "A". They did not know were "A" was, they travelled towards the *assumed last location".* This is a time thief that cannot be allowed in the Norwegian Barents Sea. There is also great risk that they may not find the helicopter in time.

The passengers were never informed about what was going on, due to messages not being broadcasted through the PA system. Preparing the passengers for what is going to happen is of utmost importance in order to keep them calm and make a safe evacuation. Although it worked out fine in this case, it cannot be assumed to do so in future events.

One raft was not used because it was deemed as too difficult to board. Fortunately, everyone could go in the other raft, but they had no redundancy here. There should have been two available rafts.

A total of seven helicopters and two vessels arriving on scene relatively quickly is unlikely in the Norwegian Barents Sea.

The same issues with temperatures as in the previous case hold here as well.

4.3.5 EVENT TREE HELICOPTER DITCHING

An Event Tree was developed for a simple analysis of a ditching. Not all aspects are included, and some points require some explanation. For a detailed risk analysis, this scenario would require further development. As mentioned in the limitations to this scenario, what happens after the controlled ditching is of interest. For illustrative purposes, a sequence of events prior to and during the ditching has been included in appendix M.

There are two possible outcomes for the helicopter when ditching; to stay afloat, or to sink. Helicopters often capsize, and also sink, leaving little time to escape. This may happen in different ways; with the main issue being underwater escape. Helicopters capsizing and remaining afloat for at least some time is perhaps more probable considering the latest events on the British Continental Shelf; however the main point is that the victims have to evacuate the helicopter. Crash landing is not covered in this thesis. The sequence of events would be much the same as for a ditching, however survival will also be dependent on injuries and damage to the helicopter.

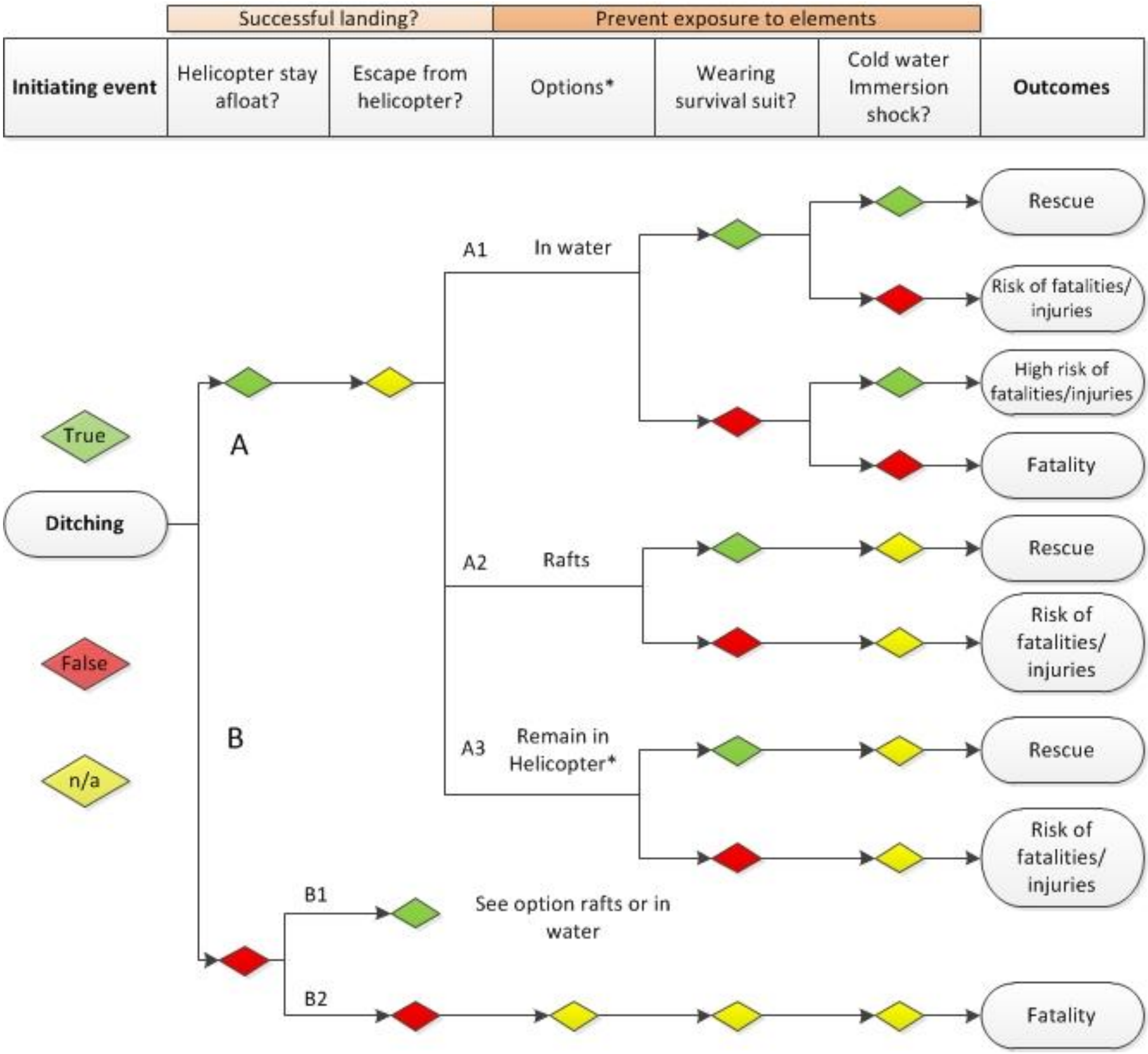


FIGURE 55 - EVENT TREE DITCHING

There are two main paths to follow in this event tree:

A. Helicopter floating[52]; allowing controlled escape and also the possibility of remaining in the helicopter for some time, as was the case in the 1996 ditching in the North Sea [103].
B. Helicopter not floating; fills with water, submerged or capsized leading to underwater escape.

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52 The use of the word "floating" is deliberate as it does not specify whether or not the helicopter is floating with the right side up.

Path A – Helicopter Afloat

A.1 Personnel in rafts
A.2 Personnel remain in the helicopter*
A.3 Personnel in water

A.1: This option will in general involve more rapid cooling than if personnel are able to remain in the helicopter; however, remaining in the helicopter is not considered to be a feasible option due to the risk of not being able to escape the helicopter if it should capsize. If the victims leave the helicopter they will be more exposed; still, entering a life raft eliminates the risk of being trapped inside of the helicopter.

A.2*: Both path A.1 and A.2 have similar development. The possibility of remaining on board can provide more protection from the elements; however, this is not a feasible solution today. The risk of the helicopter capsizing and trapping people inside is too great. Helicopter stability is a great issue, and sea conditions are critical. The personnel must be prepared to leave the helicopter on short notice. Fatigue and hypothermia may cause fatalities, they are however not considered as very probable outcomes in this thesis, due to the fact that the requirement for pickup is 120 minutes when the victims are in water.

A.3: People in the water may occur in various ways; after escaping a capsizing or sinking helicopter, or in the event of life raft deployment being unsuccessful. In the 1996 ditching the first life raft was punctured upon deployment [103]. Life rafts are hard to control and vulnerable to wind. This means that persons may be separated, or even unable to board. Survival suits and tracking devices are necessary, and are also a requirement for helicopter transport in Norway.

Path B –Helicopter not afloat

B.1 Escape
B.2 No escape

These paths are more complicated with regards to survival. If the personnel are not able to escape the helicopter they will be lost (path B.2). This path will thus not be looked further into.

B.1: For this path to be successful, a number of preparations should be made, as illustrated in appendix M. These preparations are also required even if the landing is successful; however it may not be as critical. Upon escape there are two possible turns of events: helicopter capsizes and may sink within a short period of time, or the helicopter is sinking. The case of the helicopter staying afloat is covered in path A. Path B.2 will then look the same as path A.3. Additional factors may be injuries or trauma from the escape.

Comments to the Event Tree

The points in this event tree will be discussed further in this chapter. At this point, some general comments to the options and events will be presented.

The option *"wearing survival suit?"* is in practice not very relevant due to the requirement on using survival suits. The event tree originally included leaking survival suits (immersion either impaired or wrong size), however according to [55], the new survival suit[53] "SeaBarents" do not leak.

The event "*fatality"* when wearing survival suit is due to drowning. It could be argued that cooling is also a cause of death when wearing a survival suit. This has not been considered probable. The reason for this is that, providing the survival suit is functioning as intended, the body core temperature will never reach deadly levels within the required time to rescue. This time to rescue also has a safety factor of three[54]. The event of drowning is hard to model, and body core temperature is a usual factor used to predict survival time. Drowning often occurs early, before hypothermia sets in, often in relation to initial cold shock. Should the body core temperature drop by 2°C a common reaction is unconsciousness, greatly increasing the risk of drowning.

Some of the events provide prolonged survival times. The analysis is a qualitative one, and the requirement of rescue within 120 minutes is used in the term "*rescue"*.

Hypothermia is not included. The reason for this is that after the steps displayed in the figure are completed, the only thing between the victim and rescue is hypothermia, thus it was omitted from the event tree. If the victim is not rescued within 120 minutes the rescue mission is for the purpose of the thesis failed, although people may still be alive.

Where the barrier or additional event is not applicable for the option, the line was continued, and a "not applicable" (n/a) sign was included.

[53] Upgraded version of the SeaAir survival suit
[54] Rescue should be within 120 minutes (two hours), while the survival suits should keep the core temperature from dropping more than 2°C for six hours in circulating water (0 – 2°C).

4.3.6 BOW TIE ANALYSIS – DITCHING

The bow tie analysis was performed using the available information about human factors and emergency preparedness. It was discovered near the end of the analysis that the bow tie and the evaluations made were very compatible with Jacobsen's thorough analysis and results in [110]. The outcomes of a ditching have been limited to investigate risk to humans. No economic or environmental consequences are discussed. The unwanted outcome is fatality.

There were three main barriers in the analysis performed in this thesis, regarding the objective of the barrier system: keeping personnel alive. Although it has been stated that how the ditching occurred is of no interest, a short discussion has been included.

1. Successful evacuation from helicopter
2. Prevent exposure to elements
3. Rescue

An overview of the bow tie is shown in figure 56. In the following sections, each part of the bow tie will be discussed.

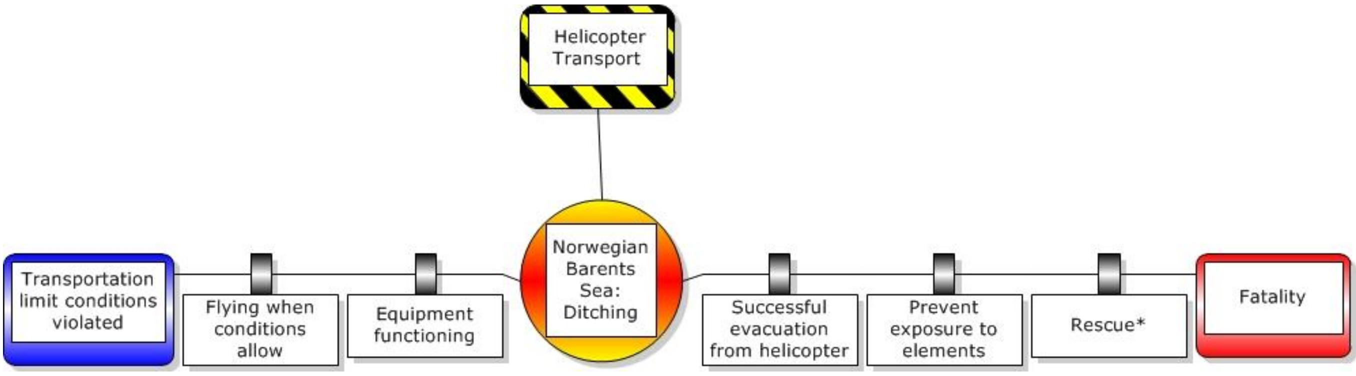

FIGURE 56 - BOW TIE DITCHING, OVERVIEW

The first part of this bow tie analysis was the event tree presented and discussed earlier in this chapter. The main issues were to; have a successful evacuation from the helicopter and prevent exposure of the victims to the elements, with three main possible fatal outcomes; cold shock, hypothermia[55] and unable to escape helicopter.

4.3.6.1 SUCCESSFUL EVACUATION FROM THE HELICOPTER

A successful evacuation means getting every passenger and the crew out of the helicopter before any harm can happen to them. There are two main performance shaping factors[56] for this barrier, with their respective sub-factors:

1. Sea state
2. Personnel preparation for ditching

[55] When hypothermia occurs it was considered too late in the section, the option is therefore not present in the figure.
[56] BowTieXP uses *escalation factor* instead of *barrier performance shaping factor* (see chapter 3.4.2).

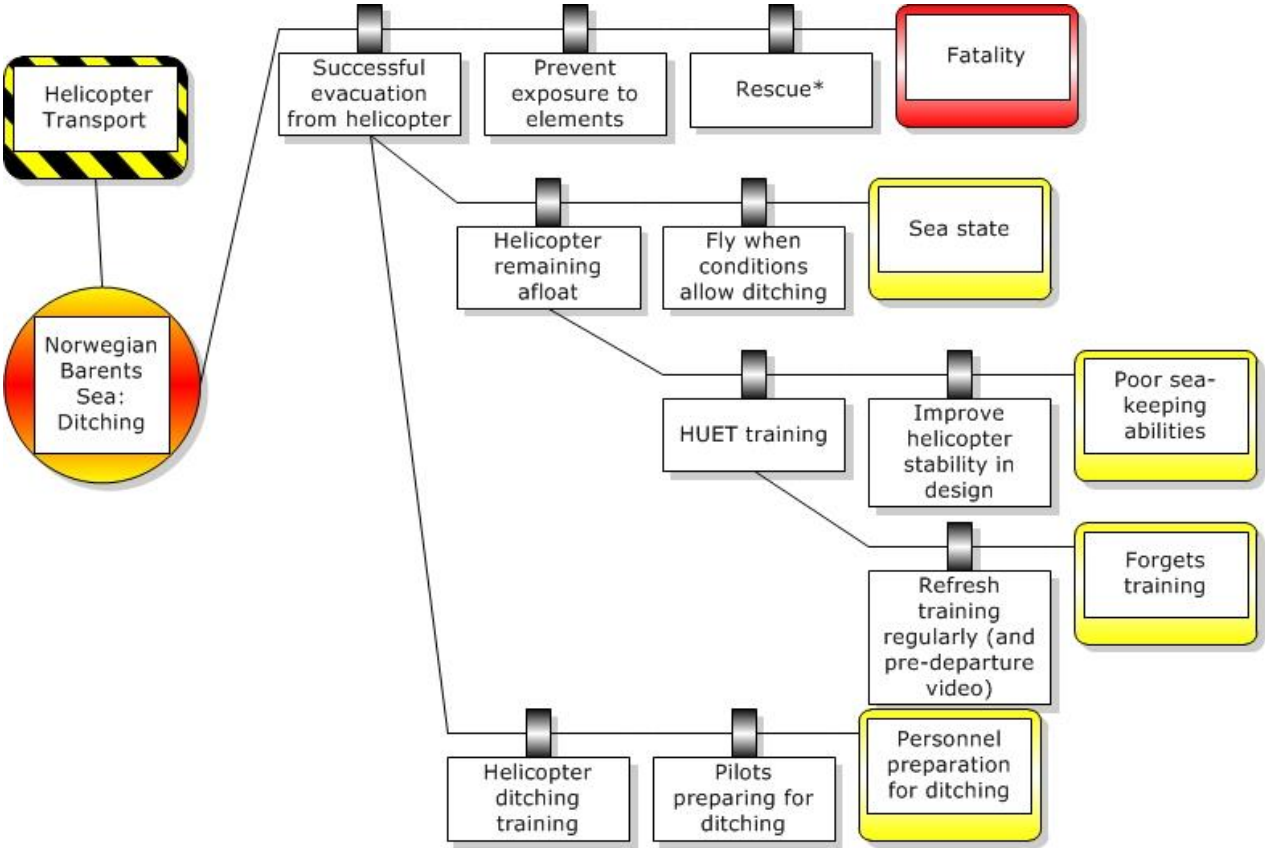

FIGURE 57 - BOW TIE DITCHING, SUCCESSFUL EVACUATION FROM HELICOPTER

Sea state

The sea state greatly affects the chances of having a successful ditching in the first place. The main barrier elements were:

- Flying when conditions allow for a safe ditching
- Helicopter remaining afloat

Flying when conditions allow for a safe ditching means that the metocean conditions must not be worse than the limitations for the helicopter. This also means that rescue shall be possible.

Helicopter remaining afloat is of utmost importance. Should the helicopter sink while people are inside, their chances for survival are greatly reduced. It is not specified whether or not the helicopter capsizes. Helicopters do not possess great sea-keeping abilities. It must therefore be expected that the helicopter will capsize, however, not necessarily sink within relatively short time after the ditching. Two barrier elements were included for this:

- Helicopter Underwater Escape Training (HUET)
- Improve helicopter stability in design

HUET training is already a requirement and effort to improve helicopter stability in water is being performed. An addition to HUET, training should include cold-water experience. This will be discussed further in the next section regarding *prevention of exposure to elements.*

The sea state is important for a number of reasons, as discussed in previous chapters. The option of remaining in the helicopter is today not feasible due to the risk of being trapped inside should the helicopter capsize. As [105] points out; *Emergency flotation systems (EFS) have been mandated on UK offshore helicopters since the 1970s for extended flights over water. It is difficult if not impossible; however, to design practical flotation systems that will keep a helicopter afloat and stable in the more severe sea conditions prevalent in the northern North Sea during winter months*. Using the helicopter as a first place to stay after a ditching would be desirable, as it provides more protection from the elements. Today life rafts are common and the use of life rafts separate victims from the water, and thus reduce the risk of fatalities.

Personnel preparation for ditching

Preparation for a ditching event is important. This begins with the pilots telling passengers to prepare and requires passengers and crew knowing what to do, and also what will happen. The two main barriers for this performance shaping factor were:

1. Helicopter ditching training
2. Pilots preparing for ditching

Helicopter ditching training makes the passengers and the crew more able to handle the situation successfully. This training is basically a list of tasks that must be performed prior to contact with the water. The survival suit must be zipped, loose objects secured, location of emergency exits must be known and crash positions must be prepared.

Having experience with cold water immersion would be desirable, and should be included in training. Knowing how your body reacts when exposed to cold water will not only assist in combating cold water immersion shock, but also mentally preparing for the sequence of events. This must be seen in relation to cold shock and potential injuries that may have occurred in the ditching.

Pilots' preparing for ditching is a wide barrier. There are two ways of looking at this barrier;

- Preparing the personnel for what is going to happen
- Preparing the helicopter for ditching; including sending distress calls

As with HUET the passengers may forget their training. This was not included as a separate branch. The safety briefing pre-flight is meant to assist in refreshing the training, and the pilots preparing the passengers will also assist here. Regular onshore training of the personnel working offshore is already a requirement and this thesis emphasizes the importance of it.

If the distress call is not sent it may lead to a delay in SAR or even no SAR before it is too late.

4.3.6.2 PREVENT EXPOSURE TO ELEMENTS

The second important factor for avoiding fatalities is to prevent the victims from being exposed to the elements. This barrier has three main performance shaping factors:

1. Cold (water, air and wind)
2. Sea state
3. Water in respiratory system

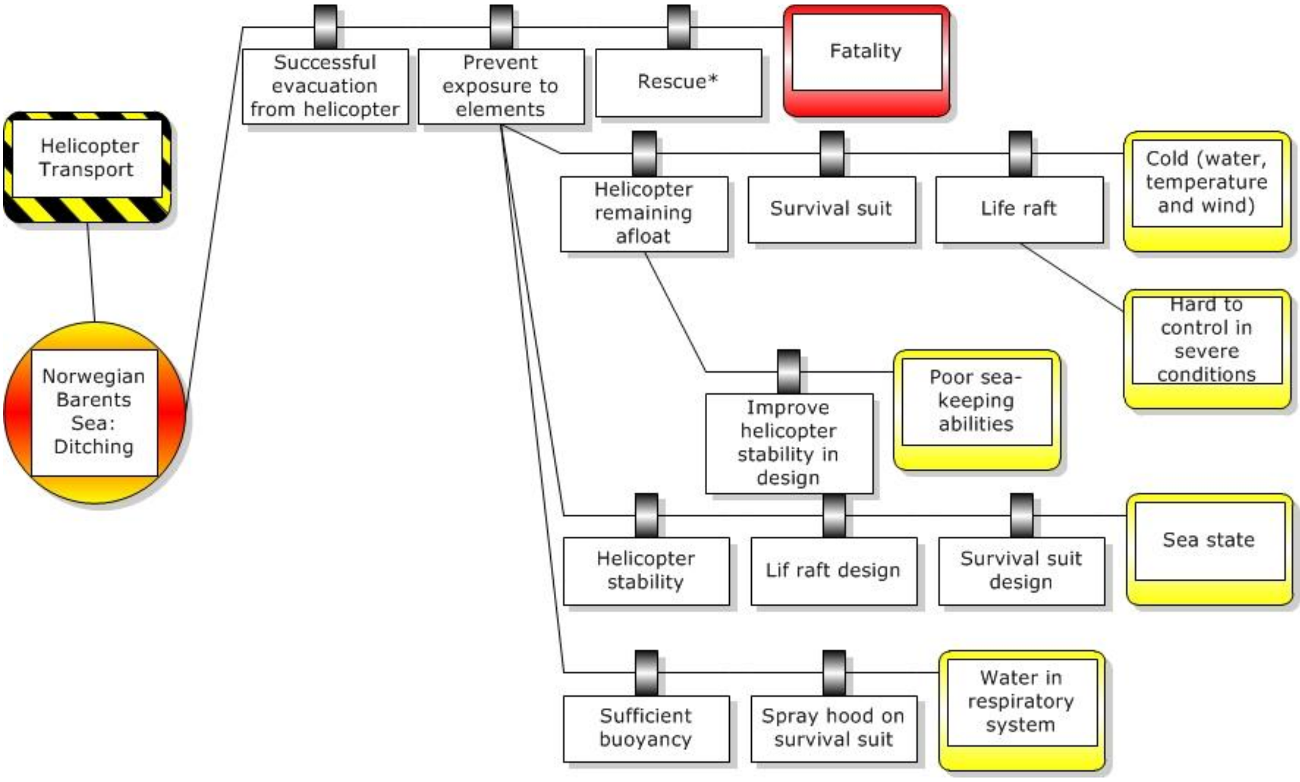

FIGURE 58 - BOW TIE DITCHING, PREVENT EXPOSURE TO ELEMENTS

Cold

Cold is a very important factor for survival. There are three main barrier elements here:

- Helicopter remaining afloat
- Survival suit
- Life raft

The barrier *helicopter remaining afloat* was discussed in the previous section. The option of remaining in the helicopter is desirable, but not feasible today.

Survival suits are mandatory today, and are the most important equipment the individual has. As is shown in the chapter on human factors; wearing normal clothes (and with sufficient buoyancy) will give a victim well under one hour of expected survival time. After less than ten minutes, the survival chances go from “good” to “bad” [8].

Cold shock is the greatest danger at an early stage. The life raft is the preferred barrier. Wearing a survival suit with proper clothing underneath is the most important physical barrier when a person is forced to enter the water. Remaining in the helicopter or life raft are preferred ways of avoiding cold shock. Having experience with cold water immersion is also preferable. Knowing how your body will respond increases the chances for survival.

For the case of hypothermia (often causing drowning due to loss of consciousness [55]); rescue, survival suit and proper clothing underneath the survival suit are vital. Rescue is, as pointed out by Jacobsen, the single most effective remedy for hypothermia. Rescue will be discussed in a later section. Having a life raft will increase your survival chances significantly, due to the reduced cooling rate from air compared to water.

Sea State

Handling the sea state has many similar barrier elements to cold. In order to handle the sea state the same three barriers are applied:

- Helicopter stability
- Life raft
- Survival suit

Improved helicopter stability is, as previously discussed, desirable because the helicopter would provide better protection from the elements. Still, the risk of remaining inside the helicopter is per today too great.

The sea state may cause the helicopter to capsize; requiring personnel to either enter a life raft, or jump in the water first. As shown in the 1996 ditching [103]; life rafts can be hard to handle, and so if this second barrier fails the personnel in the sea rely on the survival suit. Life raft design and survival suit design are thus of paramount importance.

Water in Respiratory System

Water in the respiratory system is a severe danger when a victim is in the water. The first barriers could arguably be the same as before; remaining in the helicopter and using a life raft, removing water from the equation. When in the water there are two main barriers:

- Spray hood on the survival suit
- Sufficient buoyancy

Even with the survival suit, water in the respiratory system is an escalation factor. Therefore spray hoods need to be a part of the survival suit design. This is taken care of in the new survival suit [56]. The escalation factor of water in the suit has been removed after new information from [55] was presented. The new survival suit, SeaAirBarents, does not leak. This requires that the suit is being worn correctly, however not so much as the previous suit.

Having sufficient buoyancy is also necessary. This is important for two reasons; the first is keeping the victims head above surface, and the second is regarding heat loss. If the victim is required to tread water heat loss will happen much faster. Armpits, groin and head are the three parts of the body that release the most heat, and any movement will involve more water circulating through those areas.

4.3.6.3 RESCUE

For rescue, a separate bow tie was created. The hazard is still helicopter transportation and the unwanted event is having a rescue mission. Ideally there should not be need for a rescue mission. The unwanted consequence is in this case a *failed rescue mission.* By failed it is meant that the victims from the ditching are not rescued and/or that the rescue team is lost. An overview of the bow tie is shown in the figure below. Only the right hand side of the bow tie will be considered.

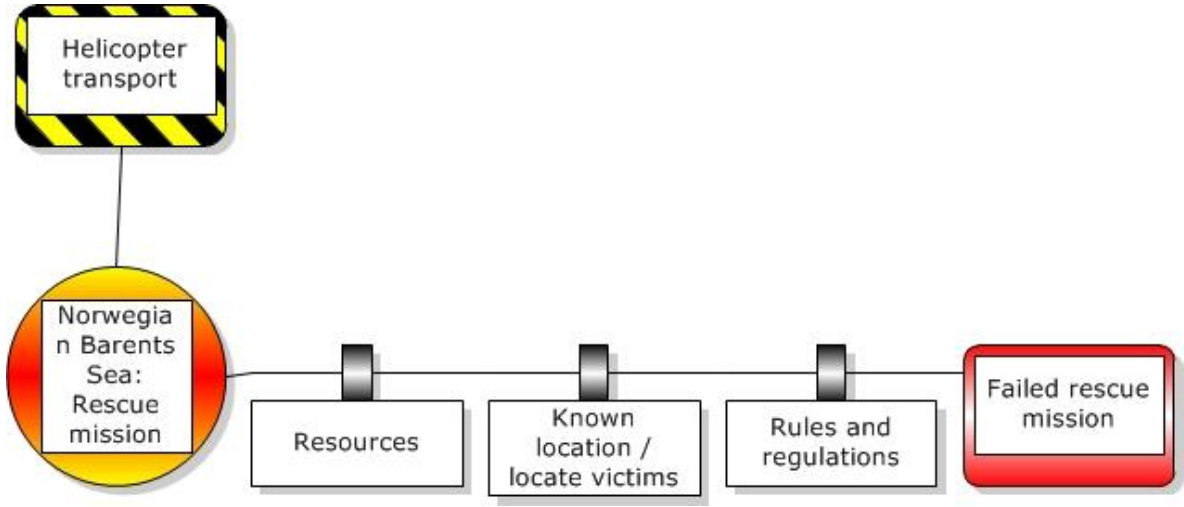

FIGURE 59 - BOW TIE DITCHING, RESCUE OVERVIEW

The main elements needed to rescue someone are to know where the victim is (or locating quickly) and having the necessary resources to rescue the victim. If the rescue team has the resources but not the location or the other way around, the rescue mission is failed. Rules and regulations are included as a barrier system that focuses on the rescue team. When do you go out, and when do you not? The selected barrier systems where thus:

1. Resources
2. Known location / locate victims
3. Rules and regulations

Some of these elements are of a general character and will not be discussed in detail. The Barents Sea specific elements will be the area of focus.

4.3.6.3.1 RESOURCES

For the barrier system resources there were four main performance shaping factors:

1. Inadequate SAR resources
2. Extreme conditions
3. SAR personnel unable to perform rescue
4. Time

Here; 1 and 4 are the ones that differ most from the rest of Norwegian Continental Shelf.

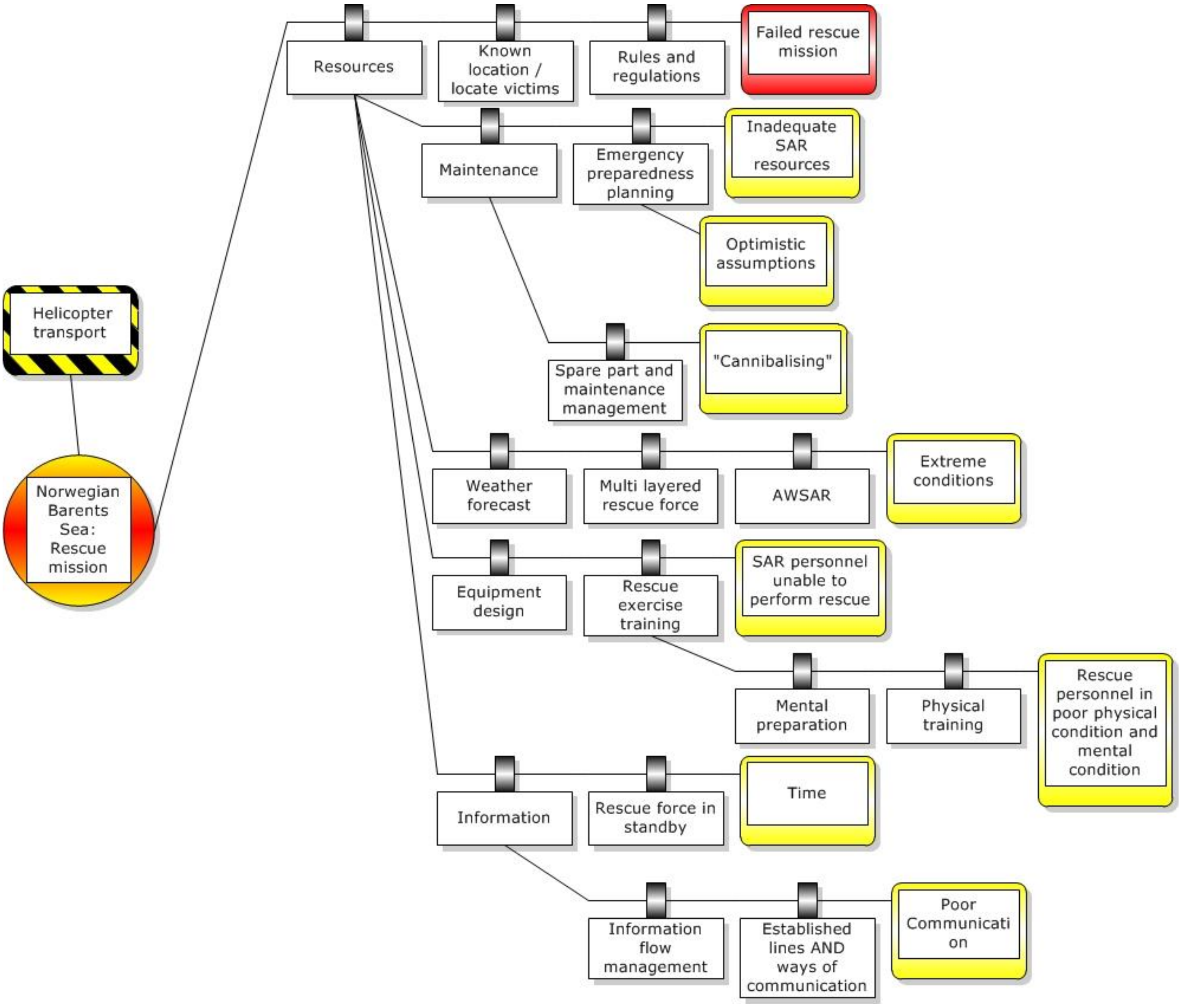

FIGURE 60 - BOW TIE DITCHING, RESCUE, RESOURCES

Inadequate SAR Resources

The main barriers found were:

- Emergency preparedness planning
- Maintenance

Inadequate SAR resources can be countered for via proper emergency preparedness planning and also maintenance of equipment. Here, remoteness and lack of rescue resources and infrastructure are an important part of the planning. Optimistic assumptions can cause problems for the planning, and not having the right spare parts may cause cannibalising; limiting the available resources. Jacobsen [110] points to the same important factors here. The area emergency preparedness that has been implemented in the other parts of the Norwegian Continental Shelf should be implemented in the high north. This is a part of the emergency preparedness planning barrier. Area emergency planning will benefit the industry as it moves further north. Accidents are still unlikely, and cooperation in this field will lower costs for individual partners, while providing better coverage. At the Skrugard field (estimated start-up in 2018) it was suggested to have an offshore hangar for SAR helicopters. This has already been done successfully in other locations.

Inadequate SAR resources are not necessarily a Barents Sea specific issue. However, being so far north can lead to lack of supplies. Proper emergency planning and maintenance and spare part management will assist here.

Extreme Conditions

The main barriers found here were:

- Weather forecast
- Multi-layered rescue task force
- AWSAR

The metocean conditions will, in addition to being vital for the victims, set the terms for the rescue. Therefore it is important to have an adaptable rescue task force. Waves and wind are not necessarily worse than conditions found on the rest of the Norwegian Continental Shelf. Rapidly changing weather and icing are issues that are more unique for the Norwegian Barents Sea. Improving weather forecasts is important here. The adverse conditions would make the use of All Weather Search And Rescue (AWSAR) beneficial. Also, having a multi-layered rescue task force would create a more resilient operation that could perform rescue in adverse conditions. Combining helicopters, ERVs, MOB and FRDC (see appendix P) could increase the range of rescue.

SAR Personnel Unable to Perform Rescue

The two main barriers here were:

- Training
- Equipment design

An important, yet not Barents Sea specific threat included here is SAR personnel unable to perform rescue. Training exercises and equipment design were the two main barriers selected. Equipment must be easy to use, both for the rescue personnel and the victims. The physical and mental condition of the rescue man (particularly, but not excluding the rest of the team) are very important. As Jacobsen points out, the rescue man is a single resource that is critical for the operation. This person should be capable of helping up to 21 persons, and must also be mentally prepared for the operation.

Time

Time is an important factor, and with colder water and greater distances it is likely there will be less of it. The two main barriers were:

- Information
- Rescue force in standby

Planning and appropriate information are amongst the key barriers to perform within the time window of 120 min. Communication must be clear and the way of communicating must be defined and prepared. By prepared it is meant that; everyone speaks the same language and uses the same way of speaking. In the airline industry it has been suggested not to talk, but rather use automatic messages using a few clicks on a keyboard, and also keeping regular speech as a backup. A rescue mission may require a level of improvisation that regular airline traffic does not experience, but it could be an option for parts of the flight. Also, the ability to track and locate the helicopter is an important barrier. Should the situation arise where the pilots are unable to send a mayday (although this thesis assumes a "normal" ditching), knowing where the helicopter is will be of paramount importance.

Having the rescue task force on standby could help in reducing mobilisation time.

4.3.6.3.2 KNOWN LOCATION / LOCATE VICTIMS

If you don't know where the victims are and you are unable to locate them, the rescue is failed. Either knowing where they are or the ability to locate them quickly is thus very important. Known location of victims is for a large part the normal situation in offshore emergency scenarios today.

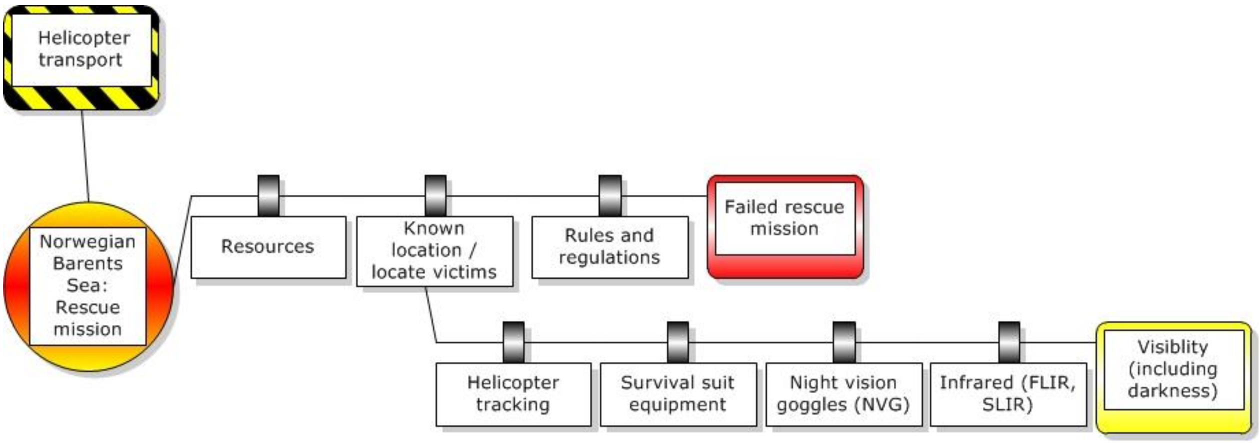

FIGURE 61 - BOW TIE DITCHING, RESCUE, KNOWN LOCATION / LOCATE VICTIMS

Visibility is of great concern in the Norwegian Barents Sea. The four main barriers were:

- Helicopter tracking
- Survival suit equipment
- Night Vision Goggles (NVG)
- Infrared (FLIR/SLIR)

Helicopter tracking

Helicopter tracking enables the rescue task force to know at all times were the helicopter is. The pilots should report in the ditching and their location prior to contact with the water. Should the pilots for some reason be unable to send out a Mayday, the flight tracking will let the rescue team know where to look. Transportation helicopters are required to be equipped with emergency locator transmitters (ELT).

Survival suit equipment

Lights and bright colours on the survival suits in addition to personal locator beacon (PLB, standard today) will greatly aid locating and rescuing victims. Should the victims need to enter the water, drifting apart from each other is not unlikely.

Night Vision Goggles (NVG)

Night vision goggles (NVG) will also assist in the rescue when the rescue task force is close to the victims.

Infrared

Infrared (forward looking and side looking, FLIR and SLIR respectively) will detect heat sources in the water. A potential problem here is the thermal insulation the survival suits provide, giving weaker signals.

4.3.6.3.3 RULES AND REGULATIONS

The final barrier system selected was rules and regulations. There are a number of rules and regulations that must be followed; however the purpose of this section is not to go into the details of all of them. For the purpose of the rescue the limits for a rescue mission must be known. Knowing when *not to go* is the essence.

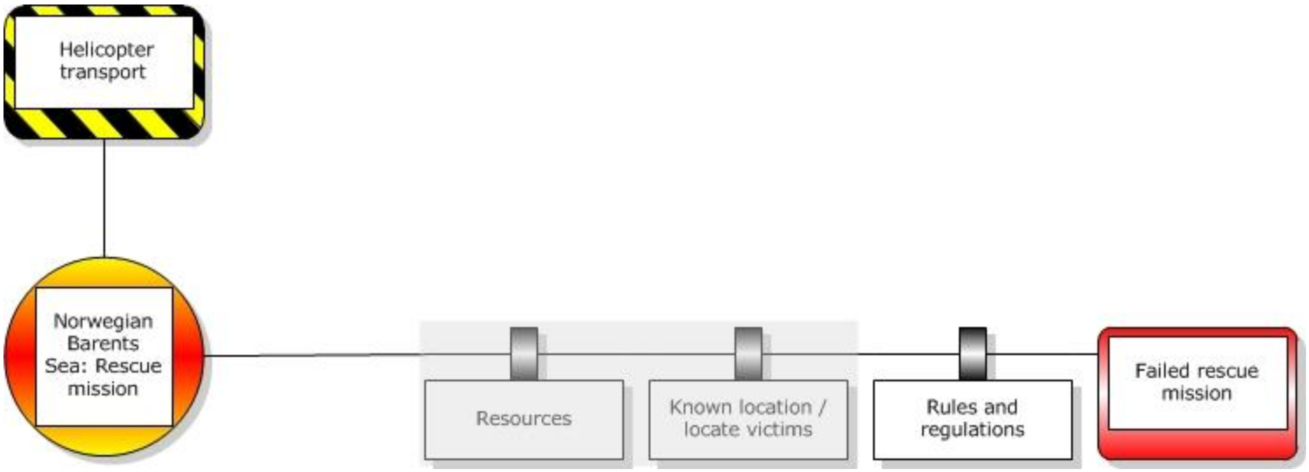

FIGURE 62 - BOW TIE DITCHING, RESCUE, RULES AND REGULATIONS

The main guidelines for the use of helicopter on the Norwegian Continental Shelf are:

- OLF guideline 066 [28]
- OLF guideline 095 [29]
- BSL-D 5.1 [30]

4.3.6.4 THREATS LEADING TO A DITCHING

Transportation limit conditions were selected because it involves some uncertainty to conditions that will be Norwegian Barents Sea specific and that may lead to a ditching. This analysis does not look into reasons for the ditching occurring; however, this factor should be mentioned.

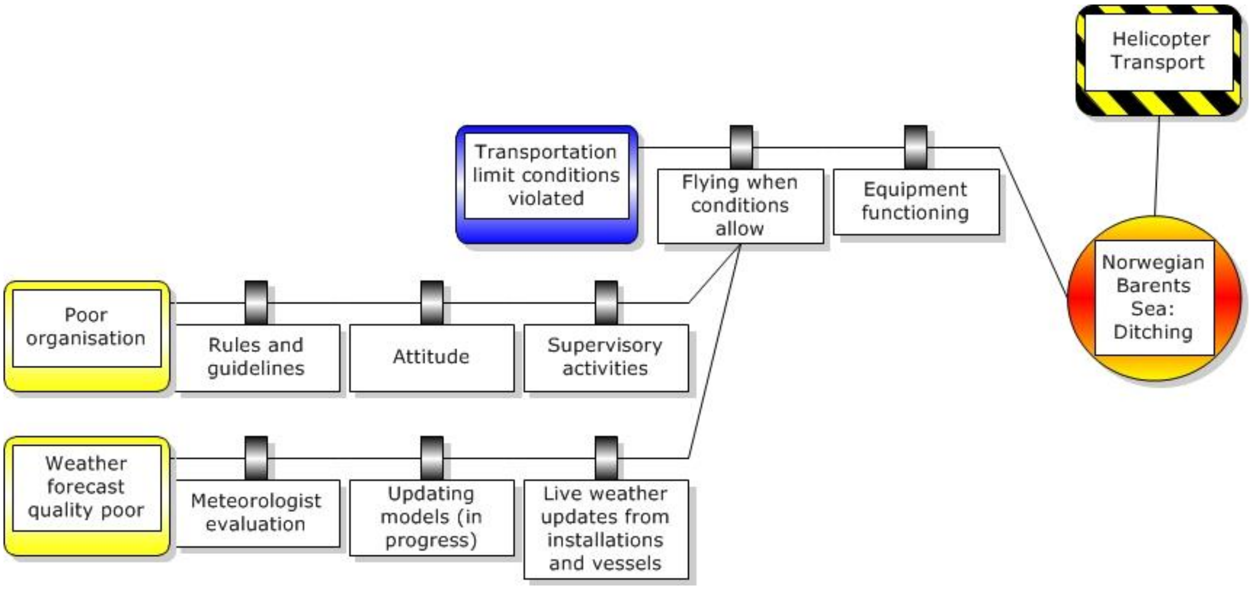

FIGURE 63 - BOW TIE DITCHING, THREATS LEADING TO A DITCHING

Other threats could be included that may lead to a ditching; however, the main difference between the Norwegian Barents Sea and the rest of the Norwegian Continental Shelf are the conditions.

The barriers put in place to avoid flying when limit conditions are not met were:

- Fly when conditions allow
- Equipment functioning

The simple logic is that it is not possible to fly if the conditions don't allow it, and you can't fly if the equipment does not work.

Equipment functioning has already been discussed through maintenance, spare part management and emergency preparedness planning, and will not be discussed further here.

The two main performance shaping factors for flying when conditions allow were:

- Poor organisation
- Weather forecast quality poor

Weather forecasts have already been discussed.

Poor organisation means not having rules and regulation, having a poor attitude towards risk management. If the organisation responsible does not have proper management then violating the limit conditions becomes a possible outcome. Both established rules and guidelines (particularly OLF guideline 066), and attitude are important within the organisation. Supervisory activities are important to make sure the company is complying with the regulations and not taking short cuts.

Following the established guidelines, and updating these as more experience is obtained, is a key barrier for safe helicopter operation.

Quality of personnel with regards to training and experience could play a major factor in allowing flights in conditions outside the limits. An important escalation factor here was the quality of weather forecasts. Also, updated information from any installation would be preferable, and is being done today. Updating models for weather forecasting is also required, and is also being done. The OLF procedure for operational limits is intended for operations within the safety zone (500 m). This should be required for the whole flight.

Jacobsen's results and the ones found in this study correspond well. The issues are fairly clear, and it is thus not surprising that the conclusions were more or less the same for this operation.

4.3.7 CURRENT RULES

All US and European helicopters currently used in support of offshore oil and gas exploration and production have been certified (in addition to any national requirements) in accordance with the requirements of JAR/FAR 27 or 29. Particularly concerning the concept of *ditching* in 27/29.801. [105] Compliance with requirement 27 or 29.801 is optional for the manufacturer. Other operational rules prescribe many requirements that are applicable when the aircraft is being operated over water.

There are two different scenarios with relevance to this report; landing within the safety zone (500 m) and landing outside the safety zone. The Norwegian Oil and Gas Association (OLF) guideline 064 [111] DFU2: Personnel in the water after helicopter accident, define what is inside the safety zone: DFU2 is valid for all installations within the established area, within the safety zone around the installations (500 metres), including vessels when under the jurisdiction of the Norwegian Petroleum Law.

The general guidelines for people in the water in connection with a helicopter accident are as follows:

TABLE 13 - GUIDELINES FOR PEOPLE IN WATER WITH REGARDS TO DITCHING

Helicopter accident on water	
Rescue	
Personnel in the ocean within the safety zone wearing survival suits shall be picked up before there is danger of hypothermia.	Within 120 min[57], a full helicopter of 21 persons (2 pilots + 19 passengers) inside the 500 m zone shall be picked up. Any shorter deadlines shall be clearly stated in any emergency preparedness plans.
Necessary measures: • All personnel in the helicopter must be equipped with survival suits. • Agreements with SAR helicopter must be in place. • If any emergency preparedness resources (e.g. helicopter) is out of service, alert proper authorities. Compensate or restrict operations.	

Helicopter activity outside the safety zone is not considered to be part of petroleum activities and is thus considered an aviation operation. Emergency response is then governed by aviation regulations and civil rescue services. [112] Any rescue operation will be coordinated by the Joint Rescue Coordination Centres (one is located at Sola, the other in Bodø). Resources will be brought in from the 330 Squadron Sea King Helicopters, SAR helicopters operated by the petroleum industry and vessels in the area of the incident. For their activities in the Barents Sea, Statoil and ENI have established a SAR helicopter service in Hammerfest.

As pointed out by Jacobsen [110]: *The sea conditions are directly comparable within the 500 meters safety zone and the sea over which the helicopter flies in order to reach the offshore facility. There is no logical safety reason why the 120 minutes requirement should not apply for the entire transport of personnel over water. The capability to rescue persons from the sea within 120 minutes should be considered as a normal requirement for the entire helicopter flight path.* This is now being covered in the requirements for the NAWSARH project, taking into account flights off the coast.

In appendix O a list of required equipment can be found, and in appendix P a *time to rescue* model is shown.

[57] The definition for this requirement can be found on page 50 in 104. Vinnem, J.E., *Retningslinjer for områdeberedskap. Underlagsrapport med dokumentasjon av forutsetninger og faglige vurderinger i Norsk olje og gass 064:2012, Anbefalte retningslinjer for Etablering av områdeberedskap*, 2012..

4.3.8 SUMMARY OF IDENTIFIED BARRIERS

This chapter has investigated necessary barriers for surviving a helicopter ditching and for having a successful rescue mission.

The identified barrier systems for surviving and being rescued are:

- Successful evacuation from helicopter
- Prevent Exposure to the elements
- Rescue

For flying when the transportation limits are not violated the barrier systems were:

- Flying when conditions allow
- Equipment functioning

The barriers that in the Norwegian Barents Sea are weakened and need improvement have been emphasised, and are in *italic.*

Successful evacuation from helicopter

- *Flying when conditions allow for a safe ditching*
- Helicopter remaining afloat
- *Helicopter Underwater Escape Training (HUET)*
- Improve helicopter stability in design
- Helicopter ditching training
- Pilots preparing for ditching
- *Preparing the personnel for what is going to happen*
- *Preparing the helicopter for ditching; including sending distress calls*

Prevent Exposure to the elements

- *Helicopter remaining afloat*
- *Survival suit*
- *Life raft*
- Helicopter stability
- Spray hood on the survival suit
- Sufficient buoyancy

Rescue

1. *Resources*
2. *Known location / locate victims*
3. Rules and regulations

For the barrier system resources there were four main performance shaping factors:

5. *Inadequate SAR resources*
6. *Extreme conditions*
7. SAR personnel unable to perform rescue

8. *Time*

Inadequate SAR Resources

The main barriers found were:

- Emergency preparedness planning
- Maintenance

Extreme Conditions

The main barriers found here were:

- *Weather forecast*
- Multi-layered rescue task force
- *AWSAR*

SAR Personnel Unable to Perform Rescue

The two main barriers here were:

- Training
- Equipment design

Time

Time is an important factor, and with colder water and greater distances it is likely there will be less of it. The two main barriers were:

- Information
- Rescue force in standby
- *Helicopter tracking*
- *Survival suit equipment*
- Night Vision Goggles (NVG)
- Infrared (FLIR/SLIR)

Lights and bright colours on the survival suits in addition to personal locator beacon (PLB, standard today) will greatly aid locating and rescuing victims. Should the victims need to enter the water, drifting apart from each other must be expected.

The main guidelines for the use of helicopter on the Norwegian Continental Shelf are:

- OLF guideline 066 [28]
- OLF guideline 095 [29]
- BSL-D 5.1 [30]

Threats Leading to a Ditching

- *Fly when conditions allow*
- *Equipment functioning*

The highlighted barriers

4. Main Analysis

These barriers were selected as being weakened in the Norwegian Barents Sea compared to the rest of the Norwegian Continental Shelf.

- *Flying when conditions allow for a safe ditching*
    - *Follow procedures, rules and regulation*
    - *Conditions may change rapidly*
- *Helicopter Underwater Escape Training (HUET)*
    - *Different in very cold water*
- *Preparing the personnel for what is going to happen*
    - *Emergency landing in cold and dark conditions*
    - *Zip-up survival suit. Colder water in the suit means more rapid cooling.*
- *Preparing the helicopter for ditching; including sending distress calls*
    - *Not different from the rest of the Norwegian Continental Shelf; however, with greater areas, these preparations become even more important*
- *Helicopter remaining afloat*
    - *Can provide more protection, however too risky to remain inside helicopter today.*
- *Survival suit*
    - Spray hood
    - Lights
    - Bright colours
    - Personal locator beacon (PLB)
    - Warm clothes (although the new SeaAirBarents is designed not to require special clothing underneath)
- *Life raft*
    - *Improved handling*
- *Resources*
    - *Potential lack of resources can be countered for in emergency preparedness planning. Isolation could cause problems for supplies.*
- *Known location / locate victims*
    - *Greater area and less time available to save victims upon arrival.*
- *Weather forecast*
    - *Poor quality at this point.*
    - *Polar lows are a major threat.*
    - *Predicting icing.*
- *AWSAR*
    - *More diverse weather. Conditions are covered in the NAWSARH project.*
- *Helicopter tracking*
    - *Emergency locator transmitter (ELT)*
- *Survival suit equipment (see: survival suit)*
- *Fly when conditions allow*
    - *Due to the possible increase in consequence, flying conditions must be monitored closely.*
- *Equipment functioning*
    - *Cold may affect equipment negatively, in addition to icing and problems with maintenance and spare part management*

4.3.8.2 ISSUES WITH REQUIREMENTS AND BARRIERS

One issue that was discovered when reading the requirements was the requirement for pilots to wear life jackets, or suits with buoyancy, when inside the helicopter. If the helicopter capsizes, wearing a life jacket or having additional buoyancy may make escape difficult. It is not until after leaving the helicopter that buoyancy is needed.

The use of EBS is difficult when the body is suddenly immerged in cold water.

4.3.9 RECOMMENDATIONS – DITCHING

The critical factors for this and other SAR operations in the high north are:

- Early warning
- Efficient and effective search
- Rescue resources on site quickly and coordination of the rescue operation
- Personal protective equipment

The results from this chapter are for a large part the same as Jacobsen [110] concluded with in his report. Recommendations 1-3 are the same as in his report. The general recommendations for a ditching event put forward in this thesis are:

1. The 120 minutes requirement for rescue within the safety zone should be required for the entire flight route.
2. The helicopter departure criteria should hold for entire flight route, not just within the safety zone.
3. Provide (voluntary?) training for cold water immersion. This way, crew members and other personnel can experience the effects and be better prepared; both physically and mentally, should the situation present itself. This will aid in many difficulties, for example; use of EBS, panic and cold water immersion shock.
4. Requirement to clothing worn under the survival suit for flights in the Norwegian Barents Sea.
5. Improve helicopter stability. The option of remaining in the helicopter for as long as possible is a factor that will separate victims from the elements for a prolonged period of time, delaying possible cold water immersion shock and hypothermia.
6. Tracking equipment is of utmost importance. Both for the helicopter and for the victims. Greater distance means less time and removing uncertainty such as location is paramount. PLB and ELT are a requirement on the Norwegian Continental Shelf today. A rescue planner could be developed; logging helicopter location, wind speed and direction, always calculating the fastest route.

4.4 MAN OVERBOARD (MOB)

Man overboard (MOB) is a critical situation where immediate action is necessary, and is also relevant for design of emergency preparedness on all types of facilities on the Norwegian Continental Shelf where work over water is performed. In the darker and colder conditions in the Norwegian Barents Sea a MOB situation may be more critical.

This thesis will not evaluate the general risk of having a MOB-situation (although it will be mentioned), but assume that the situation is already a fact, regardless of how it occurred.

MOB may occur to personnel where work and traffic over water is carried out. The consequences for MOB are purely on personnel. No damage to the environment or materials is considered.

4.4.1 DATA

MOB is an event that is dimensioning for emergency preparedness on every facility on the Norwegian Continental Shelf. It has proven hard to establish an overview of the total number of cases of MOB, due to the fact that events are not always properly reported if they do not lead to injury [89]. From 1990 until August 2007 there were no casualties in connection with MOB. One person, who disappeared from a production facility in 1999, is not included in the statistics.

The average for the period is one incident per year. During the last nine years there have been eight incidents from ships, and only one from a mobile facility. During a period of 22 years there have been four incidents on mobile facilities, and two from fixed installations. The two latter occurred in the first half of the 1990's. [89] The statistics from the period is shown in the figure below.

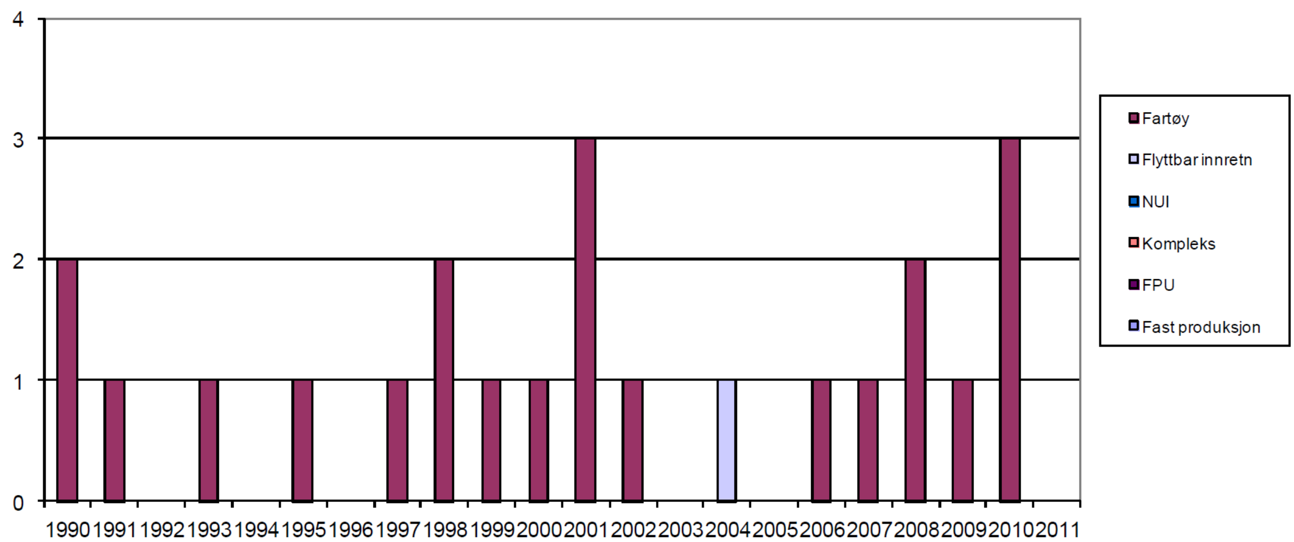

FIGURE 64 - MOB INCIDENTS. FIGURE FROM [89]

This figure suggests that there was a period, at the end of the 1990's and early 2000's, where there were more incidents. There is however not possible to state any statistical trends based on the data.

The average frequency of MOB incidents on the Norwegian Continental Shelf, including vessels that are a part of operations, are:

- Production- and mobile facilities: 3.2 per 10^8 work hours.

This frequency corresponds to a yearly frequency of MOB incidents on the Norwegian Continental Shelf of:

- 1.3 MOB incidents per year.

4.4.2 MOB – SCENARIO

Planned work is the basis for this scenario. The coldest probable scenario has been selected[58]. The argument for doing this is that the regulations and procedures should reflect the minimum time window for rescuing a person immersed in water. Criteria for work over water are facility specific.

- Time of year: January
- Water temp: 0 °C
- Air Temperature[59]: - 8 °C
- Wind Speed[60] [61]: 14 m/s. Boundary between Beaufort 6 and 7, strong breeze near gale.
- WCI: ~ -20 °C
- H_S: 3 m[61]
- Ice: N/A
- Weather conditions: Overcast, little or no precipitation. Polar night.

Fall did not cause any particular injury. The work being performed was scheduled and the alarm was raised immediately.

4.4.3 EVENT TREE – MOB

A simple event tree for MOB was developed. The event tree used the limitations from the MOB scenario. This simplified analysis will require further in depth development for a complete risk analysis. Some of the points require some explanation.

The MOB event tree is divided into two main paths; divided by whether or not the alarm is raised. When the alarm is not raised, it is assumed in this thesis that the incident will result in a fatality. This may occur in many ways, however with planned work being the foundation for this study; it is considered to have a very low probability of occurrence. Therefore the path analysis will focus on the situation where there is a MOB situation and the alarm has been raised.

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[58] It was not investigated whether this was beyond the permitted work conditions on facilities.
[59] January normal-average for Bjørnøya according to data from http://www.yr.no/place/Norway/Svalbard/Bj%C3%B8rn%C3%B8ya_observation_site/statistics.html
[60] Data from same source as temperature.
[61] In accordance with numbers used in the industry.

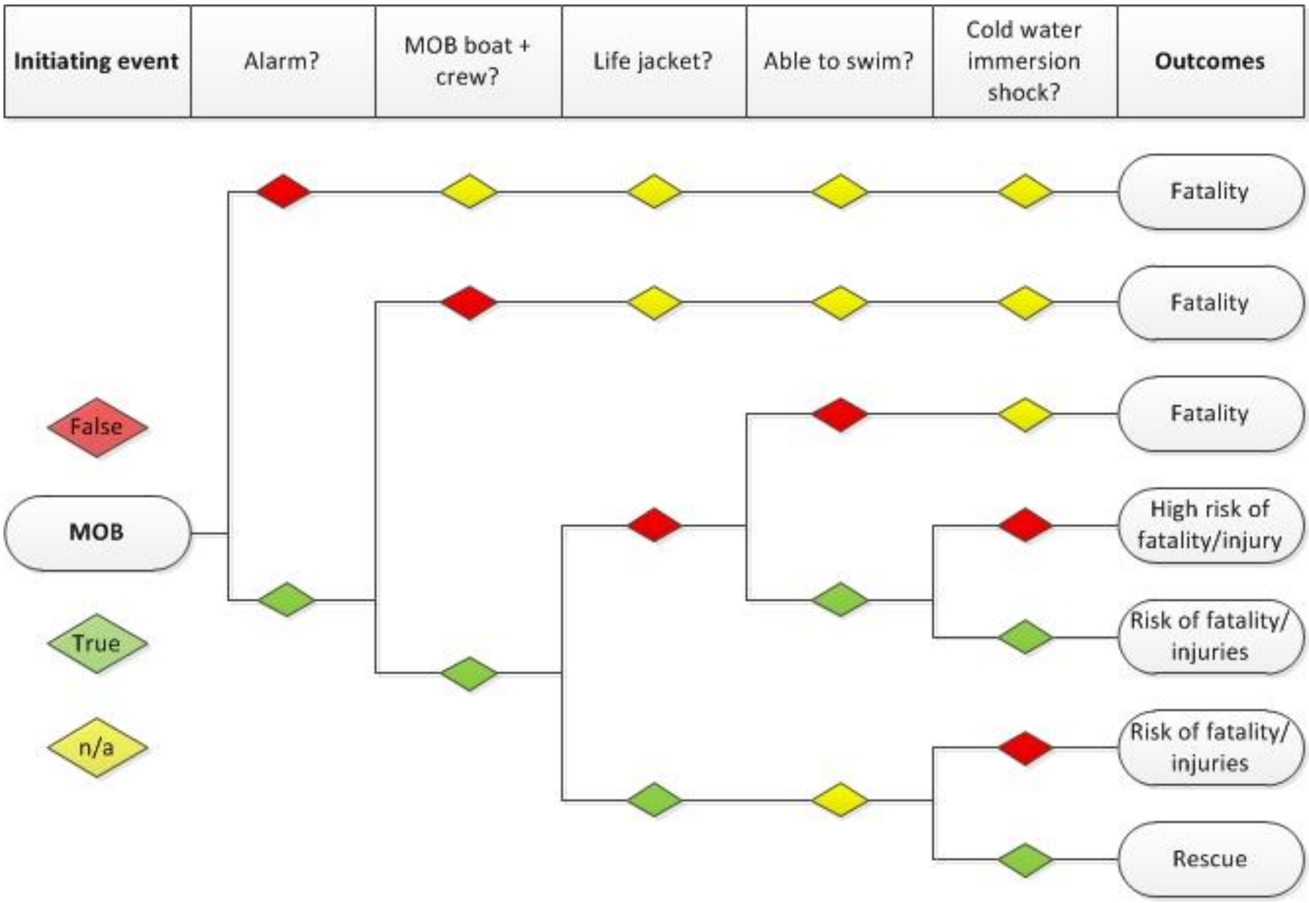

FIGURE 65 - EVENT TREE MOB

There are two possible main paths of interest:

A. Alarm is raised, and emergency response commences immediately.
B. Alarm is not raised, and the victim is lost.

Path A

Path A is divided into two:

A.1 MOB boat (and crew) available
A.2 No MOB boat available

A.1: When the alarm is raised, the MOB team should be ready and deploy the MOB boat immediately. A general requirement for work over water is weather; if the weather is more than the MOB boat can handle the work should not proceed. Life jackets (or other means of buoyancy) are required when working over water. In the event that a life jacket is not worn the probability of survival drops dramatically. Even if the victim is able to swim, cold shock is probable and may cause drowning within minutes or even seconds (see chapter 2.4). Should the victim manage to stay afloat through this, rescue may be successful. This will strongly depend on abilities to swim (which can be difficult considering clothing) and weather. With no MOB boat or crew (**A.2**), fatal outcome must be expected.

Path B

If no alarm is raised the victim is considered lost. This will not be discussed further in this thesis.

Comments to ET – MOB

- Rescue means pickup from water within 8 minutes.
- It is assumed that a person working over water is wearing clothes that make the person concerned visible.
- MOB boat is the preferred mean of rescue; however other means of rescue may be applicable. “No MOB boat” means that no mean of rescue is available, thus the victim is lost.
- Cold water immersion shock is the biggest threat when the victim is in the water. In any of the cases where proper means of rescue are available, and the alarm has been raised; cold shock and drowning are the biggest issues.

4.4.4 BOW TIE ANALYSIS – MOB

The bow tie analysis was performed using the available information about human factors and emergency preparedness.

There were two levels to this analysis;

1. The MOB
2. The rescue task force.

The first part of this bow tie analysis was the event tree presented and discussed earlier in this chapter. The main issues were to isolate the victims from the elements, with two main possible fatal outcomes; cold shock, and unable to stay afloat.

4.4.4.1 THE MOB

The hazard was defined as work over water, with the associated top event of *MOB “not safe”.* Safe means here that the only thing standing between the victim and survival is rescue. The victim is positively buoyant with head over water and not suffering cold shock.

The main threats were:

- No alarm
- Insufficient buoyancy
- Cold
- Work operation limits violated.

More specific barrier elements were used in the first part of this bow tie, responding to concrete threats. The second part has more focus on the barrier functions.

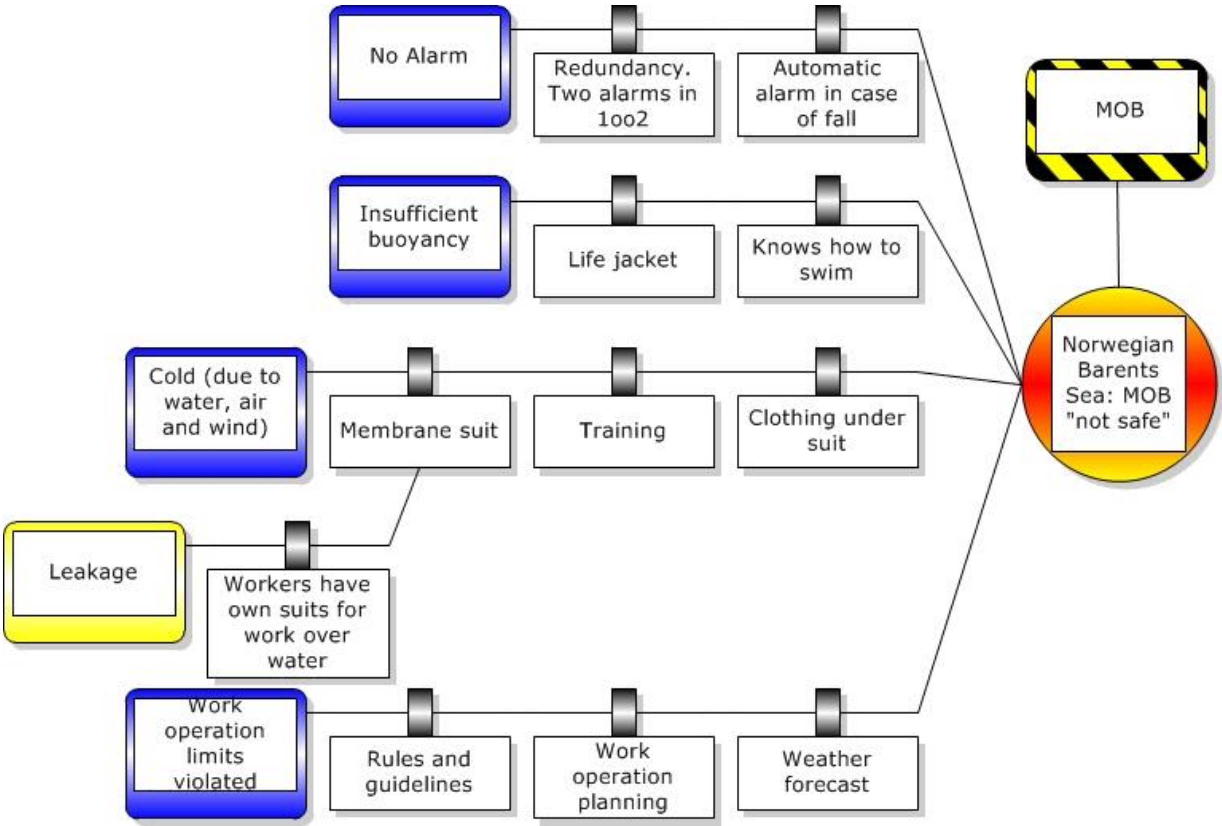

FIGURE 66 - BOWTIE (LEFT HAND SIDE) MOB

No alarm

The alarm is meant to be raised by an observer. It would not take much effort to expand this by applying some form of alarm that tells if the worker is not connected to a harness, or when the person hits the water. Having redundancy in a 1oo2 (or more) system would limit potentially fatal errors.

Insufficient buoyancy

Insufficient buoyancy can be counteracted by having the worker wear a life jacket (a requirement today), and also requiring the worker to be able to swim.

Cold

The cold is still an issue, although hypothermia is not regarded as an issue. The industry norm is to pick the person up within eight minutes, which is before hypothermia will be a problem. Wearing a worker membrane suit would protect a victim in the water from the worst heat loss. Also, requiring specified clothing underneath would be of great assistance. Leakage into the suits could be a problem. A simple way of fixing this issue is for the workers to have their own set of clothes for work over water.

Work operation limits violated

Work operation limits violated are important both for the worker and for the rescue crew. If work commences in conditions beyond what the rescue team can handle. Important barriers here are rules and guidelines, and operation planning. This also includes fulfilling the requirements for emergency preparedness such as having the MOB crew ready.

The figure below illustrates the consequences and the barriers.

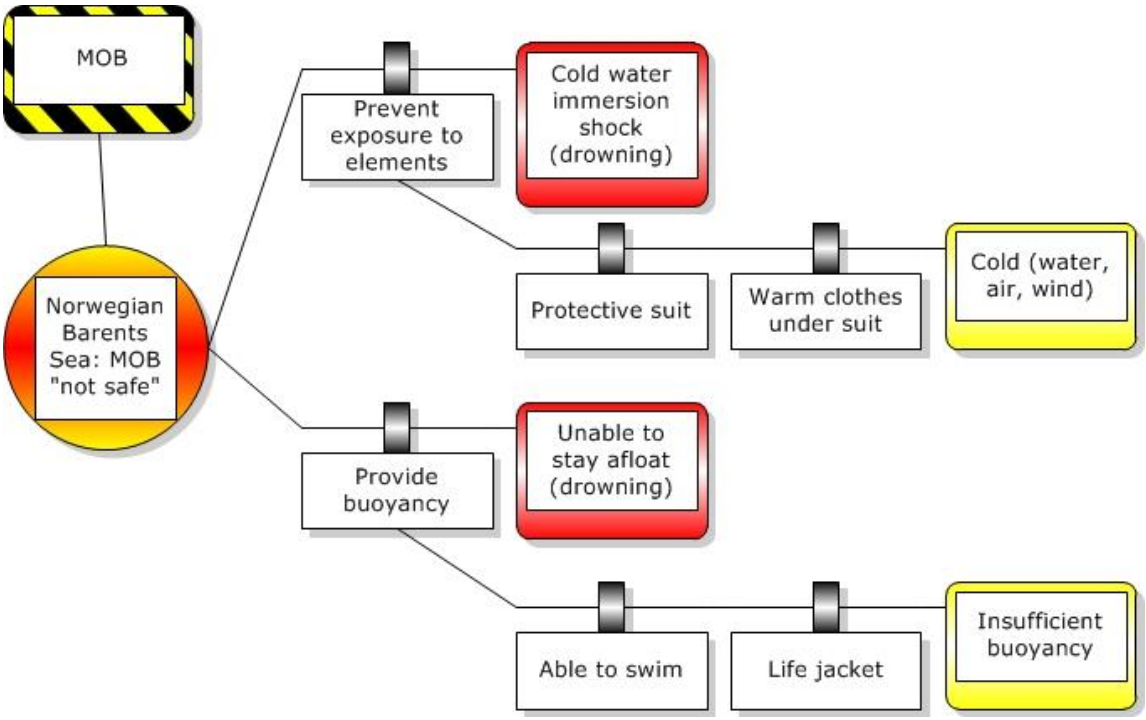

FIGURE 67 - BOW TIE (RIGHT HAND SIDE) MOB

Due to the selection of unwanted event, the consequences and the threats are closely linked. Why the MOB situation occurred was outside the scope of this thesis.

The two unwanted consequences both involve fatality; the cold and ability to remain afloat are key factors. The two barriers were thus:

- Prevent exposure to elements
- Provide buoyancy

Both were discussed in the section above. One threat that was not included here, but was included in the helicopter ditching scenario, was "water in respiratory system". It was assumed that this would, like hypothermia, not be an issue. The cold shock, in addition to the initial fall, will be the main threats that could lead to water in the respiratory system.

4.4.4.2 THE RESCUE TASK FORCE

The rescue task force will for a large part face similar challenges as the rescue task force in the helicopter ditching scenario. An overview of the threats that may lead to a "failed rescue" is presented below.

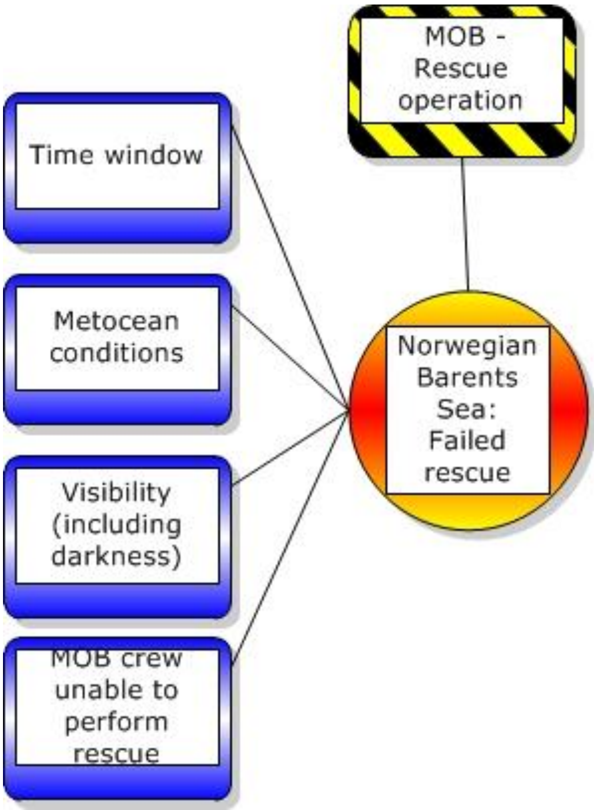

FIGURE 68 - BOW TIE MOB, RESCUE

The consequence of a failed rescue is fatality and is not discussed further in this chapter.

The main threats to the rescue mission were:

- Time window
- Metocean conditions
- Visibility (including darkness)
- MOB crew unable to perform rescue

Both metocean conditions and visibility were discussed in the analysis of the helicopter ditching and will not be discussed in detail here.

Time window

The person performing work over water cannot be expected to wear the same survival suit as a helicopter passenger. The two main barriers here, as illustrated in the figure below, were:

- MOB crew ready when work over water begins
- MOB extra protection

Limiting the time to mobilise the MOB crew while at the same time providing the MOB with additional protection will assist in making a faster rescue operation, and increase the safety of the MOB.

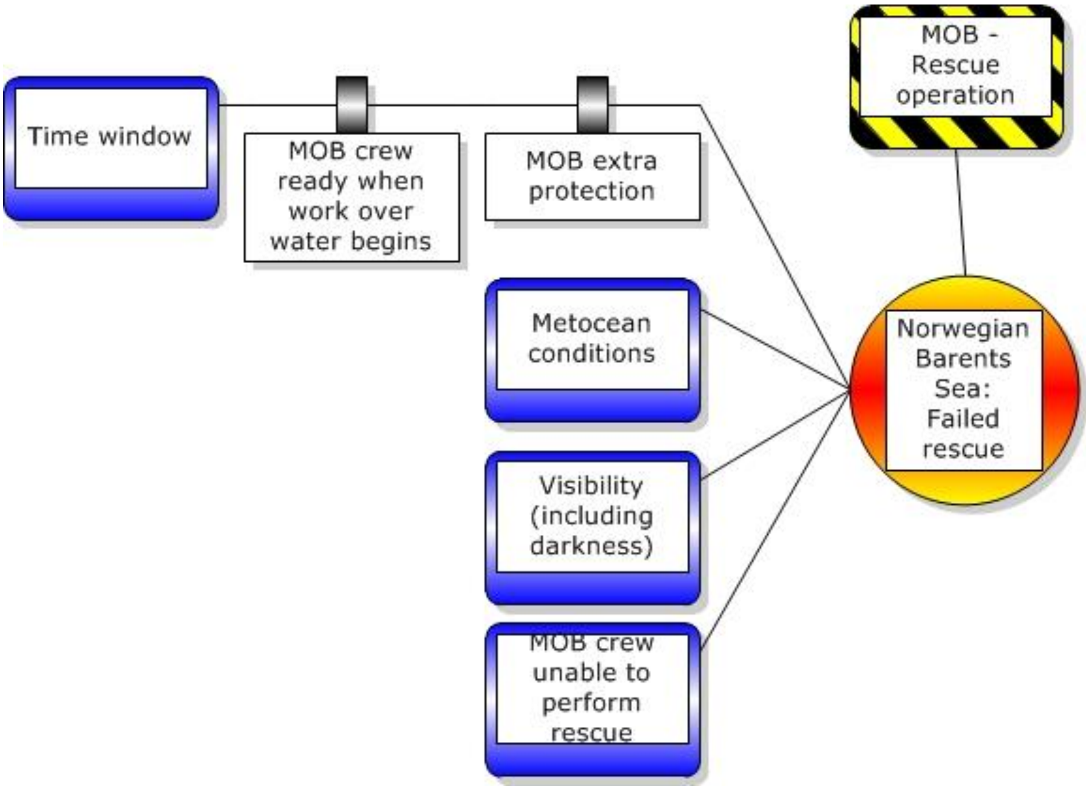

FIGURE 69 - BOW TIE MOB, RESCUE, TIME WINDOW

Metocean conditions

The metocean conditions are of great concern for a MOB situation. Metocean conditions were discussed in the helicopter ditching scenario, and will be discussed further in the threat “MOB crew unable to perform rescue”.

Visibility (including darkness)

This was discussed in the chapter on helicopter ditching. The advantage in this scenario is that the MOB should be watched at all times, and thus the location should be known. Still, the same barriers as with a helicopter ditching should be applied. Figure 70 illustrates the main barriers.

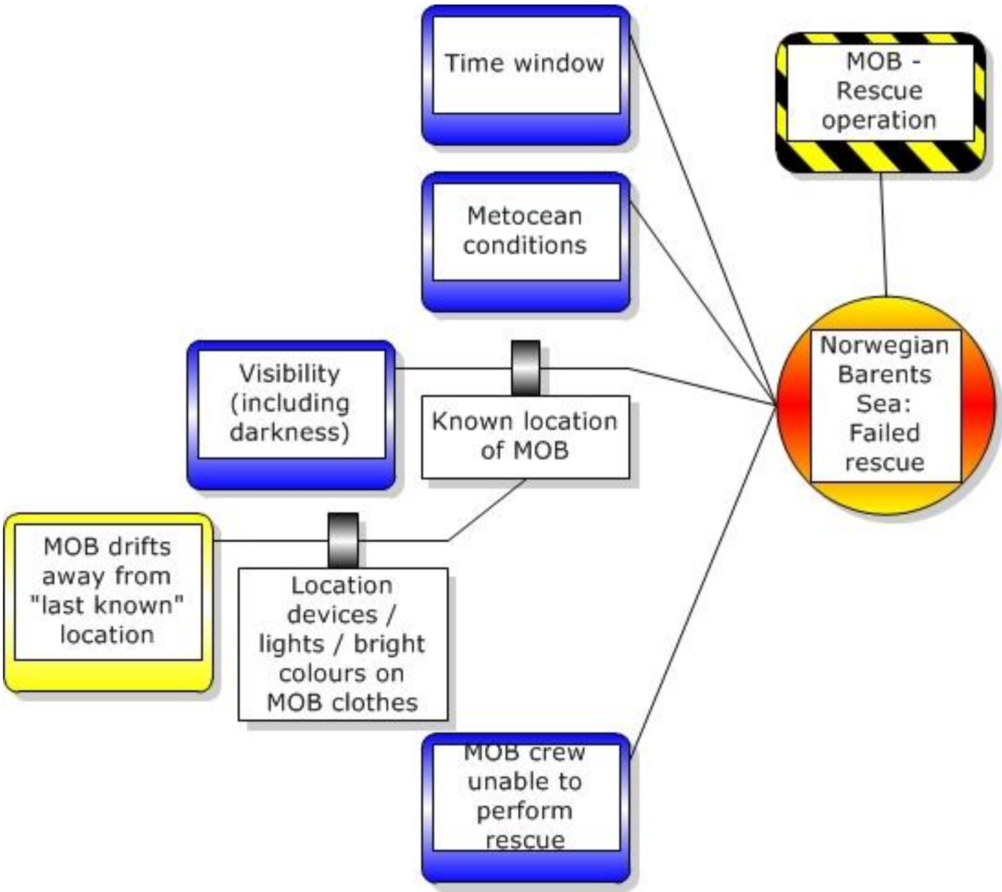

FIGURE 70 - BOW TIE MOB, RESCUE, VISIBILITY

MOB crew unable to perform rescue

This threat is similar to the one discussed in the helicopter ditching scenario. The main barriers are

- Resources
- Within limit conditions

Figure 71 illustrates the main barriers for this threat.

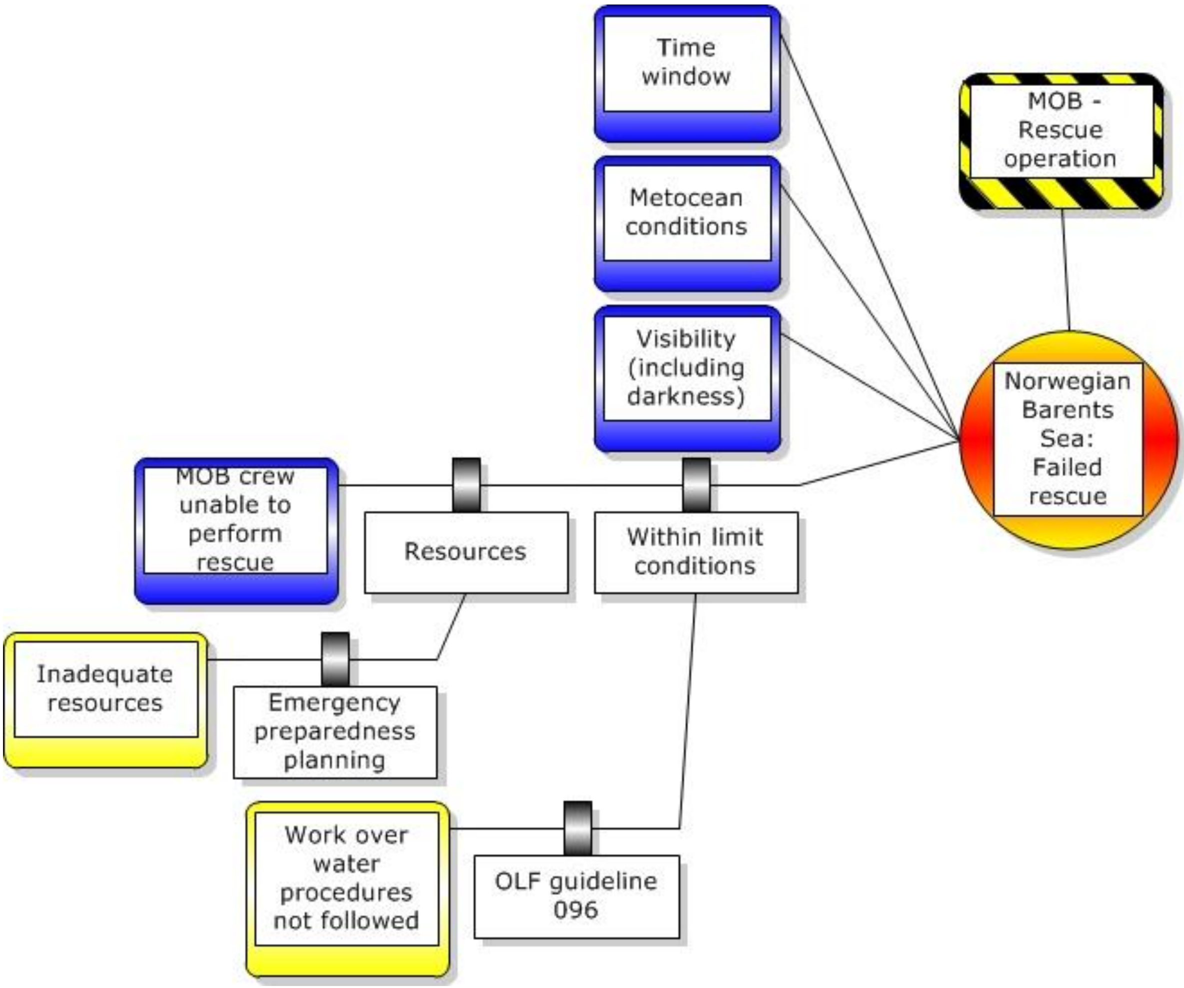

FIGURE 71 - BOW TIE MOB, RESCUE, MOB CREW UNABLE TO PERFORM RESCUE

Resources necessary to perform a rescue includes MOB-boat, properly trained crew and other equipment needed for a rescue. This was discussed in more detail in the chapter on helicopter ditching. Proper emergency preparedness planning is a key factor here. MOB is often a design factor for emergency preparedness on an installation.

Within limit conditions refer to the rule that work over water should not commence if the conditions don't allow a rescue. This is stated in OLF guideline 096 [113]. If these conditions are not met, the MOB crew are in too great danger if they attempt to rescue the MOB.

4.4.5 CURRENT RULES

The industry norm for MOB-emergency preparedness is the OLF-guideline 096. The current requirements for prevention of MOB-situations are used for operations in the Norwegian sector:

TABLE 14 - CURRENT RULES MOB

Man overboard in the case of work over water	
Warning	**Comments**
Dedicated response personnel for MOB situations shall be oriented before any work over water.	"Oriented" meaning that the response personnel shall know when and for how long the work over water will last. MOB-response can be covered by an emergency response vessel. By dedicated response personnel is meant the MOB-crew.
When working over water, means enabling immediate warning in case of MOB shall be in effect.	In a MOB or suspected MOB-situation, the control room shall be warned,
Rescue	
MOB-victims shall be picked up from the water before there is danger of hypothermia.	The industry norm for picking up personnel not equipped with survival suits is set to 8 min.
MOB-vessel with crew and crane operator shall at all times be ready when work over water is taking place.	

The demand for pickup within eight minutes holds for the time when work over water is taking place. Situations involving MOB will generally happen when work with scaffolds are taking place, or climbing is performed. These do not exclude to possibility of persons falling in the water for other reasons. These are however not considered as dimensioning for emergency preparedness.

4.4.6 ISSUES

The main risk when falling into cold water, apart from the fall itself, will be cold shock (see chapter 2.4) and buoyancy. Requirements to workers and work over sea are in general facility specific. Life jackets are mandatory; however clothing is in many cases not specified.

Escalating factors are such as; the weather (wind, current, visibility and temperature), failure of MOB-boat or crane, the observer loses visual contact with victim and improper use of communication equipment.

4.4.7 RECOMMENDATIONS – MOB

The requirement is already eight minutes from the alarm is raised until the MOB should be picked up. This study has not found any reason to shorten this time further. The issue is the initial cold shock, and hypothermia will not be an issue within this time window. Protection against the cold shock and sufficient buoyancy are therefore two vital elements in survival. The requirements to work clothing are often location specific (with the exception of wearing a life jacket, which is mandatory), and some installations already require a special suit to be worn.

Having the MOB crew ready should be required and this is also already in the requirements. Section 6.3 in OLF 096 specifies how being a MOB crewmember can be combined with daily tasks. They shall not have other tasks that may interfere with the role as a MOB crewmember.

5. MAIN DISCUSSION

Is it possible to go north and is it worth it from an economical perspective? These questions are fundamental for development of the high north. During the writing of this thesis, several projects in the Arctic have been put on hold, or even shut down. At the time of writing, it seems as if the Barents Sea is the only area that will see any development in the immediate future. With recent developments in the petroleum market, such as the US becoming a net exporter of petroleum products for the first time since 1949, shale gas and oil sands, question has been raised as to whether going north is actually profitable. Gas-on-gas competition will definitely challenge development in the Arctic. Shale gas, coal seam gas (CSG) and liquefied natural gas (LNG) have increasing non-frontier estimates, at less cost with lower environmental risk compared to Arctic gas. And for most of the Arctic Ocean, recent developments, for example with Shell in the Chukchi and Shtokman in Russia, suggest that the Arctic is within reach; however not yet profitable.

The Norwegian Barents Sea seems to be an exception. There are good reasons for this as have been discussed in this thesis. The conditions in the Norwegian Barents Sea seem to be more favourable than the rest of the areas north of the Arctic border.

Is the Norwegian Barents Sea really worse?

It is interesting to note that popular belief seem to be that the operational challenges in the Norwegian Barents Sea are significantly different and worse than on the rest of the Norwegian Continental Shelf. It has not been investigated in this thesis, but it would be interesting to compare the debate regarding the Barents Sea with what happened around 1970 when Norway first began oil production.

Data provided by the Norwegian Meteorological Institute indicate that greater wave heights are recorded on the Statfjord field in the North Sea than in the Barents Sea and offshore Lofoten and Vesterålen. To many peoples surprise there is on average more daylight in the north than in the southern parts of the Norwegian Continental Shelf. The summer nights compensate for the Arctic winter; however, operations in the Arctic night will still be necessary and more demanding. While it is colder in the Barents Sea, it is not that much colder in the area of interest in this thesis.

Icing and a low number of weather observation stations seem to be the main issues differing from southern parts of the Norwegian Continental Shelf. In the part of the Barents Sea which has been opened for petroleum activities, this type of icing usually occurs in coastal areas, caused by the strong, cold winds from the south and southeast. This kind of icing does not present any distinct limitations for oil spill protection operations other than those already found in other contingency regions on the Norwegian shelf. The small scale weather systems that may develop can at this point avoid being detected by the coarse observation network. Installing more weather data buoys and other equipment for gathering weather data should be a small cost in the bigger picture.

The main concerns found in the Norwegian Barents Sea are less significant than what is the case for the rest of the Arctic Ocean. Various types of sea ice may be an issue in the far eastern parts, and measures should be taken; however the absence of sea ice in general and the less rough weather conditions (with the exception of polar lows) makes the Norwegian Barents Sea a feasible option for petroleum activities.

The big problem with the Norwegian Barents Sea at this point seems to lie in the infrastructure and logistics. Reports studied during the writing of this thesis all point to the lack of a developed infrastructure in the area as vital. Comparisons made often consider the rest of the Norwegian Continental Shelf as being safer because of the fact that it is developed. The challenge for the petroleum industry in the Norwegian Barents Sea thus becomes to develop, while maintaining an acceptable level of risk and safety.

As safe as the North Sea?

Acceptable risk and safety are hot topics; what is acceptable? Currently, equal risk as the rest of the Norwegian Continental Shelf is acceptable. With risk being a function of probability and consequence, and the consequences considered greater in the north, probability must drop.

As mentioned, some of the issues discussed in this thesis suggest that the main problem with operations in the Norwegian Barents Sea is underdevelopment. The lack of area emergency preparedness, great distances between installations, lack of quality weather forecasts and other data are amongst the key factors. [110] concludes that "*With regard to the hypothesis "All year petroleum activity is not possible everywhere in the Barents Sea with regard to emergency preparedness unless sufficient attention is given to critical factors influencing evacuation and rescue" it may be concluded that the hypothesis stands and that there are issues that must be resolved in order to facilitate all year activity.*"

This refers to a rescue point of view, where, as pointed out in this thesis, there are holes in the rescue capacity, with areas beyond the reach of the solutions used today. With more development the consequences should be expected to go down for some scenarios, such as the ditching scenario. Time to rescue should be expected to drop, and in general, help will be closer. The claim that the consequences are worse holds for most of the scenarios possible for as long as the area remains underdeveloped; although not necessarily significantly worse. For the operational scenarios investigated in this thesis, there is no indication that the operational risk will increase by any significant number. It also depends on whether one is looking at human, asset or environmental risk. If for example disconnection is necessary in an offloading operation, small spills may occur, but no real danger to people or equipment is expected.

When talking about risk reduction in the Norwegian Barents Sea, probability is the key factor that must go down. For the emergency preparedness scenarios studied in this thesis, there should not be an increase in consequence, if the new survival suits function as intended, and the area emergency preparedness is improved; which will happen in time. The frequency of helicopter ditching and man overboard incidents may not change at all compared to the rest of the Norwegian Continental Shelf. Helicopters must be equipped with de-icing equipment, procedures for safe flight must be followed, but other than that there is no reason to believe that operational conditions will change in a manor causing more ditchings. In the MOB scenario, the use of a protective suit to assist against cold shock and strict regulations on work permits is already a requirement in many areas, and should be followed up closely in the Norwegian Barents Sea.

For offloading and flotel operations, rapid weather change may cause an increase in drift off incidents. With warning systems in place, ST and flotels should not have any problems with handling the weather, or moving away to a safe position in time. For the case of the flotel; the probability of being hit by a polar low without any warning from the worst possible angel seems remote. And with the new set up that will be applied at the Goliat field for offloading; the operational risk will go down. The Barents 2020 phase 3 report states that the number of incidents in offloading operations will not change. The research made for this thesis indicate that there may be a small increase in drift off incidents due to rapid weather change; however, with the available data it is hard to say anything about whether this is a significant increase; the evidence point towards an insignificant one.

In order to keep the risk level the same as for the rest of the Norwegian Continental Shelf, some measures must be taken. These are however not very different from the measures that are required on the rest of the continental shelf. [110] mention several important aspects such as; operational planning, critical issues related to helicopter transport and rescue and sound risk management. In risk management, ALARP is the typical requirement applied today. Several reports highlight the importance of ALARP. [110] also emphasise that; *It must not be forgotten that the minimum requirements in the regulations shall be met and then the ALARP requirement shall be applied additionally*. The Management regulations [114] state that *The operator shall set acceptance criteria for major accident risk and environmental risk.* This has in many cases led to the interpretation of ALARP as “As Little As Possible”. Follow-up of the criteria may be an effective way of reassuring the public that the operations are safe (or not).

Risk communication and key takeaways

Communicating the risk in the Norwegian Barents Sea is a three-headed beast. Industry partners seem to agree on the challenges and risks, and that they are not significantly different or worse than in the North Sea. The media tend to focus on the environmental aspects, mainly due to the fact that this creates more sensation-news, and therefore sells. The third head, the general public, is thus presented with a somewhat biased view. This is a major problem because public opinion matters, and quite considerably. Understanding the results of a risk analysis that are expressed in small numbers can be hard for the analyst; and much worse for persons with no experience. The consequence has a tendency to become the focus, not how likely it is that it will occur. Worst-case thus becomes the focus. More general “small” issues such as everyday safety of offshore personnel are then forgotten.

One of the key takeaways from this thesis is in fact the importance of risk communication. The analysis has not shown significant added risk, and in most areas, conditions seem favourable compared to the North Sea. This corresponds well to the conclusions made by sources researched for this thesis. So how should the industry communicate this? This thesis cannot claim to solve this question. One important point is that; if activity in the North Sea is accepted, and if the Norwegian Barents Sea is not worse, why is it that the opposite seems to be the public conclusion? The weather conditions differ from the North Sea with; lower temperatures, icing, more fog, heavy snowfalls, and most importantly; sudden change. Features that are worse in the North Sea are waves and wind.

Another key takeaway is that special attention must be paid to operation planning and emergency preparedness. The reason for this is not that the Barents Sea is significantly more dangerous than the rest of the Norwegian Continental Shelf, but because of the underdevelopment. The scale of the operation therefore becomes bigger than what it would have been in the North Sea, but only because that particular operation must be prepared to handle more on its own. A recommendation is thus: if the industry is moving into the Norwegian Barents Sea, go all in. Getting a similar infrastructure and area emergency preparedness is necessary for keeping the same risk level as the rest of the Norwegian Continental Shelf. The easiest way of doing this is thru a gradual advance. This way, learning from conditions as the industry gradually moves north will improve the safety, while at the same time allowing technology to develop. It is important that equipment, organisation and working methods are designed for the Barents Sea environment. This will reduce the probability of undesired incidents.

The quality of this analysis

Bow tie analysis has been the core in this thesis for understanding the barriers involved. Barriers have been an important topic for risk management for some time. It is therefore interesting that it was not until relatively recently that a common terminology was defined. Special attention was made towards barrier functions in this analysis. Earlier it was more common to focus on the individual barrier elements, however functions are considered more important for breaking down the problem, and also makes it easier to find barrier elements that occur on multiple levels. While the bow tie method is a good way to graphically present, in a simple and qualitative way, complex systems or processes, it also requires a high level of knowledge.

With limited previous knowledge and experience about the operations and scenarios this required a significant amount of research. The knowledge and expertise was obtained gradually through working with this thesis; still, some information may have slipped through or may not have been available or provided. The simple fact that some sources did not reply may have affected parts of the analysis.

Due to the limited use of numbers in this thesis, not much uncertainty is expected here. The example calculations performed in chapter 4.2 are only meant as rough indications. They omit certain factors end are thus not correct. They are intended for giving a sense of the time frame from drift off until collision and the possible impact energy. The numbers provided by the DNV model were not questioned as the tools necessary to check them was unavailable. A remark was raised as to the possible optimistic assumption of the DP operator's reaction time. The general uncertainties in the Barents Sea have not been investigated in this thesis; however, issues such as weather forecasts and little observation data are among the factors that contribute to greater uncertainty.

"The North Sea is an area with severe weather conditions, but we have carried out safe oil and gas operations here for forty years. Many people like to think that the Barents sea is significantly rougher, but that simply isn't the case,"

Sjur W. Knudsen, Managing Director of the Norwegian Clean Seas Association for Operating Companies (NOFO) [115]

6. CONCLUSIONS

Is it possible to carry out the operational scenarios? And is it feasible to handle the emergency preparedness scenarios selected in this thesis? The research performed for this thesis indicates that the answer to these questions is *yes.*

The operational scenarios, particularly offloading, may require some special attention in planning and during operation. The rapid weather changes that occur in the area may happen during an offloading. Making the setup used at the Goliat FPSO for offloading a standard in the Norwegian Barents Sea should be done.

The emergency preparedness scenarios, as with the operational scenarios, require some special attention. For the case of MOB no significant differences were found when compared to the North Sea. Emphasis on wearing of a special suit, preventing cold shock, was the only remark. The requirements for helicopter flights in the Norwegian Barents Sea and for rescue are for the most part sufficient. Three recommendations (mainly the same as in [110]) were made for helicopter flights in the Norwegian Barents Sea;

1. The 120 minutes requirement for rescue within the safety zone should be required for the entire flight route.
2. Requirement to clothing worn under the survival suit for flights in the Norwegian Barents Sea.
3. The helicopter departure criteria should hold for entire flight route, not just within the safety zone.

A final remark for the issue of rescue; the helicopters in use today, with the bases that are available, are not able to cover the entire part of the sector that has been looked into in this thesis.

In chapter 3.4.1 it was suggested rephrasing the DNV definition for *Performance shaping factors* (factors that are influencing the performance of the barrier) to *factors of importance for barrier functions and barrier elements ability to perform as intended*. The reason for this was that definitions should avoid circularity.

Are the conditions in the Norwegian Barents Sea rougher than on the rest of the Norwegian continental shelf? Considering the information that was available for this thesis, the answer is *no.* There are some differences, but the conditions cannot be said to be rougher. The availability of operations will in general not be affected much. For the case of offloading, the operation may be interrupted by a polar low. This will not be dangerous, but will cause unavailability. Flotels may also be required to disconnect, but there is no indication to this happening more frequently in the Norwegian Barents Sea.

It is possible conduct operations in the area now opened in the Norwegian Barents Sea without unreasonable costs. The low level of development in the area may for the time being give longer lead times for projects, however for the operations mentioned; the costs are not expected to unreasonably high. Transportation of oil after offloading may be an added cost due to relative distances, but not significantly higher than what is already experienced in the North Sea.

7. RECOMMENDATIONS FOR FURTHER STUDY

There are several areas that are in need of further study, and several that are being studied. As mentioned in the discussion, the expertise necessary for performing this analysis was obtained as the project progressed. When writing the discussion, some relevant issues became clearer and could have been investigated further.

A main contributor to raising the risk level in the Barents Sea is underdevelopment. A question raised by many is how development should be made in the area. For onshore activities, a lot of improvement to current infrastructure and availability are being done or researched. For offshore activities, there is a need for the same "area development" that is in the North Sea.

Polar low warnings must be improved. The current forecast of 6-12 hours for most polar lows is sufficient for the safety of the operation; however, not good enough. The number of disconnections should be kept to a minimum and the number of interrupted operations the same.

Emergency preparedness in Finnmark needs to be looked into. The research done for this thesis has found that hospital capacity in the region is too low should a major accident occur.

While it has been mentioned several times in this thesis that ice (excluding icing) is not an issue for the area investigated; the effects of sea ice and icebergs must be taken into consideration design and operational strategies, especially in the far eastern parts.

The requirement for helicopter pilots to wear life jackets while flying should be looked into. It was not specified in the requirement what kind of life jacket that was to be worn. In the case of the helicopter capsizing, the life jackets will initially hinder the pilots in the evacuation, unless the lifejackets are of a type that manually inflates when outside of the helicopter.

The effect of training in cold water should be investigated, and consider providing voluntary courses. [110] has a similar remark in the recommendations where;

a) Personnel are exposed to cold water. Experience the effects and learn how their body and mind reacts.
b) Personnel are exposed to simulated conditions that may be experienced in an evacuation.

The option of using the helicopter as shelter after a ditching should be looked into. This is not considered feasible today due to poor helicopter stability on water.

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APPENDIX

APPENDIX – A. ABBREVATIONS

ACC	Civil aviation authority
ADS-B	Automatic Dependent Surveillance – Broadcast
AIS	Automatic Identification System
ALARP	As Low as Reasonably Practicable
AooB	"A out of B"
AWSAR	All Weather Search and Rescue
cm	centimetre
DNV	Det Norske Veritas
DOF	Degree of Freedom
DP	Dynamic Positioning
EBS	Emergency Breathing System
EER	Evacuation, Escape and Rescue
EFS	Emergency flotation system
ELT	Emergency locator transmitter
EQD	Emergency Quick Disconnect
ERV	Emergency rescue vessel
ETA	Event tree analysis
FAD	Frost action damage
FLIR/SLIR	Forward/Sideways looking
FPSO	Floating Production, Storage and Offloading
FRDC	Fast rescue daughter craft
FSU	Floating Storage Unit
ft	Feet
FTA	Fault tree analysis
HF	High frequency
HIFR	Helicopter in-flight refuelling
HRA	Human Reliability Analysis
H_S	Significant wave height
HSE	Health, Safety and Environment
HSE UK	Healt and Safety Executive UK
HUET	Helicopter Underwater Escape Training
IEA	International Energy Agency
ISO	International Organization for Standardization
km	Kilometre
kts	Knots
LNG	Liquefied Natural Gas
m	metres

M-ADS	Modified-Automatic Dependent Surveillance
MF	Medium frequency
min	minutes
MJ	Mega Joule
MOB	Man overboard
Mt	Metric tonne
NCA	Norwegian Coastal Administration
nm	Nautical mile
NMI	Norwegian Meteorological Institute
NOAA	National Oceanic and Atmospheric Administration
NORSOK	Norsk sokkels konkurranseposisjon
NPD	Norwegian Petroleum Directorate
NPRA	Norwegian Public Roads Administration
NS	Norsk Standard
NTNU	Norwegian University of Science and Technology
NVG	Night vision goggles
o.e.	Oil equivalent
OLF	Norwegian Oil & Gas
PFM	Powered forward movement
PLB	Personnel locator beacon
PSA	Norwegian Petroleum Safety Authority
RS	Redningsselskapet
S.m3	Standard cubic metre
SAR	Search and Rescue
SPAR-H	Standardized Plant Analysis Risk Model
ST	Shuttle tanker
UFM	Uncontrolled forward movement
UK	United Kingdom
UKOOA	United Kingdom Offshore Operators Association
VHF	Very high frequency
VTS	Vessel Traffic Service
WCET	Wind chill equivalent temperatures
WCI	Wind chill index
WMO	World Meteorological Organization

APPENDIX – B. CLIMATE IN THE BARENTS SEA

There are many sources of information concerning the climate of the Arctic, and it is not the purpose of this report to investigate the conditions in the Barents Sea beyond what has been previously performed by others. The main sources used in this report are ISO 19906:2010[5] and Norsok N-003 Edition 2 September 2007 [116] As well as the PTIL report *Evacuation from Petroleum Facilities Operating in the Barents Sea [11]*.

The area of concern in this report is the areas of the Barents Sea that are opened for Norwegian petroleum activity and corresponds to the southern half of area II (figure 3), Western Region in ISO 19906. This area is described as having a winter climate all year, and the climatic issues and characteristics in the following sections have been recognized as relevant to operations in the Barents Sea.

In the Arctic, weather can change quickly. The weather stations are sparse, and the weather forecasts are in general more uncertain due to satellite constraints. The temperature range in some areas, both summer to winter, but also within single days, means that designs have to be adapted and special materials must be used for Arctic construction. [60]

AIR TEMPERATURE

According to [5] p. 407, the maximum average annual value in the western region is 4,4 °C, with a range of annual temperatures of 2,0 to 7,0 °C. As can be seen in figure 75, the maximum temperatures that can be expected can be found in the southwest areas near Goliat and Snøhvit, and lie in the range of 20 to 25 °C. Further north the maximum temperatures decrease towards a range between 15 and 20 °C. However, the number of days with these extreme temperatures are not taken into account in [116].

The minimum average annual temperatures in the western region is -7,7 °C, with an annual range of -6,0 to -9,0 °C. As can be seen in figure 75, the minimum temperatures range from -15 °C in the southern parts, to -20 °C further northeast and down to -30 °C further north. Again, [116] does not give an estimate for the number of days with these extremes. For Bjørnøya, the Norwegian Meteorological Institute has a report on temperatures, ice and icing where they have measured quarterly temperatures. The report is on Svalbard and the surrounding area, north of the selected area for this report, however, Bjørnøya is included.

TABLE 15 - QUARTERLY AVERAGES OF OBSERVED 2 M AIR TEMPERATURE (T2) IN DEG C FOR SELECTED STATIONS [10].

	Bjørnøya	Hopen	Isfjord	Longyear	Ny-Ålesund
January-March:	-6,91	-12,65	-11,79	-13,68	-12,76
April-June:	-1,17	-4,74	-3,60	-3,62	-3,62
July-September:	4,26	2,15	3,65	4,18	3,26
October-December:	-3,06	-7,09	-6,90	-8,39	-8,12

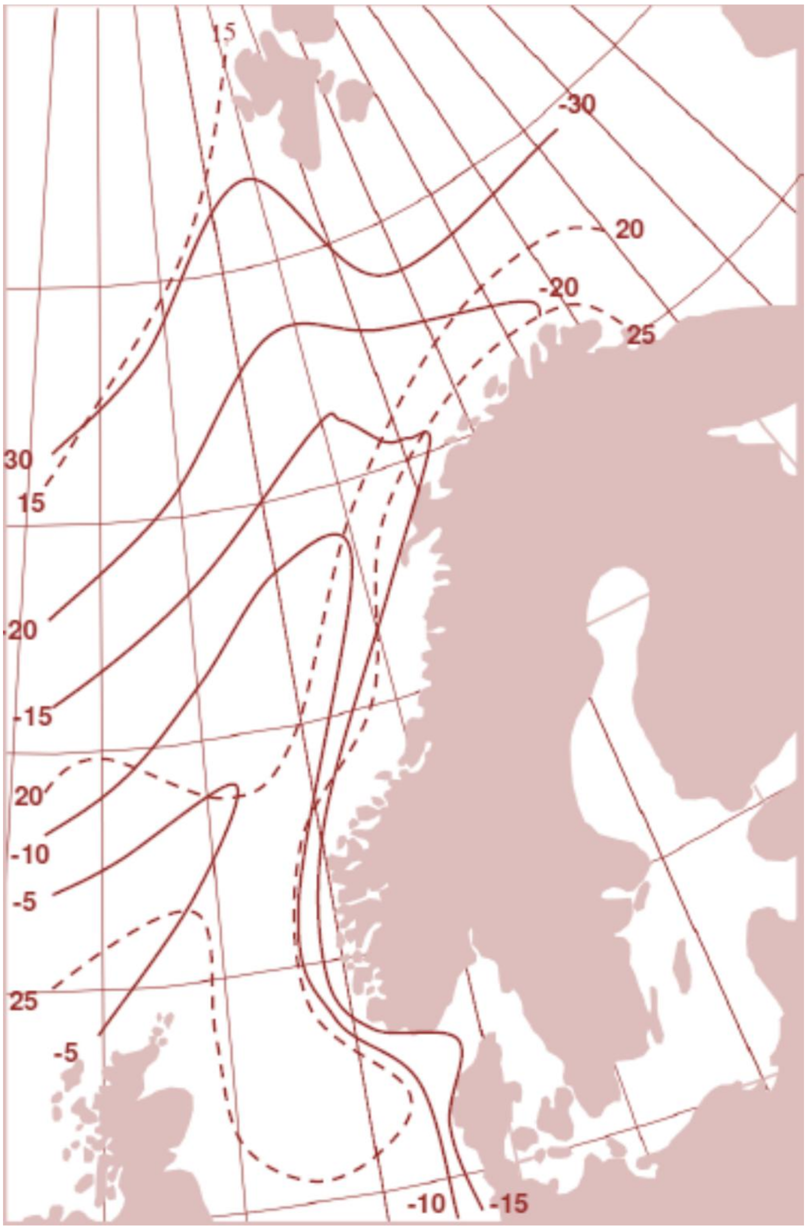

FIGURE 72 - HIGHEST AND LOWEST AIR TEMPERATURES WITH AN ANNUAL PROBABILITY OF EXCEEDENCE OF 10^{-2} (ALL TEMPERATURES GIVEN IN °C) [116]

SEA TEMPERATURE

According to [5], the average annual summer surface[62] maximum temperature is 9,0 °C, and the range is 7,0 to 11,0 °C. The summer surface average is 7,0 °C with a range of 5,0 to 9,0 °C. As can be observed in figure 76 the average temperatures that can be expected in the selected area range from 12,5 to 10 °C.

From figure 77 the minimum sea temperature that can be expected in the area of interest is close to 2,0 °C (up to 4 °C in the far southwest) and pushing further north

[62] What is defined as surface water varies from different sources, from 1 mm to 20 metres. For the purpose of this report it seems necessary and safe to conclude that the surface water goes deep enough to be relevant for the scenarios presented later in the report.

towards Bjørnøya, the sea temperature drops from 2,0 °C to -2,0 °C. This happens where the colder Arctic water meets the warmer Atlantic water, as can be seen in figure 77.

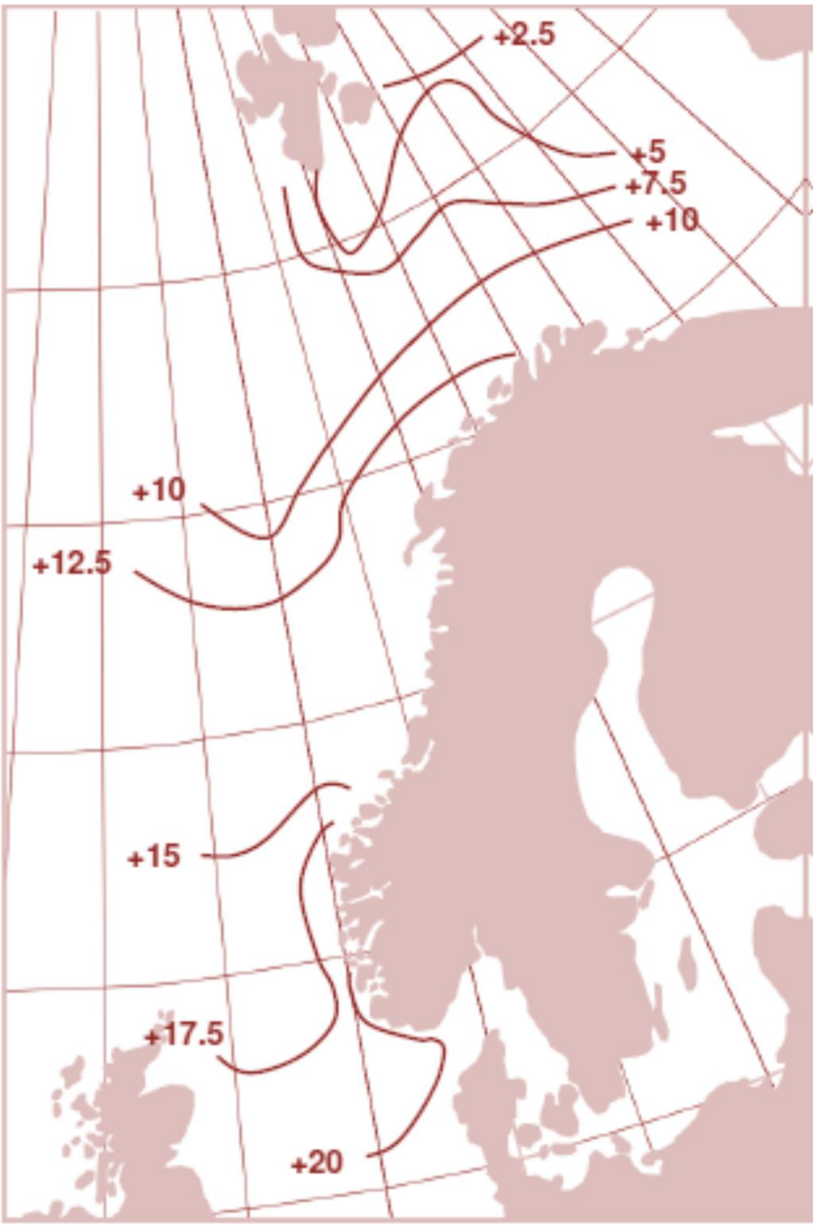

FIGURE 73 - HIGHEST SURFACE TEMPERATURE IN THE SEA WITH AN ANNUAL PROBABILITY OF EXCEEDENCE 10^{-2} (THE TEMPERATURES ARE GIVEN IN °C) [116]

FIGURE 74 - LOWEST SURFACE TEMPERATURE IN THE SEA WITH AN ANNUAL PROBABILITY OF EXCEEDANCE 10^{-2} (THE TEMPERATURES ARE GIVEN IN °C) [116]

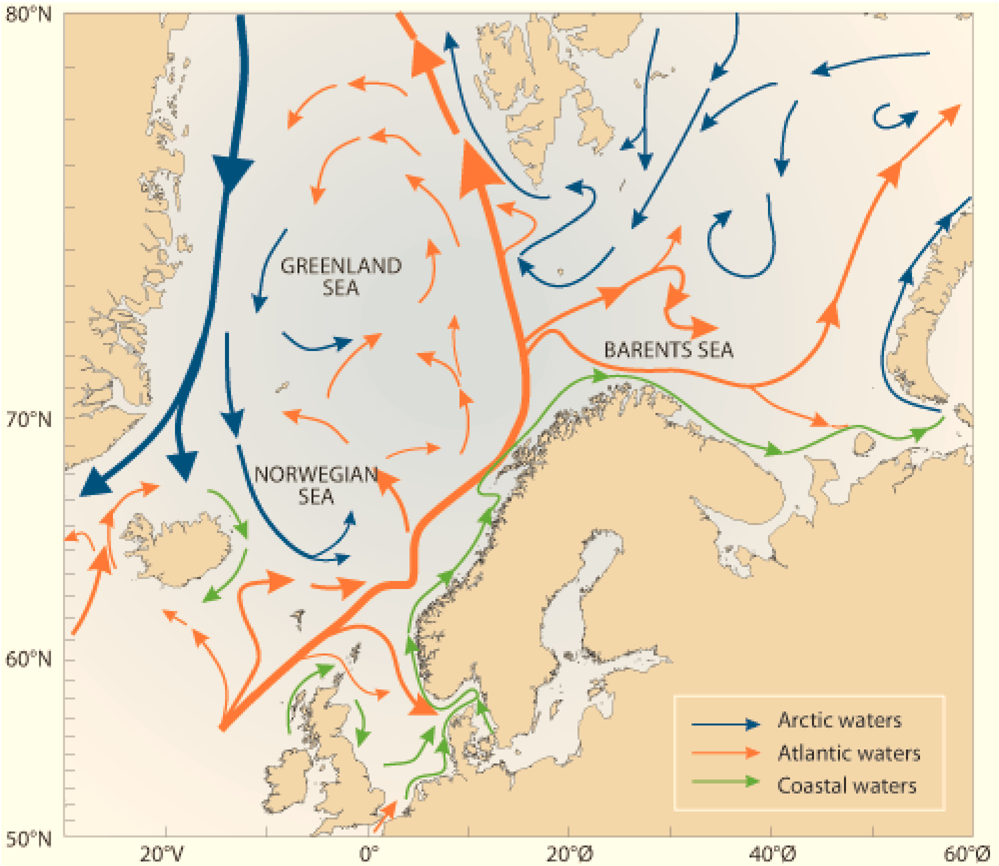

FIGURE 75 - THE MAP SHOWS THE SYSTEMS OF CURRENTS IN THE NORTH SEA, THE NORWEGIAN SEA, THE GREENLAND SEA AND THE BARENTS SEA [117].

WIND

In the winter, the dominant wind direction is northeast, and in the summer, the dominant wind direction is west. The 10 minute average annual value at 10 metres elevation is 26,6 metres per second, and the range is 25 to 28 metres per second.

Extreme wind speeds can occur, particularly during polar lows and polar front conditions.

SEA STATE

As can be observed in figure 76, the significant wave height that can be expected within the area in question (highlighted in yellow) is up to 16 metres in the far west and decreasing to 14 metres towards the far east part of the area. This can readily be compared to the rest of the Norwegian waters where petroleum activities are taking place. Although the wave period is somewhat shorter in the south (from 19 seconds further out and down to 15 seconds in the far south) the significant wave height is not greater in the Barents Sea. [18] found that the maximum wind speed would be lower than the wind speeds that are occurring on the installations of Goliat, Heidrun and Statfjord. Also, the significant wave height is estimated to be somewhat lower towards the east of the area [118].

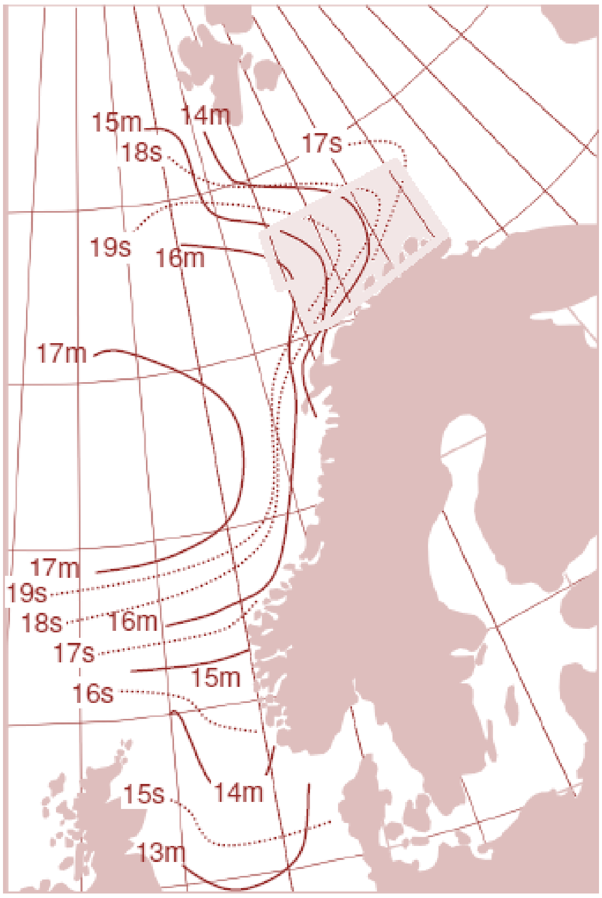

FIGURE 76 - SIGNIFICANT WAVE HEIGHT AND RELATED MAXIMUM PEAK PERIOD WITH ANNUAL PROBABILITY OF EXCEEDANCE OF 10^-2 FOR SEA-STATES OF 3 H DURATION. ISO-CURVES FOR WAVE HEIGHTS ARE INDICATED WITH SOLID LINES WHILE WAVE PERIOD LINES ARE DOTTED. FROM NORSOK N-003

SEA ICE AND ICEBERGS

For Arctic operations, sea ice is the single most important environmental factor. Ice affects all of the many aspects of oil and gas activities. From the design and construction of the facilities to the transport and rescue related operations. There is today no simple description or set of design criteria associated to sea ice. [17]

There are many forms of floating ice that may be encountered at sea. The most extensive is the ice resulting from simple freezing of the ocean surface[63], see figure 80. However, ice originating from land, such as icebergs and ice islands, are dangerous factors for operations in the Arctic and in the Barents Sea (figure 81). [119]This type of ice may also be mechanically stronger as it often consists of more or less pure fresh water[120]. Icebergs are large masses of floating ice originating from glaciers. They are very hard and can cause considerable damage to a ship in a collision. Ice islands are vast tabular icebergs originating from floating ice shelves. Smaller pieces of icebergs are called bergy bits and growlers and are especially dangerous to ships because they are extremely difficult to detect. [119]

[63] By sea ice, this report means all kinds of ice caused from the freezing of ocean water; including solid ice sheets, pack-ice, slush and drift ice.

Conditions vary greatly around the Arctic. For example, the ice-conditions in the areas around Sakhalin and the Sea of Okhotsk (both located south of the Arctic Circle) in Russia are far worse than those found along the northern coast of Norway [60]. Sea ice may occur in the northernmost part of the selected area from January until June. The extent varies from year to year and cyclic fluctuations also occur. The Norwegian Meteorological Institute has during recent years registered a trend of reduced ice coverage, however an increase is expected in the period from 2014-2016. [18] In appendix E, a chart showing the ice coverage and also the arctic ice coverage trend can be found.

Iceberg management systems are already in use in several locations in the Arctic. These identify icebergs as early and far away from vulnerable installations as possible and thus allow for countermeasures such as moving the icebergs using tugs or taking evasive actions. The seawater in the Barents Sea will normally freeze when the water temperature is -1,7 °C to -1,9 °C depending on the salinity of the water.

A challenge with sea ice for emergency preparedness is the fact that sea ice is constantly moving, channels open and close. It is a very dynamic system that is greatly affected by currents and wind. [18]

The two figures below display probabilities of encountering ice [121].

FIGURE 77 - LIMITS OF SEA ICE IN THE BARENTS SEA WITH ANNUAL PROBABILITY OF EXEEDANCE OF 10-2 (SOLID LINE) AND 10-4 (DOTTED LINE). FROM NORSOK N-003

FIGURE 78 - LIMITS FOR COLLISION WITH ICEBERGS WITH A PROBABILITY OF EXEEDANCE OF 10-2 (SOLID LINE) AND 10-4 (DOTTED LINE). FROM NORSOK N-003

SEASONAL DARKNESS

The tilt of the Earth's axis means a long cycle of day and night in the Arctic regions. During polar nights there is total darkness, and during the summer the midnight sun means that the sun is constantly above the horizon. The polar day begins between mid-March and mid-May and the polar night begins between mid-September and mid-November depending on the latitude. There is to some degree twilight during the day while awaiting the suns return. There is also a rapid change in the amount of daylight. The amount of sun and daylight decreases rapidly from the autumn equinox until the polar night commences. In the same way, the amount of daylight increases rapidly from the suns return until the spring equinox. A daylight chart can be found in appendix D, including a highlighting of the area in question. Below, a table presenting the beginning and end of the polar night for selected locations is shown.

TABLE 16 - POLAR NIGHT IN THE NORTHERN AREAS [85]

Location	Midnight Sun	Polar night	Sun returns
Vardø	17. mai - 26. juli	23. nov.	19. jan.
Hammerfest	16. mai – 27. juli	22. nov.	20. jan.
Berlevåg	15. mai - 28. juli	21. nov.	21. jan.
Nordkapp	14. mai - 29. juli	20. nov.	22. jan.
Jan Mayen	14. mai - 28. juli	20. nov.	21. jan.
Bjørnøya	1. mai - 10. aug.	07. nov.	04. feb.
Hopen	25. april – 17. aug.	31. okt.	10. feb.

GENERAL VISIBILITY

There are several risks for visibility impairment in the Barents Sea. Rain and snow account for a great number of days with reduced visibility. Darkness is a big problem during the winter season, and in the summer when there is plenty of light, there is also frequently a lot of fog. For the western region, [5] shows an average annual value for number of days with visibility less than 2 km to be 64 days, with a range of 100 to 130 days, and the annual number of days with visibility lower than 1 km is 76 days, with a range of 50 to 80 days. The less than 2 km visibility is generally caused by precipitation (rain and snow or snowstorms) while the less than 1 km visibility is generally caused by fog. For Bjørnøya and Hopen, the presence of fog is significantly higher than on Svalbard and the Finmark coast. The peak is in the months of June until September, with a variation between 11 and 27 %. The rest of the year the interval is between 4 and 8 %. [18]

Visibility is not only a problem for ships moving in the area. Reduced visibility makes operations in close proximity to the installations, for example supply ships, more dangerous. Helicopter operations may also be difficult as low visibility and heavy snow obstructs their usage. The availability of helicopter transport may be lowered, and severe fog conditions may prevent helicopters from performing duties such as medical and precautionary evacuation, or rescue operations. Visibility is a key issue when operating a helicopter [37]. Landing becomes very dangerous, and landing without the aircraft and the airport having special equipment and technology, landing in foggy conditions is not possible [122]. Helicopters in general have trouble flying on instruments alone, and radar, being one of the more common instruments, experience trouble when facing heavy fog. The moisture in the air absorbs the radar energy, attenuation, and causes *clutter*[64]*.* [123]

[64] Background noice

APPENDIX – C. STABILITY

The principle for determining the stability of a ship is seen in figure 82. Where G is the centre of gravity, B is the centre of buoyancy and M is the metacentre. The red arrows represent the forces. If the ship heels to one side, the centre of gravity (G) will move a little, while the centre of buoyancy (B) will move more. This situation is known as positive static stability. The distance GZ is the arm that provides the righting momentum. However, if enough ice is allowed to form on top of the vessel, G may be raised to G*, creating negative static stability. [10, 124]

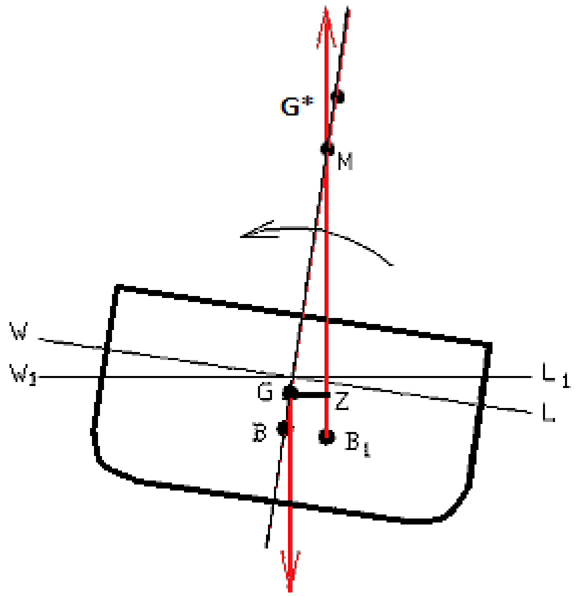

FIGURE 79 - SHIP STABILITY

APPENDIX – D. DAYLIGHT CHART

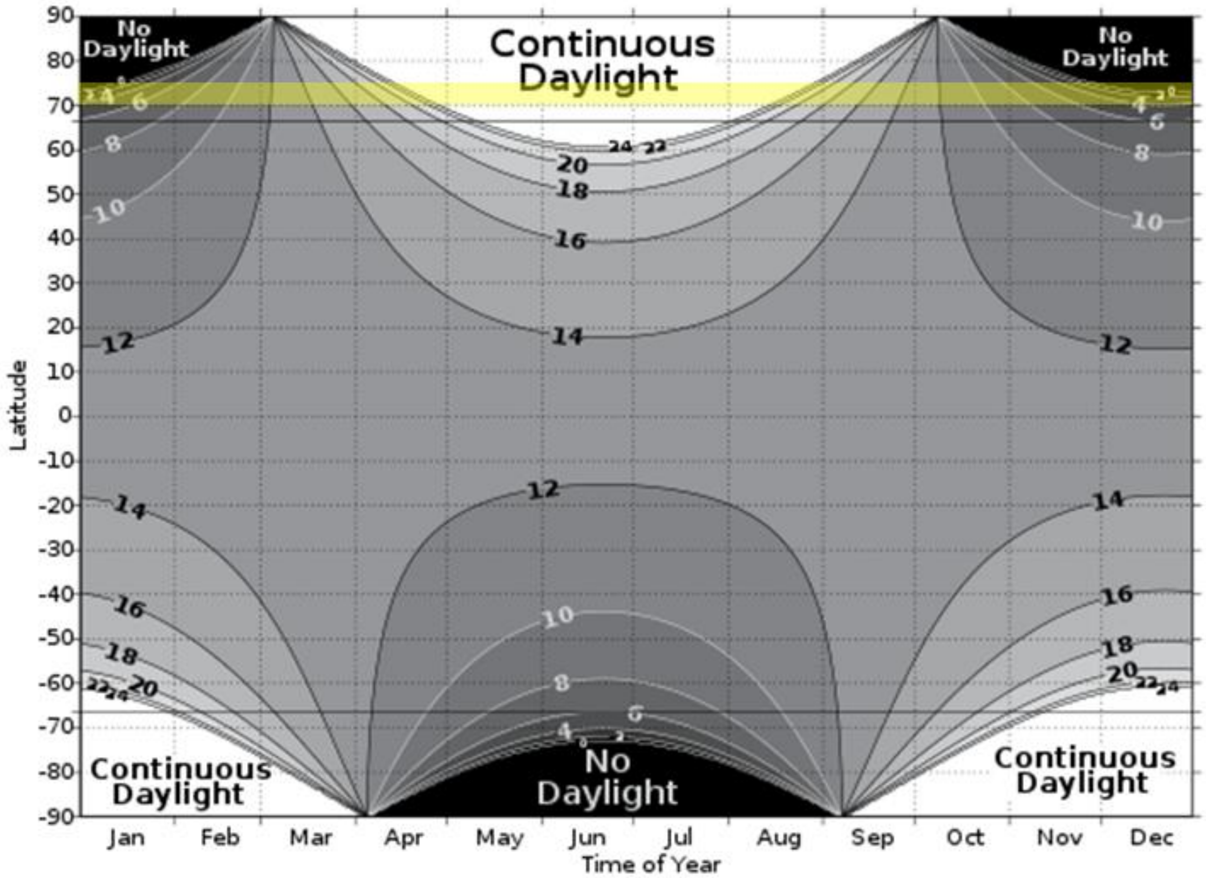

FIGURE 80 - DAYLIGHT CHART

Figure adapted from [125]. Yellow area highlights the latitudes of interest.

APPENDIX – E. ICE COVERAGE AND TREND

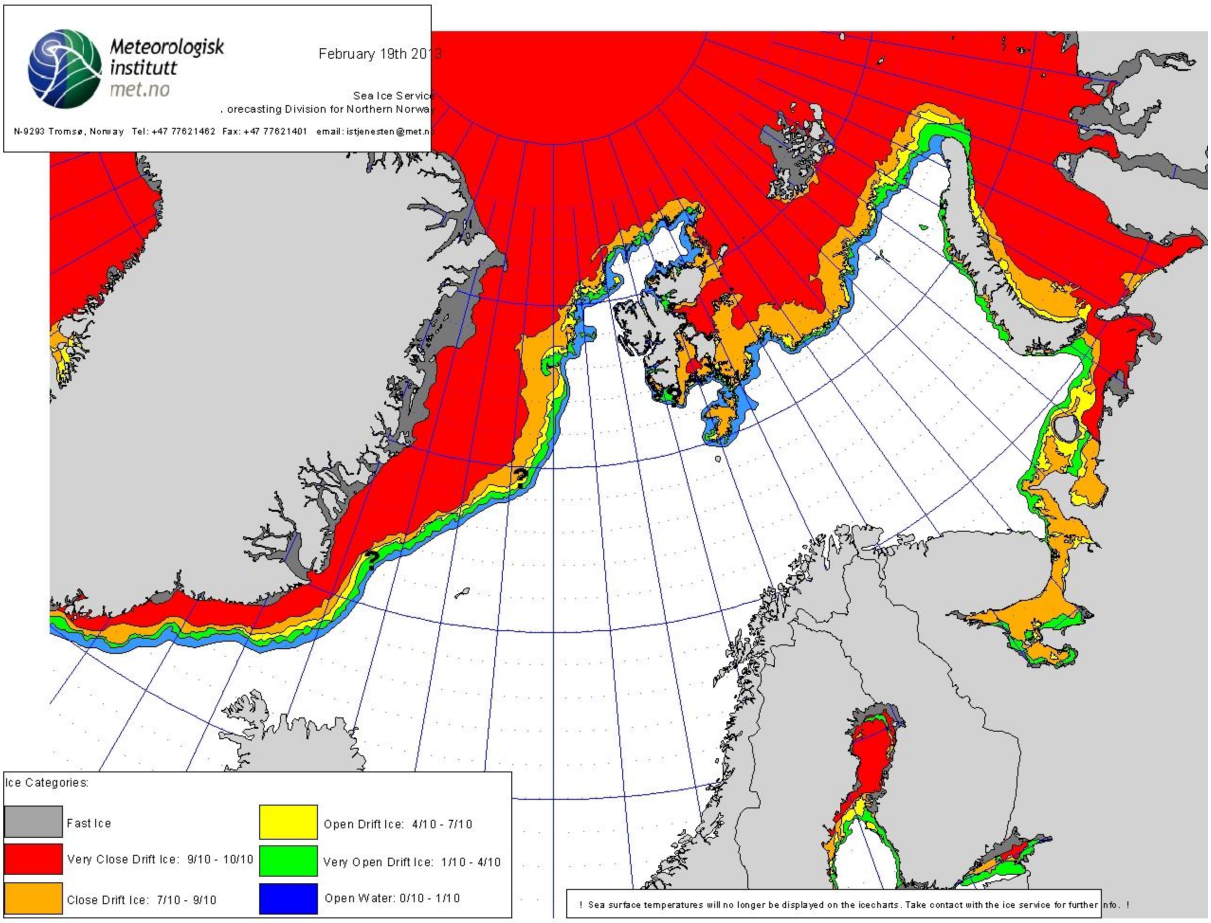

FIGURE 81 - ICE COVERAGE FEBRUARY 19TH, 2013 [126]

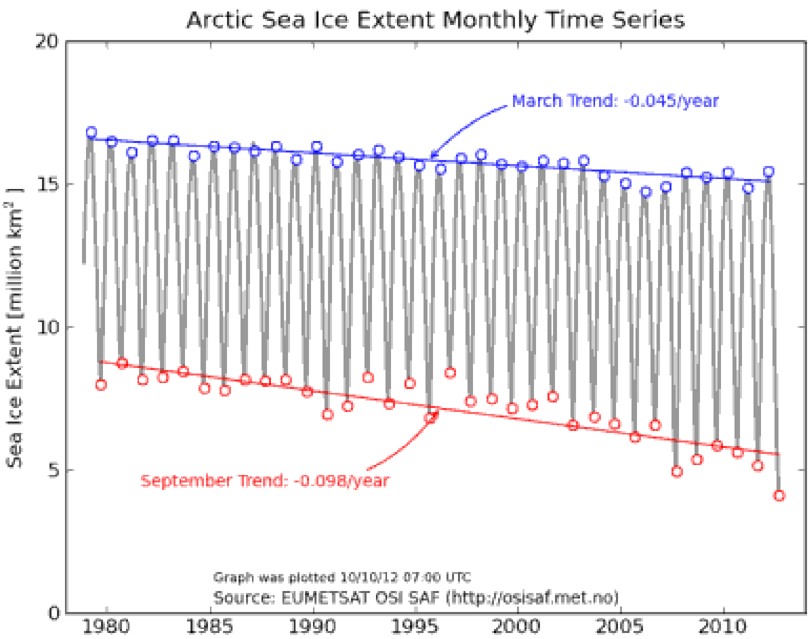

FIGURE 82 - ARCTIC SEA ICE EXTENT MONTHLY TIME SERIES [127]

APPENDIX – F. BEAUFORT WIND SCALE

TABLE 17 - BEAUFORT WIND SCALE

Force	Wind (Knots)	WMO Classification	Appearance of Wind Effects	
			On the Water	On Land
0	Less than 1	Calm	Sea surface smooth and mirror-like	Calm, smoke rises vertically
1	1-3	Light Air	Scaly ripples, no foam crests	Smoke drift indicates wind direction, still wind vanes
2	4-6	Light Breeze	Small wavelets, crests glassy, no breaking	Wind felt on face, leaves rustle, vanes begin to move
3	7-10	Gentle Breeze	Large wavelets, crests begin to break, scattered whitecaps	Leaves and small twigs constantly moving, light flags extended
4	11-16	Moderate Breeze	Small waves 1-4 ft. becoming longer, numerous whitecaps	Dust, leaves, and loose paper lifted, small tree branches move
5	17-21	Fresh Breeze	Moderate waves 4-8 ft taking longer form, many whitecaps, some spray	Small trees in leaf begin to sway
6	22-27	Strong Breeze	Larger waves 8-13 ft, whitecaps common, more spray	Larger tree branches moving, whistling in wires
7	28-33	Near Gale	Sea heaps up, waves 13-19 ft, white foam streaks off breakers	Whole trees moving, resistance felt walking against wind
8	34-40	Gale	Moderately high (18-25 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks	Twigs breaking off trees, generally impedes progress
9	41-47	Strong Gale	High waves (23-32 ft), sea begins to roll, dense streaks of foam, spray may reduce visibility	Slight structural damage occurs, slate blows off roofs
10	48-55	Storm	Very high waves (29-41 ft) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility	Seldom experienced on land, trees broken or uprooted, "considerable structural damage"
11	56-63	Violent Storm	Exceptionally high (37-52 ft) waves, foam patches cover sea, visibility more reduced	
12	64+	Hurricane	Air filled with foam, waves over 45 ft, sea completely white with driving spray, visibility greatly reduced	

APPENDIX – G. ICING IN NEAR FREEZING TEMPERATURES

TABLE 18 - ICING IN NEAR FREEZING TEMPERATURES

UA (m/s)->	0,51	1,54	3,09	5,14	8,23	10,80	13,89	16,98	20,58	24,18	28,29
Tw (deg C)	0	1	2	3	4	5	6	7	8	9	10
-3	1,30	3,91	7,83	13,04	20,87	27,39	35,22	43,05	52,18	61,31	71,75
-2	1,18	3,53	7,07	11,78	18,85	24,74	31,81	38,88	47,13	55,38	64,80
-1	1,07	3,22	6,45	10,74	17,19	22,56	29,01	35,45	42,97	50,49	59,09
0	0,99	2,96	5,92	9,87	15,79	20,73	26,65	32,58	39,49	46,40	54,29
1	0,91	2,74	5,48	9,13	14,61	19,18	24,65	30,13	36,53	42,92	50,22
2	0,85	2,55	5,10	8,49	13,59	17,84	22,93	28,03	33,98	39,92	46,72
3	0,79	2,38	4,76	7,94	12,70	16,67	21,44	26,20	31,76	37,32	43,67
4	0,75	2,24	4,47	7,45	11,93	15,65	20,13	24,60	29,82	35,03	41,00
5	0,70	2,11	4,21	7,02	11,24	14,75	18,97	23,18	28,10	33,01	38,63
6	0,66	1,99	3,98	6,64	10,63	13,95	17,93	21,92	26,56	31,21	36,53
7	0,63	1,89	3,78	6,30	10,08	13,22	17,00	20,78	25,19	29,60	34,64
8	0,60	1,80	3,59	5,99	9,58	12,57	16,17	19,76	23,95	28,14	32,93
9	0,57	1,71	3,42	5,71	9,13	11,98	15,41	18,83	22,83	26,82	31,39

(shaded)	Beaufort Windscale	Knots to m/s
Tf	-1,9	0,5144444
Ta	-9	

$$PR = \frac{U_A(T_F - T_A)}{(1 + \phi(T_W - T_F))}$$

APPENDIX – H. WIND CHILL INDEX

TABLE 19 - WIND CHILL INDEX

	Wind Speed		Air Temperature											
Beaufort	(km/h)	(kts)	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
1	5	2,7	4	-2	-7	-13	-19	-24	-30	-36	-41	-47	-53	-58
2	10	5,4	3	-3	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63
3	15	8,1	2	-4	-11	-17	-23	-29	-35	-41	-48	-54	-60	-66
4	20	10,8	1	-5	-12	-18	-24	-30	-37	-43	-49	-56	-62	-68
	25	13,5	1	-6	-12	-19	-25	-32	-38	-44	-51	-57	-64	-70
5	30	16,2	0	-6	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72
	35	18,9	0	-7	-14	-20	-27	-33	-40	-47	-53	-60	-66	-73
6	40	21,6	-1	-7	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74
	45	24,3	-1	-8	-15	-21	-28	-35	-42	-48	-55	-62	-69	-75
7	50	27,0	-1	-8	-15	-22	-29	-35	-42	-49	-56	-63	-69	-76
	55	29,7	-2	-8	-15	-22	-29	-36	-43	-50	-57	-63	-70	-77
	60	32,4	-2	-9	-16	-23	-30	-36	-43	-50	-57	-64	-71	-78
8	65	35,1	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79
	70	37,8	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-80
9	75	40,5	-3	-10	-17	-24	-31	-38	-45	-52	-59	-66	-73	-80
	80	43,2	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81

Colour Scale

- Uncomfortably cold
- Very cold, risk of skin freezing
- Bitterly cold, risk of exposed skin freezing within 10 min
- Extremely cold, risk of exposed skin freezing within 2 min

(Adopted from [8])

APPENDIX – I. HEALTH PROBLEMS DUE TO THE COLD

CHILBLAINS

Inflammatory condition due to exposure to cold and moisture. Hands and feet start to swell, itch and become painful. Symptoms may develop hours after exposure, and may persist for days.

TRENCH FOOT

Caused by continuous exposure to the cold without freezing, combined with constant dampness or immersion in water. Often found if wet socks are worn for long periods of time.

FINGERTIP FISSURES

Deep, intractable and painful fissuring may occur on the fingertips when exposed to prolonged or repeated cold, particularly in dry conditions.

FROST-NIP

Freezing of the skin and superficial tissue. Underlying tissue not affected.

FROSTBITE

Freezing of deeper as well as superficial tissue.

First degree: Freezing without blistering and peeling of the skin, skin changes color.

Second degree: Freezing with blistering and peeling of the skin, pain and increasingly violet skin color.

Third degree: freezing with blackening and death of skin tissues, and in some cases deeper tissue.

COLD BURN

The instant, superficial freezing when touching a very cold object (e.g. metal).

SNOW BLINDNESS

Not necessarily a cold induced illness, however, the excessive exposure of ultraviolet light reflecting from ice and snow may cause "sunburn" to the eye, known as snow blindness.

HYPOTHERMIA

Chilling of the body's core temperature below 35 °C.

The figure below shows the human body's heat production and loss.

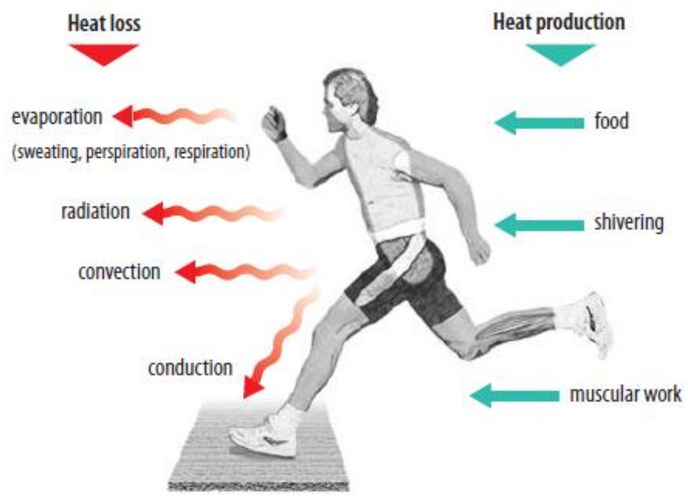

FIGURE 83 - HEAT LOSS AND HEAT PRODUCTION, FIGURE ADOPTED FROM [128]

APPENDIX – J. THE PROCESS FOR A TANDEM OFFLOADING OPERATION IN THE NORTH SEA

The table shows a generic example for a tandem offloading operation in the North Sea (adopted from [85] appendix D). The purpose of including this table is to clarify how a tandem offloading operation is carried out.

TABLE 20 - THE PROCESS FOR A TANDEM OFFLOADING OPERATION IN THE NORTH SEA

Time/Distance	Operational Activities	Phase
3:30 am / 3 nm	Due to dense fog, approach is postponed	-
5:30 am / 4800 m	ST begins approach towards FPSO FPSO heading 175° ST heading 272°, speed 15 kn Wind 18 kn, 280°, wave Hs 1,2 m	Approach phase begins
2400 m	ST speed 12 kn Contact from FPSO to ST	
1900 m	ST speed 10 kn	
5:53 am / 1870 m	Start DP manual ST speed 8,35 kn	
1718 m	ST speed 3,2 kn	
1500 m	ST 2,4 kn, heading 170°	
1000 m	ST speed 2,5 kn, heading 166°	
6:18 am / 500 m	ST speed 1,36 kn, heading 168° Contact from FPSO to ST	Total duration 1 h 20 min
350 m	ST speed 0,56 kn, heading 172°	
294 m	ST speed 0,39 kn, heading 176°	
233	ST speed 0,34 kn, heading 172°	
200 m	ST asking FPSO to change heading to 180°	
6:33 am / 165 m	Start DP Approach mode	
6:43 am / 118 m	DP drop-out test	
6:50 am / 75 m	Distance alarm setting, 3 m warning, 5 m alarm	Connection phase begins
75 m	ST contacts FPSO Ready for shooting messenger line	
7:00 am / 75 m	FPSO shoots messenger line on ST	
7:15 am / 75 m	Mooring connection, messenger line rolling	
7:20 am / 75 m	Chain stopper is locked	
7:21 am / 75 m	Start DP Weather vane mode. Take hawser tension input in DP reference input	
7:30 am / 75 m	DP Weather vane mode with 'operator selected heading'. FPSO heading 182°, ST heading 193°. This is in order to facilitate hose connection operation.	Duration 1 h 46 min

7:35 am	Hose connection completed. ST asks FPSO to change heading to 195°.	
7:45 am	Pump test, shutdown test. FPSO has initial problems with pump, problems are fixed.	
8:05 am	ST gets no signal of receiving oil. New pump test initiated. Chief Officer takes over for the 1st Officer on the bridge.	
8:36 am	ST commences loading FPSO 194°, ST 198°. Conditions: H_s: 1,1 m, Current 2,5 m/s, Wind 9 kn.	Loading phase begins
9:00 am	2nd DARPS back to normal Position reference used: Artemis – position origin 1st & 2nd DARPS – relative distance	
9:10 am	ST in loading FPSO 194°, ST 204°	
9:25 am	Captain leaves bridge. Chief Officer on DP watch. 2nd Officer on the loading operation.	
12:45 pm	FPSO 239°, ST 243°	Duration 11 h 24 min
3:30 pm	FPSO 314°, ST 315°	
4:00 pm	Dense fog, unable to FPSO stern. Wind 16 kn. Loading continues.	
6:00 pm	FSU 1°, ST 5°	
7:00 pm	Loading stopped. Begin to flush hose from FPSO.	
7:50 pm / 75 m	Finish flushing hose. Close coupler valve. Close crude valve.	Disconnection phase begins
8:00 pm	Hose is dropped. Send back hose messenger line.	
8:11 pm	Chain stopper is opened. Send back hawser, chain and messenger line.	Duration 21 min
8:14	Begin DP Approach mode. 100 m set as point distance.	Departure phase starts
97,6 m	FSU 11°, ST 35°.	
200 m	Begin DP manual	Duration 11 min
8:25 pm	All messenger line is sent back ST sails away.	
TOTAL		**15 h 2 min**

APPENDIX – K. OFFSHORE HELICOPTER ACCIDENTS AND ACCIDENT RATES

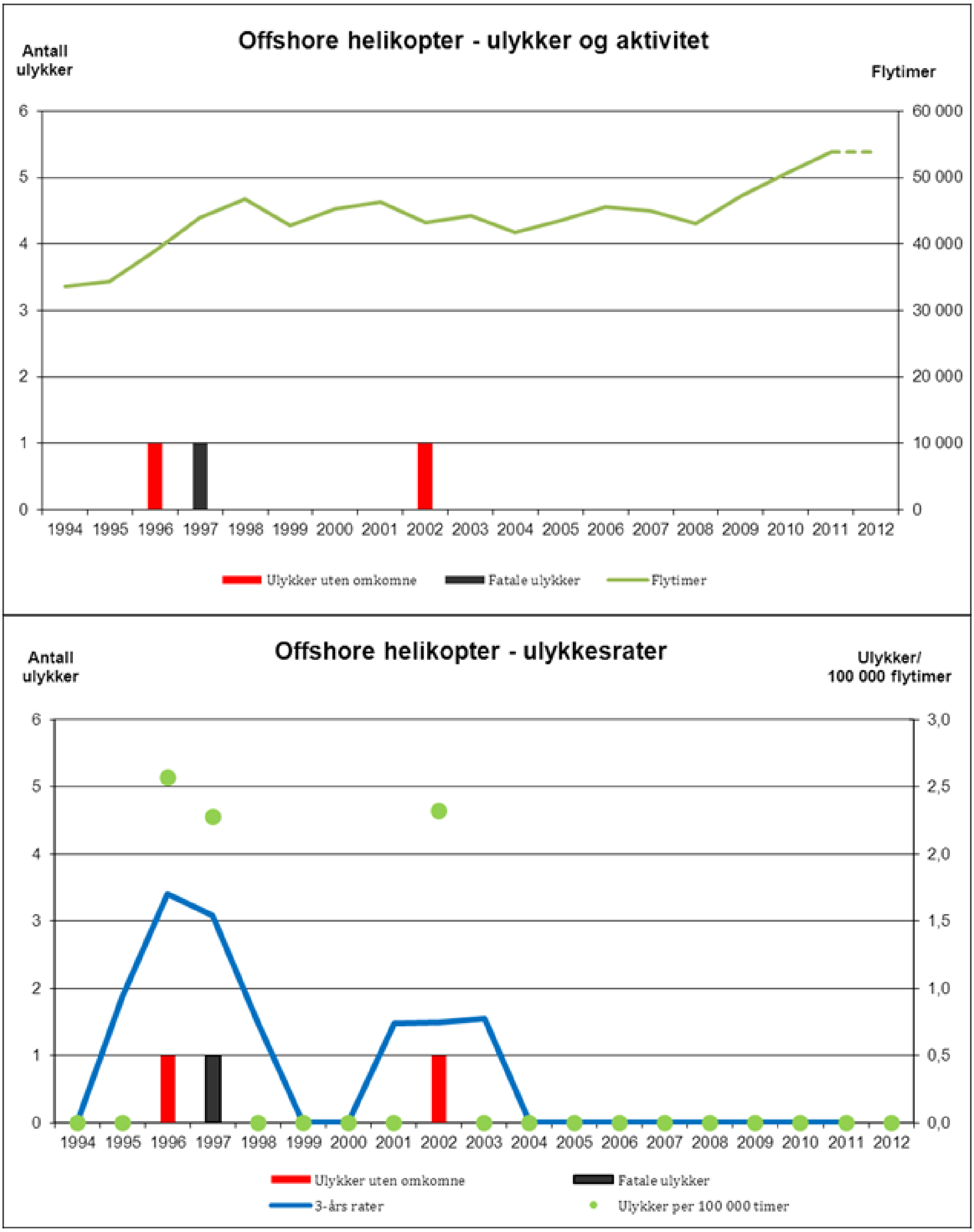

FIGURE 84 - ACCIDENTS AND ACCIDENT RATES ON THE NORWEGIAN CONTINENTAL SHELF. FIGURE FROM THE NORWEGIAN CAA.[65]

[65] http://www.luftfartstilsynet.no/flysikkerhetsstatestikk/A_offshore.htm

APPENDIX – L. RISK METRICS

INDIVIDUAL AND SOCIETAL RISK

There are two ways of expressing risk to people. Individual and societal risk can was defined by [74].

Individual risk: The risk to any particular individual, either a worker or a member of the public. A member of the public can be defined either as anybody who live within a defined radius from an establishment, or somebody following a particular pattern of life.

Societal risk: The risk to society as a whole, as represented for example, by the chance of a large accident causing a defined number of deaths or injuries. More broadly, societal risk can be represented as a 'detriment', that is to say the product of the total amount of damage caused by a major accident and the probability of this happening during some specified period of time.

There is a need to consider both in order to present a proper risk picture. The next section will briefly discuss some of the more common individual and societal risk metrics.

INDIVIDUAL RISK METRICS

With individual risk, the metrics express the probability of an individual getting killed or injured during an appropriate period, such as a year, a number of kilometres driven or similar ones. Individual risk is very important for all aspects of society. With regards to the Arctic the limited information on individual risk may be hard on people who are going to work there. The main expressions for individual risk are individual risk per annum (IRPA) and localised individual risk per annum (LIRA).

INDIVIDUAL RISK PER ANNUM (IRPA)

[70] defines individual *risk as the probability that a specific individual (for example the most exposed individual in the population) should suffer a fatal accident during the period over which the averaging is carried out (usually a 12 month period).* When the period is indeed 12 months, the metric IR is denoted IRPA. IRPA is sometimes referred to as the average individual risk (AIR).

$$IRPA_a = f_a * p(exposed\ to\ risk) * p(A\ specific\ individual\ dies | if\ exposed)$$

Where f_a is the frequency of an activity associated with the hazardous event in question.

LOCALISED INDIVIDUAL RISK PER ANNUM (LIRA)

LIRA is defined as *the probability that an individual, being unprotected and continuously present in a particular location, will suffer a fatal accident during a year [72].*

Contrary to IRPA, which is dependent on the characteristics of the actual or hypothetical individuals in question, LIRA is a property of the location.

In a sense, individual Arctic risk (IARPA or LIARA perhaps?) would require a bit of both. The risk will indeed be much localised, however the people working in the Arctic will be protected and never continuously in the presence of danger. A measure using LIRA as a basis could be used; however, IRPA seems more sufficient as it focuses on the most exposed individuals.

SOCIETAL RISK METRICS

Societal risk may be a somewhat confusing term. [129] suggested three categories of societal risk:

1. *Collective risks*, covering non-accidental exposure to harmful materials
2. *Societal risks*, concerning single accidents with potential of causing multiple fatalities
3. *Societal concerns*, associated with the overall impacts of particular technologies

In the following section, the three frequently used societal risk metrics; potential loss of life (PLL), fatal accident rate (FAR), and F-N (or f-N) – curves will be presented. Also, the concept of risk matrix will be covered.

POTENTIAL LOSS OF LIFE (PLL)

Potential loss of life is defined by [70] and the definition states that: *The PLL value is the statistically expected number of fatalities within a specified population during a specified period of time.* In other words, PLL is the expected number of fatalities associated with certain activities, *without* taking the exposure into account. PLL is often based on historical statistics, which is a problem for Arctic operations because there is no existing historical data.

FATAL ACCIDENT RATE (FAR)

The fatal accident rate can be defined as *the expected number of fatalities in accidents during a period of 100 million exposed hours [67].*[66] FAR is an expression for risk per time unit of an activity. In the offshore industry, there are three different FAR-definitions [70]:

- *Group-FAR*: expressing risk to a group with uniform risk exposure
- *Area-FAR*: mapping risk in a physically bounded area
- *Overall FAR*: averaged over all positions on a specific installation

Typical FAR-values are in the range of 1-30, making it a very simple metric to understand, compared to metrics with very low probabilities. FAR, contrary to PLL, provide eloquent comparison over different solutions because FAR takes exposure into account. According to [70], FAR is the most suitable of all metrics in this matter. [66] points out the fact that being conceptually linked to PLL and IRPA, FAR does not distinguish between small- and large scale accidents. Like most statistic-based metrics, FAR essentially expresses average individual risk.

[66] Putting that into perspective, with normal Norwegian work weeks (37,5 hours) it would take 1000 employees 55,6 years to work 100 million hours.

FN – CURVES

FN – curves simply display the frequency, F or f[67], of accidents with at least N persons killed in a plot. FN – curves can be used for presenting accident statistics and risk predictions, in addition to represent criterion lines for acceptable levels of societal risk. Mathematically, FN – curves are derived from the before mentioned commonly used expression of risk as a product of frequency and consequence, denoted in this case as the number of fatalities per year. A problem with FN – curves is that may be difficult to interpret for non-specialists [67].

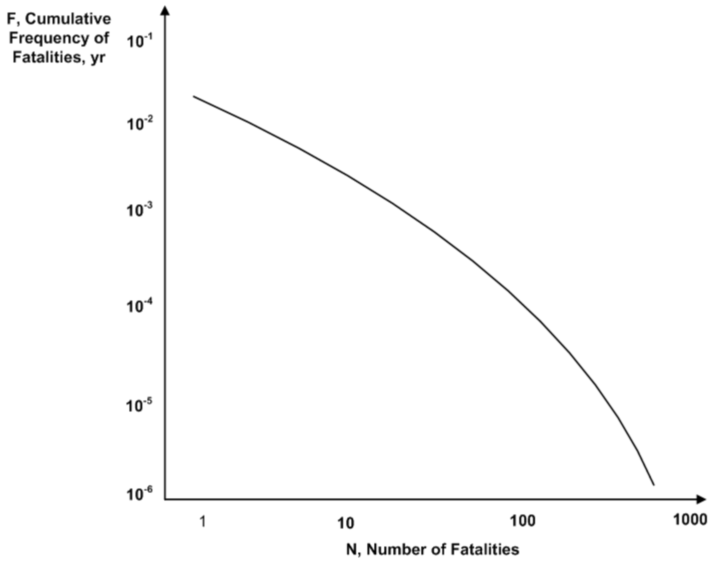

FIGURE 85 - FN-CURVE [130]

RISK MATRIX

A risk matrix is a graphical way of presenting risk, and it represents possible ways of combining probability or frequency with consequence. These categories can then be either quantitative or qualitative, and will often include consequences to personnel, environment and economy. The combinations of consequence and frequency may then be put into a table such as illustrated in figure 21. Due to great freedom in choosing consequence categories, it is possible to express both individual and societal risk in a risk matrix, and even combinations of the two.

[67] The distinction between F and f is that F expresses the cumulative frequency of N or more fatalities, while f represents the frequency of having exactly N fatalities.

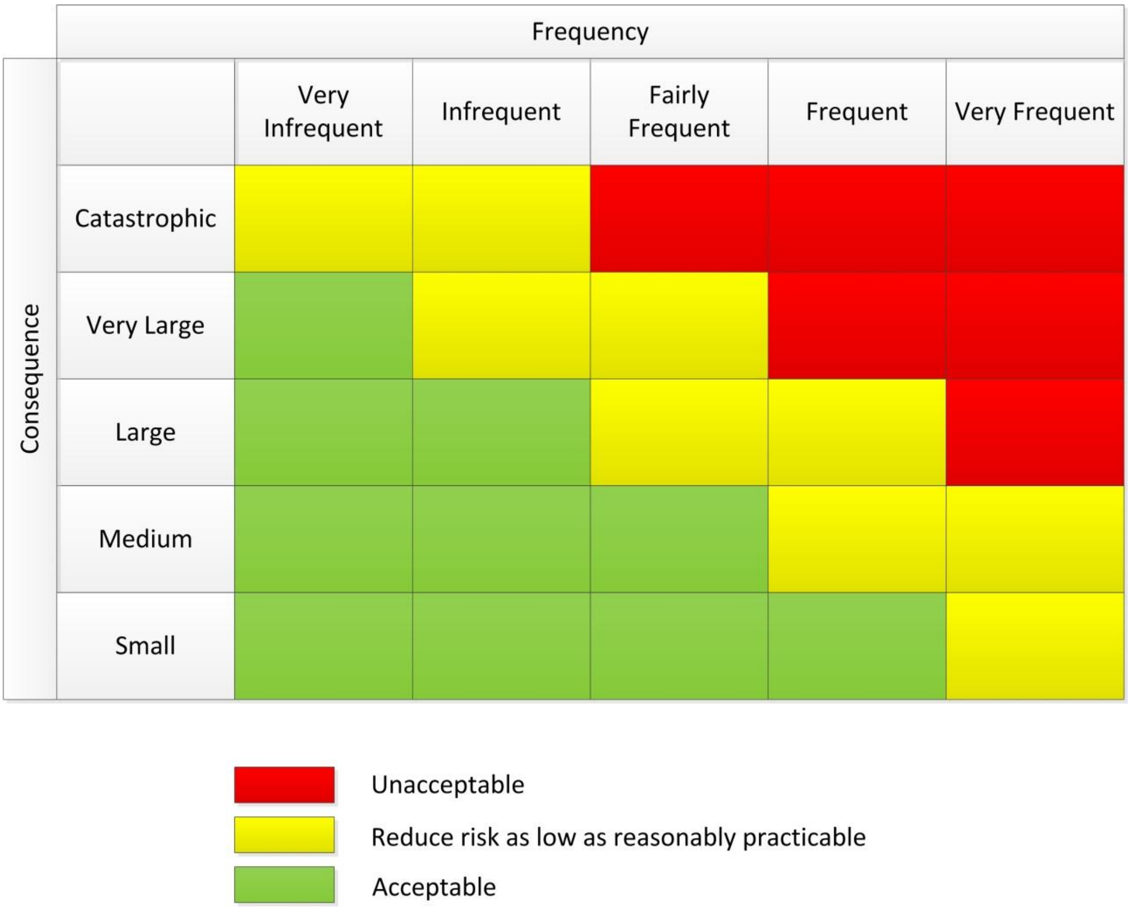

FIGURE 86 - RISK MATRIX EXAMPLE

Risk matrices, like FN – curves, represent pairs of frequency and consequence, however there is an important distinction between the two; FN – curves show the cumulative frequency, while a risk matrix express probability distributions. In other words, the cells in a risk matrix do not say anything about the chance of having a certain number of fatalities; it expresses the severity of risk given by frequency and consequence combinations. The three colours represent the risk levels and this is generally the way a risk matrix will be presented. The red zone is the most severe, or unacceptable, region, the green zone represents accepted risk, while the yellow zone requires further risk reduction [70]. This method is frequently used with reference to the ALARP-principle. ALARP will be discussed in chapter 4.6.2.

As with the other metrics, there are strengths and deficiencies with risk matrices. They enable relative ranking of risks, for prioritising risk reduction measures or the need for more thorough analyses. Mapping between the scales lead to the determination between low, medium and high risk, and facilitates *relative* ranking of the risk. It does however not provide any indication as to whether the calculated risk is acceptable, tolerable or unacceptable, such that the user is no further in making a risk-based decision than could have been established from using common sense and judgement [131]. Whenever a fully quantitative analysis is impractical, a risk matrix provides a unique tool for presenting the risks [132]. One should be cautious when selecting categories, as the coarseness will greatly affect the accuracy of any reflections made based on the risk matrix. [67]point out that in order to prioritise between the risks, a quantitative measure, such as a risk priority number (RPN) can be assigned. The perhaps greatest deficiency with the risk matrix is that the totality of the risk picture is concealed when we split the risk picture in too many contributions. It is of utmost importance that the company using a risk matrix have a sense of what risk is acceptable. [67]

SAFETY INTEGRITY LEVEL (SIL)

Safety integrity level is sometime used as a risk metrics for technical systems, such as a safety instrumented system (SIS)[68]. Safety integrity is defined by the as the *Probability of a safety-related system satisfactorily performing the required safety functions under all the stated conditions within a specified period of time [133].*

That is, safety integrity is the same as reliability when the application is safety-related. SIL is a technical criterion that is suited for decisions on technical measures related to safety instrumented systems.

LOSS OF MAIN SAFETY FUNCTIONS

Loss of main safety functions refers to the frequency of accidental events leading to impairment of main safety functions [70]. The PSA require acceptance criteria to be set for the loss of main safety functions, e.g. escape routes. Loss of main safety functions is a design related criterion and is suited for decision making on technical measures, and thus ensures that rig designs don't imply unnecessary levels of risk. A way of interpreting this is that loss of main safety functions are an indirect expression of personnel risk [132]. This will be very important for Arctic operations, e.g. a completely covered platform experience trouble and the people on board can't get out. Loss of main safety functions was developed for offshore application solely.

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[68] A safety instrumented is an independent protection layer that is installed to mitigate the risk associated with operation of a specified hazardous system, referred to as the *Equipment Under Control* (EUC) (Rausand & Høyland, 2004).

APPENDIX – M. HELICOPTER DITCHING - SEQUENCE OF EVENTS

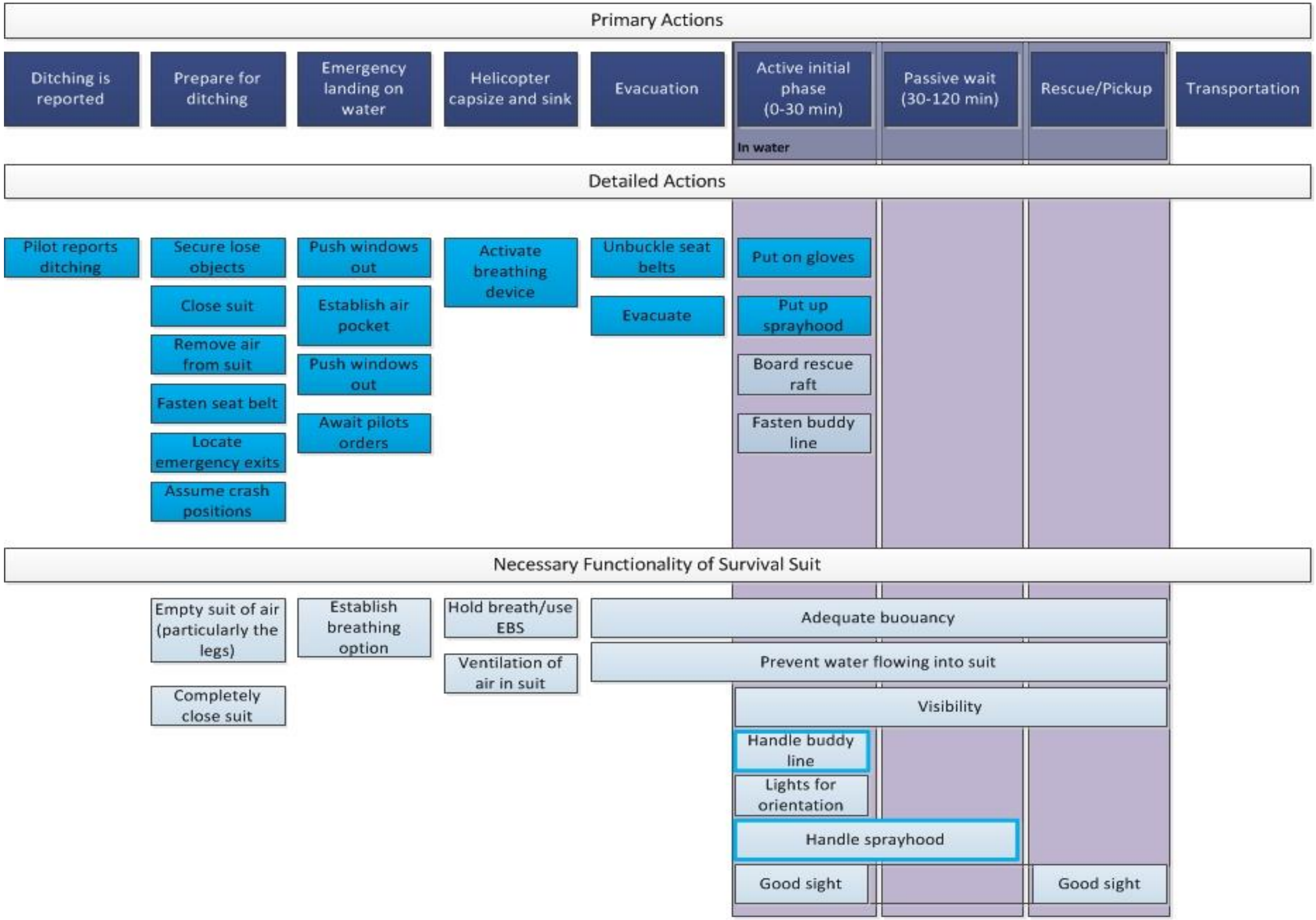

FIGURE 87 - HELICOPTER DITCHING - SEQUENCE OF EVENTS. ADOPTED FROM [56]

APPENDIX – N. IMO DP CLASS

TABLE 21 - IMO DP CLASS

Description	IMO	Corresponding class notations		
	DP Class	ABS	LRS	DNV
Manual position control and automatic heading control under specified maximum environmental conditions.	-	DPS-0	DP (CM)	DPS 0 DYNPOS-AUTS
Automatic and manual position and heading control under specified maximum environmental conditions.	Class 1	DPS-1	DP (AM)	DPS 1 DYNPOS-AUT
Automatic and manual position and heading control under specified maximum environmental conditions, during and following any single fault excluding loss of a compartment. (Two independent computer systems).	Class 2	DPS-2	DP (AA)	DPS 2 DYNPOS-AUTR
Automatic and manual position and heading control under specified maximum environmental conditions, during and following any single fault including loss of a compartment due to fire or flood. (At least two independent computer systems with a separate back-up system separated by A60 class division).	Class 3	DPS-3	DP (AAA)	DPS 3 DYNPOS-AUTRO

APPENDIX – O. EQUIPMENT

Requirements for equipment when flying over water are stipulated in [134] section 6.5 and elaborated in OLF 066 [28]. This section will give a brief overview of the required equipment, and look into the details of some. Equipment needed for helicopter flight to locations in the Barents Sea are listed below.

- Life jacket or equivalent flotation device.
  - Equipped with lights to ease SAR.
- Sea anchor.
- A paddle, bilge and ropes.
- Two life rafts (100 % passenger coverage).
  - Equipped with rescue equipment (including means for sustaining life) found suitable for the particular flight.
  - Equipped with emergency locator transmitter.
  - Also equipped with means for sending distress light signals (flares).
- A minimum of two VHF-radio transmitters (fulfilling ICAO's Annex 10).
- Externally mounted emergency locator transmitter.
- Survival suits.
  - Passengers: Shall wear survival suits during all continental shelf flights.
  - Helicopter crew: Shall have watertight flight suits available during flight. Watertight flight suits shall be worn from 1. September until 1. May.
  - Helicopter crew shall wear life jackets during flights or flight suits with built in buoyancy.
  - Flights suits shall be of a colour that makes them easily visible in the water.
  - All suits must be equipped with a personal locator beacon (PLB).

APPENDIX – P. TIME TO RESCUE AND CAPACITY

The time to rescue (TTR) is of great importance. There are two main methods of rescue; by standby vessel (SBV) or SAR helicopter. As mentioned, the current requirement is that personnel in the water within the safety zone should be picked up within 120 minutes. With proper tagging and tracking, this should also be a requirement for personnel outside of the safety zone.

For each means of rescue, the time until rescue can be written as [52]:

$$TTR(SBV) = Time\ to\ scene + Time\ to\ recover\ survivors$$

$$= \frac{Distance\ [nm] * 60}{Speed(kts)} + no.of\ people\ in\ water * individual\ rescue\ time$$

This is a coarse formula and it presumes that there is no need of bringing people to a hospital, and also neglects time to react to distress call.

$$TTR(SAR) = TA + TS + TRP + STS + OT$$

- TA – Time to Airborne
- TS – Time to Scene: $\frac{Distance\ [nm]*60}{Speed(kts)}$
- TRP – Time to Recover all Persons:
  $no.of\ people\ in\ water * individual\ rescue\ time$
- STS – Shuttle Time to Safety: $\frac{Distance\ [nm]*60}{Speed(kts)}$
- OT – Offload Time

The time to get airborne is set by the 330 squadron to be $\leq 15\ min$. Individual pickup time is estimated to be 3 min.

With the 120 minutes limit, and a full helicopter of 21 people, this leaves:

$$120 - 15 - 3 * 21 = 42\ minutes$$

Effective limitations for SAR helicopter able to cruise at 145 knots are thus:

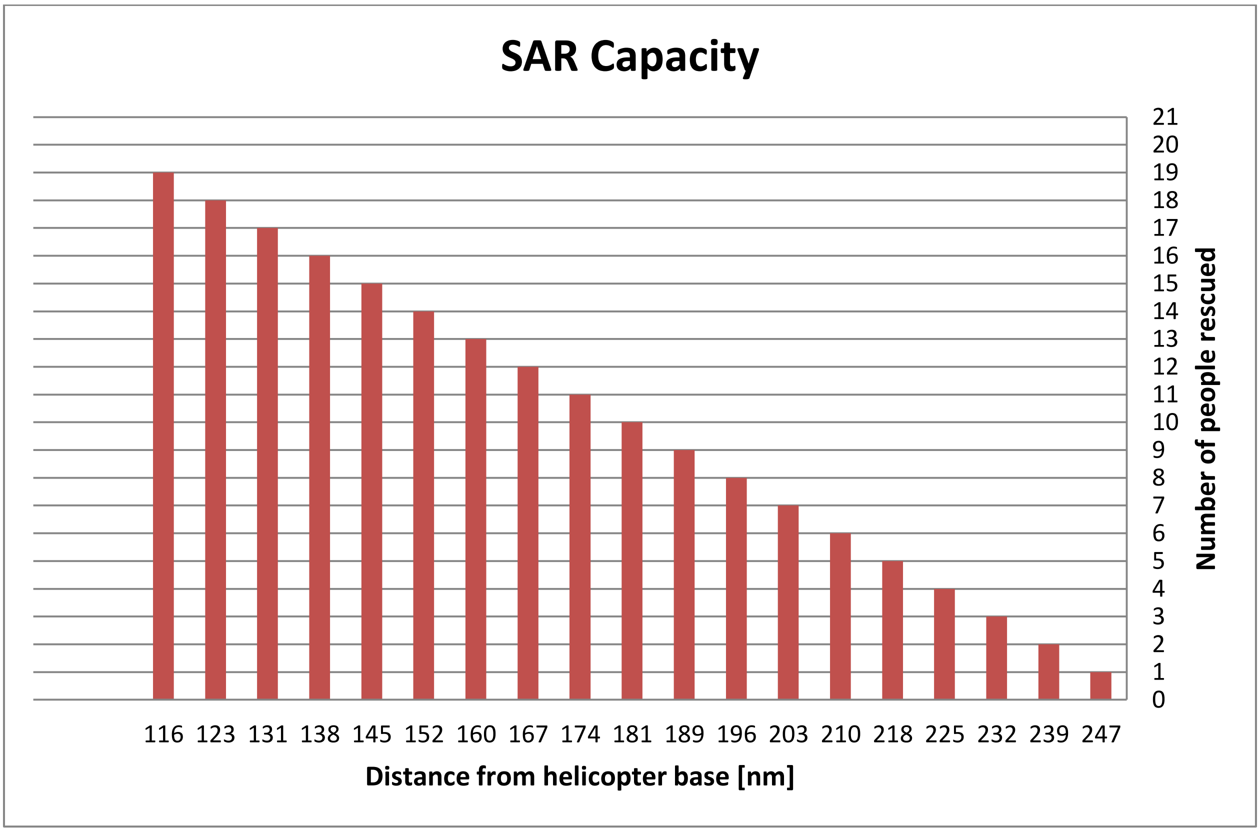

FIGURE 88 - SAR CAPACITY FOR HELICOPTER

In his master thesis, Jacobsen [110] performed an analysis of the rescue capabilities en route for long-range locations. A brief presentation and comparison of some results will be given in this chapter.

Jacobsen considered a ditching occurring somewhere in-between the airport at Berlevåg (BVG) and a petroleum facility located at 74,5° N/37° E, 260 nm apart. This was one of the more remote locations that may be considered for development in the near future.

The analysis includes:

- A SAR helicopter at BVG
- Emergency Rescue Vessel (ERV) en route to facility
- ERV at the facility
- MOB vessels
- Fast, rescue daughter crafts (FRDC)

The rescue capabilities were as presented in the figure below[69].

[69] For details see chapter 6.5 in 110. Jacobsen, S.R., *Evacuation and Rescue in the Barents Sea - Critical issues for safe petroleum activity*, 2012, Stavanger.

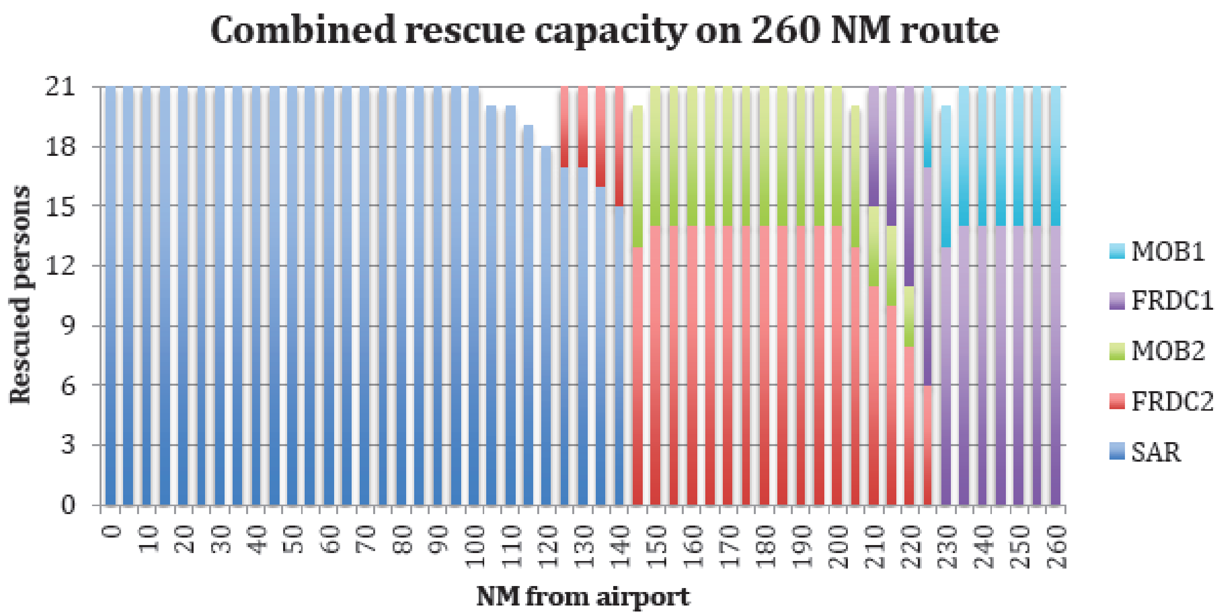

FIGURE 89 - ERV AT 0 AND 85 NM FROM FACILITY, ERV SPEED 20 KNOTS, FRDC SPEED 35 KNOTS, MOB SPEED 26 KNOTS, SAR SPEED 145 KNOTS. FIGURE FROM [110]

This analysis indicate that rescue of people involved in a helicopter should be possible for most locations. Pros and cons with this solution is presented by [110]:

Pros:

- Rescue of persons in the sea is planned and available along the entire route
- Helicopter passenger capacity and range may be increased
- The second ERV can be a shared resource if exploration activity is planned by more than one operator within a reasonable area.

Cons:

- Extra cost is incurred for the second ERV,
- There are extra costs associated with crew for both FRDC and MOB boat.

There are some weaknesses with the analysis, pointed out by Jacobsen, regarding; time to cruise speed for vessels, added risk of sending MOB and FRDC vessels out, ice is not considered.

APPENDIX – Q. PREDICTION OF ICING

There are several books, articles and papers written on predicting icing growth rates. [10] presents the formula used by the National Oceanic and Atmospheric Administration in the USA (NOAA). NOAA produce ice accretion charts for the North Atlantic and Alaskan waters, using the four categories presented in the table below. This table is dependent on a predictor (the before mentioned formula), and NOAA uses the predictor PR defined by [10, 135]:

$$PR = \frac{U_A(T_F - T_A)}{1 + \phi(T_W - T_F)}$$

- U_A – Wind Speed
- T_F – The freezing point of seawater[70]
- T_A – Air Temperature
- T_W – Sea surface temperature

TABLE 22 - ICE ACCRETION PREDICTION ACCORDING TO NOAA. TABLE ADOPTED FROM [10].

	Light	Moderate	Heavy	Extreme
Icing rate (cm/h)	< 0,7	0,7 – 2,0	> 2,0	> 5,0
Predictor PR (m°C/s)	< 20,6	20,6 – 45,2	> 45,2	> 70

Here, Φ represents a constant. [135] used vessel-icing data and statistical analysis to find a representative value for Φ, and ended on $\phi = 0{,}4$. Later, [136] obtained a slightly lower value of $\phi = 0{,}3$. This was criticised by [137], because the formula assumed Φ to be a constant when it was in fact not [138]. It is however used for illustrative purposes in this thesis.

Using the formula above, keeping the air temperature constant at the minimum of the annual range of -6,0 to -9,0 °C (see appendix B), and the freezing point of seawater[71] at -1,9 °C, and varying wind speed and water temperature the figure below was created[72]. The figure is based on a figure in [110], but using figures more relevant for the area.

[70] The freezing point is dependent on the salinity of the sea water.
[71] Freezing point varies with salinity. -1,9° C is a typical value for this part of the Barents Sea.
[72] Adopted from 110. Jacobsen, S.R., *Evacuation and Rescue in the Barents Sea - Critical issues for safe petroleum activity*, 2012, Stavanger.

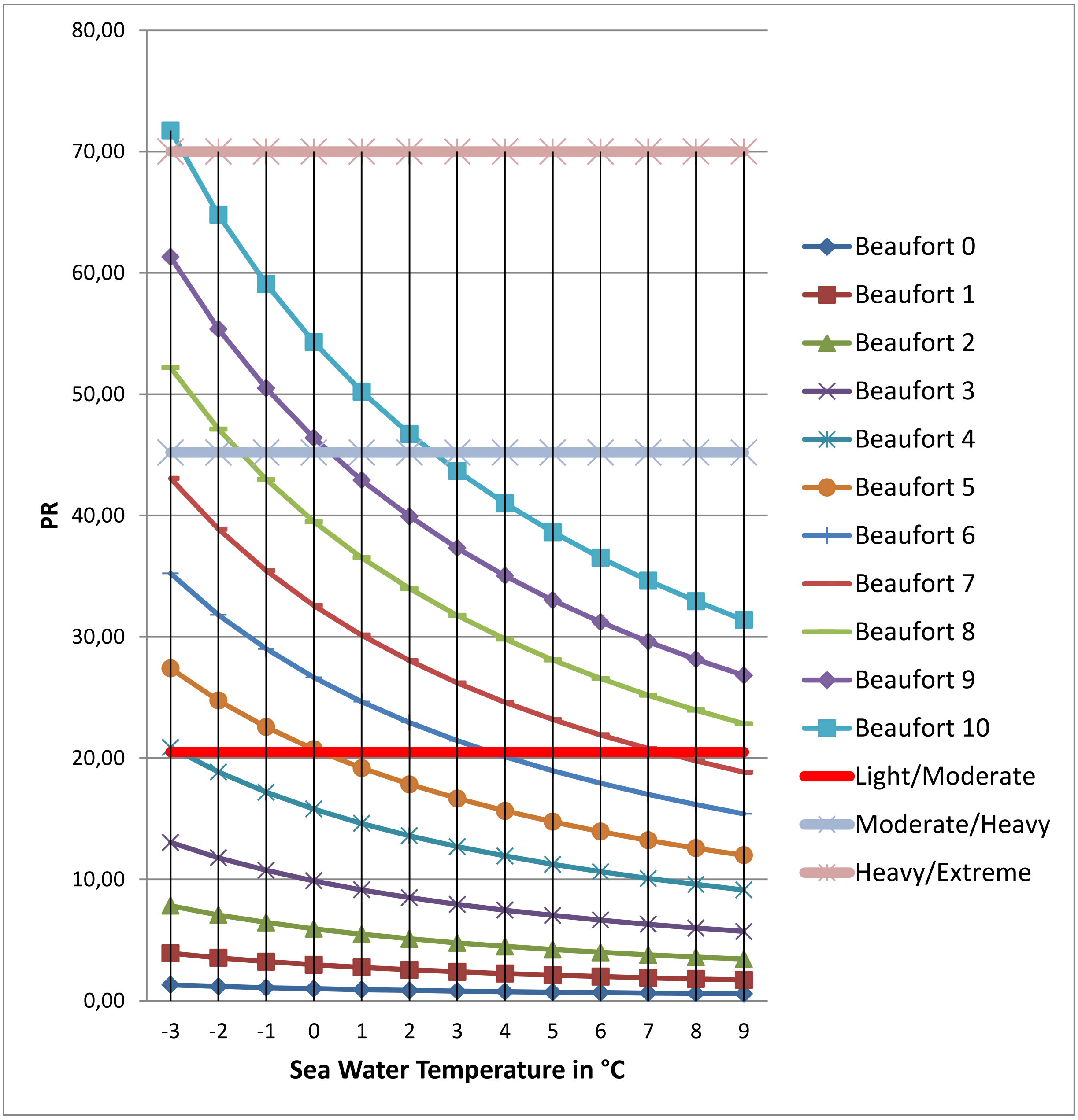

FIGURE 90 - PREDICTION OF ICING

From the figure above, it can be observed that the rate of icing increases dramatically when the sea temperature is closer to freezing and below.

APPENDIX – R. SURVIVAL SUITS

Requirements for survival suits on the Norwegian Continental Shelf can be found in Norwegian oil and gas guideline 094 [139].

As mentioned in the chapter on human factors, insulating the body from heat loss to the cold water is one of the single most important aspects of survival. Although this is stressed in many research papers, it is often mistakenly assumed that the individual immersed is primarily at risk from death directly by hypothermia [53]. Flotation and swallowing of sea water are both of almost equal importance. Drowning is often the cause of death and often occurs at an early stage. Due to the difficulties in estimating these issues, the cooling of the body core temperature is usually the measured value used in models.

The insulation begins with the persons own body, its composition, age, fitness, mental state and son on. However, in order to increase the probability of survival, survival suits are necessary. The figure below illustrates the differences in cooling rates using various means of aids[73].

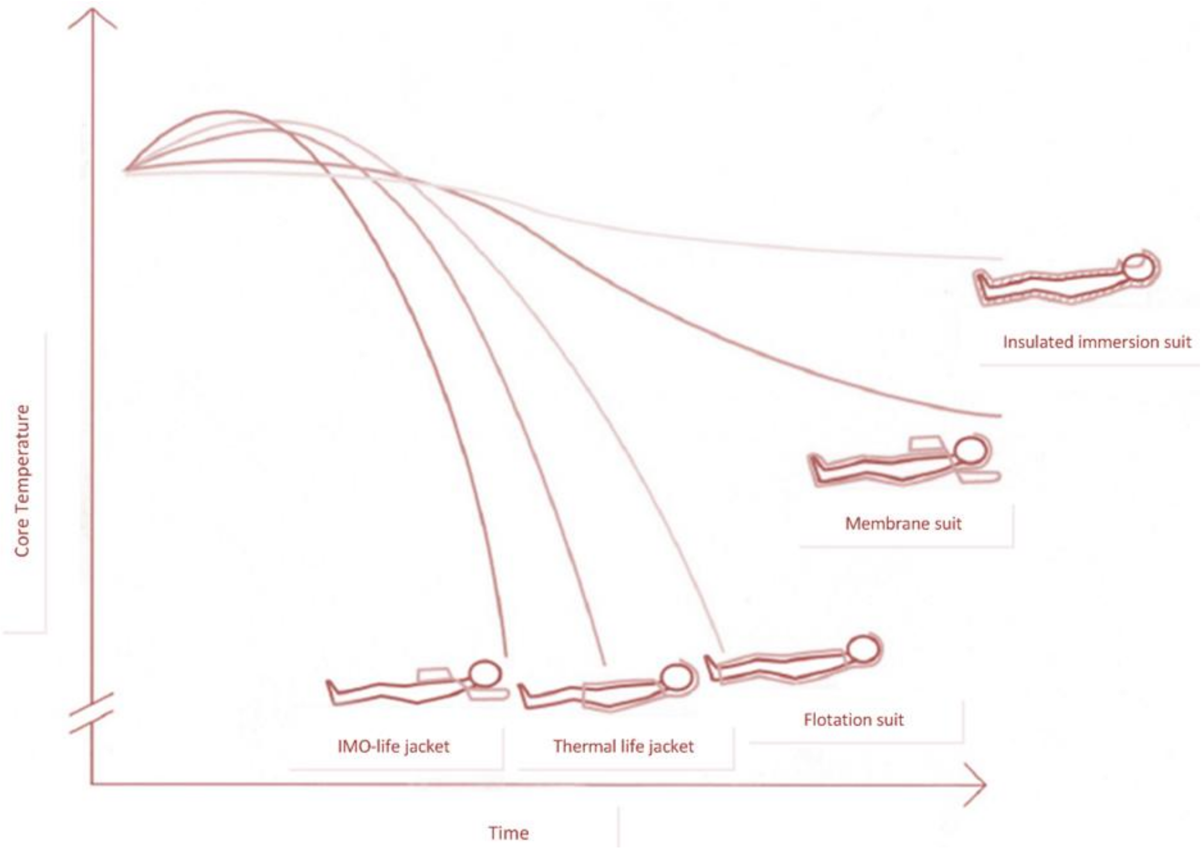

FIGURE 91 - CORE TEMPERATURE DEVELOPMENT FOR DIFFERENT TYPES OF CLOTHING AND RESCUE EQUIPMENT. ADOPTED FROM [8]

[73] The increases in core temperature seen for some of the equipment in the figure occur due to the initial cold shock. The body responds by increasing activity, and thus for a short period of time, the core temperature increases.

The insulated survival suit is the obvious first choice for increasing survivability, and has been for decades. Currently, research is being conducted in improving survival suits used in the North Sea. Important factors for these suits are; buoyancy, thermal insulation, leakage, hydrostatic forces and accessories (e.g. spray hood). Also means for locating the individual are important. The new suit “SeaBarents” does not leak [55].

APPENDIX – S. REGULATIONS

The most central regulations offshore and onshore are the HSE regulations and the new working environment regulations [140]. Unless so stated, any reference in this report to *regulations* represents the Norwegian HSE regulations issued by the Norwegian Petroleum Safety Authority (PSA), the Norwegian Climate and Pollution Agency (CPA) and the Norwegian Board of Health Supervision (BHS). The HSE regulations are[74]:

- Framework HSE [141]
- Management [114]
- Facilities [142]
- Activities [143]
- Technical and Operational [144]

Regulations that are also considered for this report are the CAA regulations involving flying on the Norwegian Continental Shelf: BSL D 5-1 [30].

There are several national and international standards and guidelines related to health and working environment in cold climates. The three perhaps most important are described below.

- ISO 15743:2008 "Ergonomics of the thermal environment – Cold workplaces, risk assessment and management" provides information, guidelines and practical tools for evaluating and safeguarding health effects and risks with working in a cold environment.
- ISO19906 "Petroleum and natural gas industries, Arctic offshore structures" is, according to the Barents 2020 project [59] the *ideal place for articulating an international functional standard for offshore operations in the Arctic.* The current draft is lacking any treatment of working environment and human factor issues. ISO19906 is therefore in need of amendment in the next revision cycle.
- NORSOK S-002 is *the best currently available functional standard to use as a starting point to offshore operations in the Barents Sea* [59]. S-002 is a more comprehensive guidance paper for working environment problems, however not in extreme environments such as the Arctic. A revised NORSOK S-002 could be used as a basis for amendments in ISO 19906.

[74] The regulations are used in this report as they were written on the 21st of February 2013.