UiT
THE ARCTIC
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Faculty of Science and Technology
Department of Engineering and Safety

Risk of Ship Collision in the Barents Sea in 2030

Academic Year 2014

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Jan Børre Hansen Balto
TEK-3901 Master's thesis in Technology and Safety in the High North

PREFACE AND AKNOWLEDGEMENT

This master thesis is the culmination of a two year master program in Technology and Safety in the High North at UiT, The Arctic University of Norway. The thesis is an individual project and is equivalent to 30 ECTS. The goal is for the student to gain in-depth knowledge and competence within a selected area in the field of technology and safety, relevant for the high north. Learning outcome through the project is to improve the student's ability to independent engineering and research work, and provide training in planning of projects, systematic processing of information and report writing.

The topic came during a meeting with Aker Solutions Tromsø in December 2013. Without any special background in maritime transport, Aker Solutions made me realize and inspire me to this theme as it is interesting and relevant in the coming years with respect to the development of the petroleum activity that's most likely are going to take place in the Barents Sea.

During the course of this thesis and preliminary work a few people have made significant contributions, and a few acknowledgements are in order. First of all a great acknowledgement to my thesis advisor, Professor Javad Barabady. All the people at Aker Solutions in Tromsø, and especially Safety and Environment Engineer Sigve Daae Rasmussen, for giving me a very inspirational stay at Aker Solutions office, and with the help to navigate my way through a large amount of documents in the initial phase of the thesis. A big gratitude goes to Trond Langemyr at Kystverket for good help and giving me aceess to the extended version of the simulation tool used in this thesis. I will also thank PhD student Jaap Van Rijckevorsel for his infectious commitment and help with the structure of the task.

A big thank you goes to my class for all the good experiences, friendships, and hardships prevailed together, you know who you are. I am grateful to my girlfriend Ragna for always supporting and encouraging me along the thesis process and to my lovely daughter Alma for constantly reminding me about what is actually important in life.

Tromsø 1st of June 2014

Jan Børre Hansen Balto

Master thesis – TEK-3901 Master Thesis in Technology and Safety in the High North

UiT - The Arctic University of Norway
Departement of Engineering and Safety
Faculty of Science and Technology

ABSTRACT OF THE MASTER'S THESIS

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Title: Risk of Ship Collisions in The Barents Sea in 2030

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Abstract:
This thesis evaluates the risk of ship collisions in the Barents Sea in 2030 between three future scenarios; Minimum, Basis and Maximum Scenario. IWRAP Mk2 program is utilized to make the calculations. Automatic Identification System (AIS) data of 2013 is used to parameterize current traffic density, while the increased traffic in the different scenarios is derived from an analysis of multiple sources, including Rystad Petro Foresight, government documents and reports from DNV.

The petroleum production in the North Sea is expected to decline, while exploration and production in the Northern part Norway is expected to increase. This will lead to that the Barents Sea will be a major contributor to oil and gas production, instead of the North Sea and the southern Norwegian Sea towards the end of 2030s.

The petroleum industry is on its way north to an area that earlier mainly has been associated with high fishing activity, but may now be more dominated by larger supply vessels. This change will cause an increase in ship traffic in the area, and the probability of ship collisions may therefore be elevated. The issues discussed in this report are important for the industry, and necessary for predicting the future risk picture in the Barents Sea. It is vital to idenfity the future risk of ship collision with regards to the increase in ship traffic due to the potential consequences with respect to the harsh and vulnerable environment and lack of infrastructure in the northern part of Norway.

This thesis will investigate how the probability of ship collision change, and also identify the risk of ship collisions in the Barents Sea within the different scenarios of petroleum development. There are five types of collision between ships which are taken into account in this thesis, these are; Head on collsion, crossing collsion, overtaking collsion, bend collision and merge collsion.

The thesis will answer the research problems regarding to how the environmental conditions in the Barents Sea are, how the increased offshore-related traffic increase the probability of ship collision in the Barents Sea in 2030, and how the risk of ship collisions change between the three scenarios.

The results show that there will be significantly differens in the likelihood for ship collisions in the three scenarios. The total likelihood for minimum scenario is 5,80E-04 incidents/year, while the likelihood in basis and maximum scenario is calculated to 1,8E-03 and 1,75E-03. The final leg into `Polarbase` (Hammerfest) is the leg in all scenarios that will have the greatest likelihood for ship collisions, and will also be the most critical leg with respect to the high density of ships in it, despite its short length. The ship type that will be the biggest contributer to ship collisions is both support ships and crude oil tankers, these collisions will be by type; head on collision and overtaking collision.

A critical situation will occur in the Barents Sea if a ship collision takes place, and especially collisions with crude oil tankers with its chemicals. This will put great demand on the oil spill management in the region.

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Keywords: Ship, Collision, Marine Accident Modelling, The Barents Sea, IWRAP Mk2

ABBREVIATIONS AND NOMENCLATURE

Abbreviations

AIS	Automatic Identification System
ARPA	Aumatic Radar Plotting Aid
CO_2	Carbon Dioxide
DNV	Det Norske Veritas
DWT	Deadweight Tonnes
FPSO	Floating, Production, Storage and Offloading
GT	Gross Tonn
IMO	International Maritime Organization
IMR	Inspection, Maintenance and Repair
LNG	Liquefied Natural Gas
MACHINE	Model of Accident Causation Using Hierarchical Influence Network
NCA	Norwegian Coastal Administration
NEZ	Norwegian Economical Zone
NG	Natural Gas
NGL	Natural Gas Liquids
PSV	Platform Supply Vessel
RNNP	Petroleumstilsynet/Petroleum Authority
SOLAS	Safety of Life At Sea
TSS	Traffic Separation System
VVTS	Vardø Vessel Traffic Service

Nomenclature

^oC	Temperature – degrees centigrade
Sm^3	Standard cubic meters is a device for volumetric measurement of oil, NG and gas condensate at standard conditions defined in ISO standard 13443.
P	Probability
N	Number of accident candidates
P_c	Causation factor
L_w	Length of the waterway
$P_{Gi,j}$	Probability that two ships of this classes *i* and *j* collide in a head-on meeting situation if no evasive manoeuvres are made
Q_i^n	Number of passages per time unit for ship class *i* moving in direction *n*
Φ	Standard normal distribution function
$\overline{B}$	Average vessel breadth
Θ	Angle
F_{flag}	Multiplication factor for flag state
F_{age}	Multiplication factor for age of the ship
F_{wind}	Multiplication factor for wind
F_{vis}	Multiplication factor for visibility
F_{nav}	Multiplication factor for the navigation status
EXP*(i)*	Exposure for certain accident type
CASRAT*(I, type, size)*	Casualty rate for a certain accident type (i), ship type and ship size

FIGURES AND TABLE LIST

Figures

Tables

1 INTRODUCTION

The Master thesis is the final assignment for the two year Master of Science program, *Technology and Safety in the High North* at the UiT The Arctic Unversity of Norway. The thesis is independent and equivalent to 30 ECTS. In the Master thesis, the student should demonstrate knowledge about the research methodology presented in the program, as well as skills in scientific reflection and analysis.

In this chapter will the background and research problem be presented along with the aim of the thesis, research questions, scope, limitation and assumptions, and the thesis outline.

1.1 BACKGROUND AND RESEARCH PROBLEM

The petroleum production in the North Sea is expected to decrease, while exploration and production in the Northern part Norway is expected to increase (Figure 1.1). This will lead to that the Barents Sea will be a major contributor to oil and gas production, instead of the North Sea and the southern Norwegian Sea towards the end of 2030s.

The petroleum industry is on its way north to an area that earlier mainly has been associated with high fishing activity, but may now be more dominated by larger supply vessels. This change will cause an increase in ship traffic in the area, and the probability of ship collisions may therefore be evaluated. The issues discussed in this report are important for the industry, and necessary for predicting the future risk picture in the Barents Sea. It is vital to idenfity the future risk of ship collision with regards to the increase in ship traffic due to the potential consequences caused by harsh and vulnerable environment and lack of infrastructure.

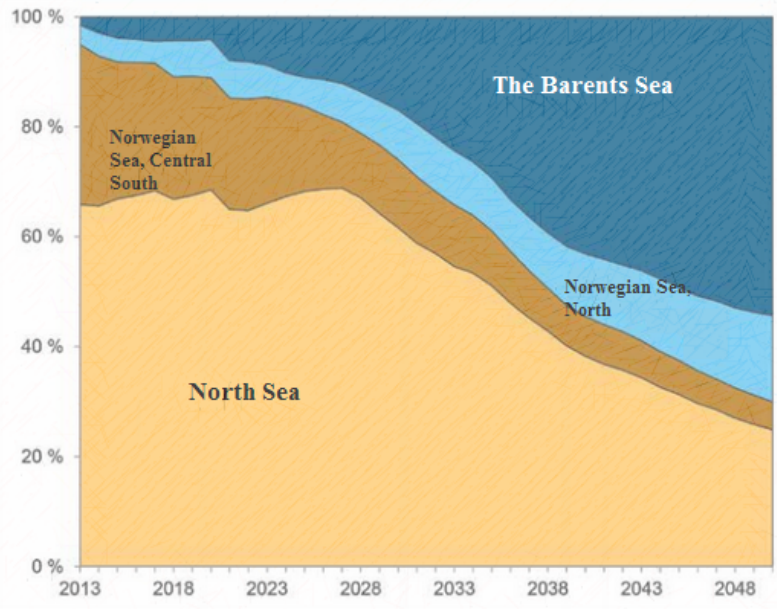


Figure 1.1: Relative daily production in Norway from 2013 to 2050 (Rystad Petro Foreseight 2030, 2012)

1.2 AIM OF THE THESIS

The main objective of the thesis will be to analyze the risk of ship collisions in the Barents Sea. This thesis will study three future scenarios for development of petroleum activity, developed by Rystad Petro Arctic. The enivornmental conditions in the Barents Sea will be identified and discussed. Secondly this thesis will discuss how the risk of ship collisions will increase with respect to the three scenarios, minimum, basis and maximum scenario, and analyse wheter or not there are any areas that will experience a higher risk than other.

1.3 RESEARCH QUESTIONS

The following research questions are posed on the basis of the research problem.

- How are the environmental conditions in the Barents Sea?
- How does the increased offshore-related traffic increase the probability of ship collision in the Barents Sea in 2030?
- How will the risk of ship collision change between the three scenarios in 2030?

1.4 SCOPE

The thesis will be based on three possible scenarios for future the field development in the Barents Sea in 2030. These scenarios (chapter 1.4.1 – 1.4.3) have been prepared by Rystad Energy for Petro Arctic in the report *Rystad Petro Foresight 2030* (Petroarctic, 2014). The thesis will only consider the increment of future traffic associated to the petroleum industry, and only focus on the probability part of the risk.

1.4.1 Minimum Scenario

Minimum scenario (Figure 1.2), consisting of proven resources: Goliat, Snøhvit and Johan Castberg. An overview over the different facilties is listed up in Table 1.1.

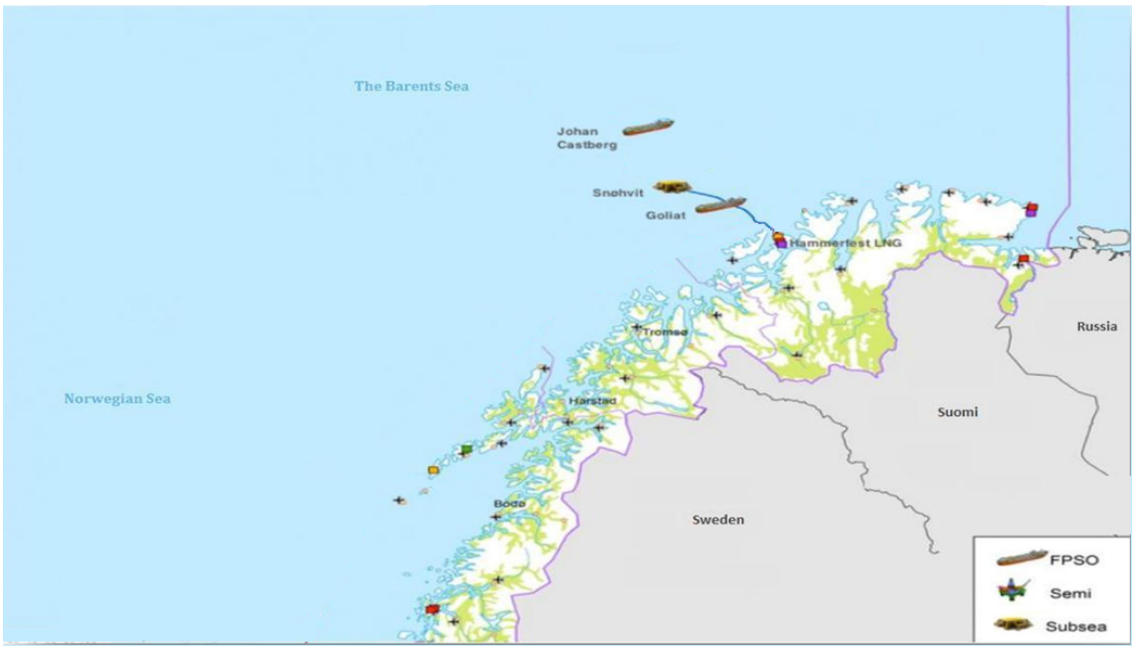


Figure 1.2: Minimum Scenario (Rystad Petro Foreseight 2030, 2012)

Table 1.1: Type of offshore facilities in Minimum Scenario

Facility	FPSO	Pipeline to shore
Johan Castberg	X	
Goliat	X	
Snøhvit		X

1.4.2 Basis Scenario

Basis scenario (Figure 1.3), includes proven resources and fields with relatively high probability of discovery: Goliat, Snøhvit, Gohta, Johan Castberg, Hoop, Lopparyggen øst and Barentshavet sydøst. An overview over the different facilties is listed up in table 1.2.

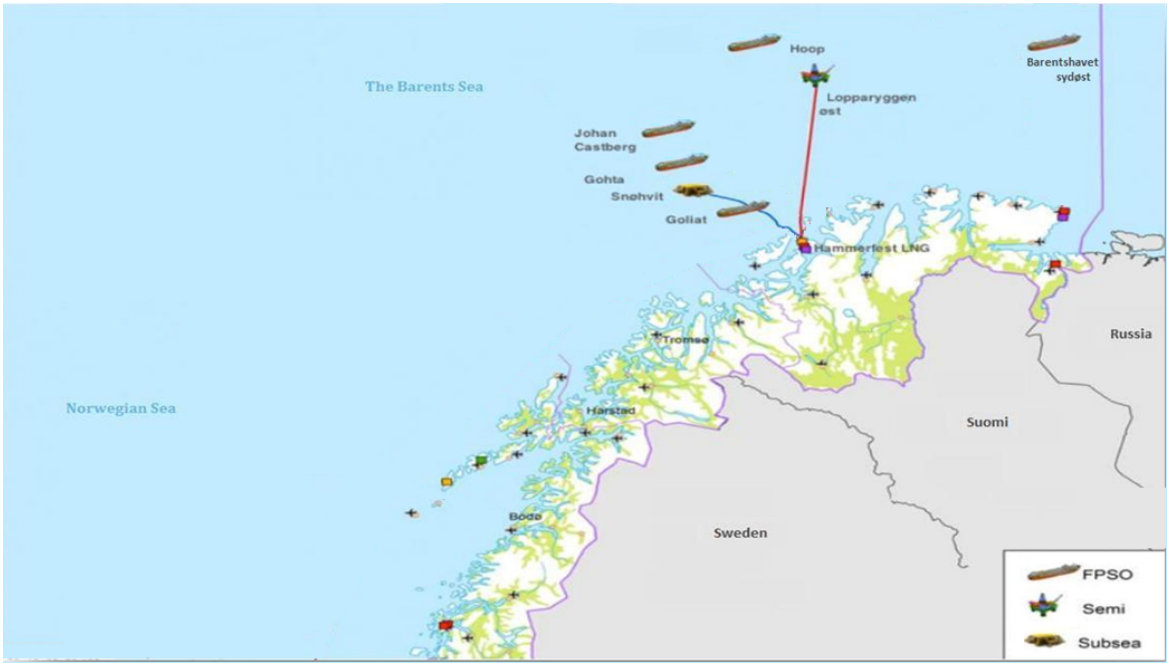


Figure 1.3: Basis scenario (Rystad Petro Foreseight 2030, 2012)

Table 1.2: Type of offshore facilities in Basis Scenario.

Facility	FPSO	Pipeline to shore
Johan Castberg	X	
Gohta	X	
Goliat	X	
Hoop	X	
Barentshavet Sydøst	X	
Snøhvit		X
Lopparyggen		X

1.4.3 Maximum Scenario

Maximum scenario (Figure 1.4), also includes the fields from basis scenario and fields in areas which today are considered to have a low probability of discovery, as well as fields in non-opened areas. The different facilities will vary between an Floating, Production, Storage and Offloading (FPSO) platforms and semi-submersible platforms with pipeline to shore and to Barents Pipe which is a pipeline (marked with red line) which is going from the east of the Barents Sea down to southern Norway, see table 1.3. The purpose of this scenario is to cover the entire geograpichal area of analysis.

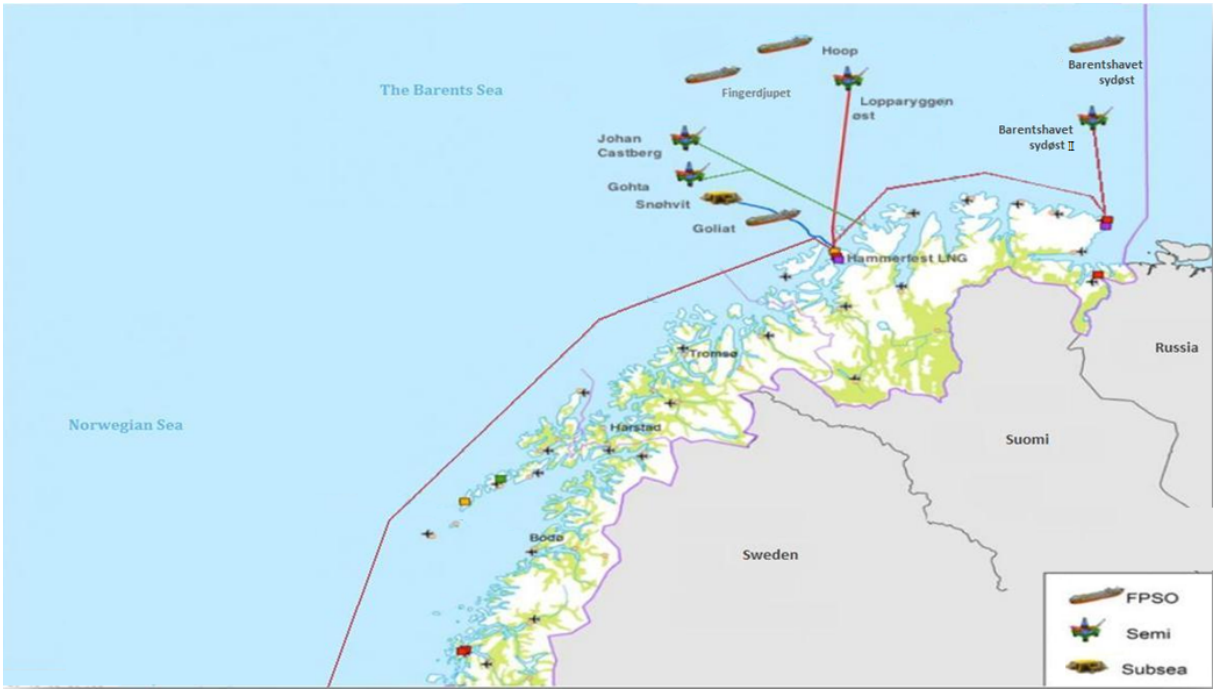


Figure 1.4: Maximum Scenario (Rystad Petro Foreseight 2030, 2012)

Table 1.3: Type of offshore facilities in maximum scenario

Facility	FPSO	Pipeline to shore	Pipeline Export
Goliat	X		
Hoop	X		
Barentshavet sydøst I	X		
Fingerdjupet	X		
Johan Castberg		X	
Gohta		X	
Barentshavet sydøst II			X
Snøhvit			X
Lopparyggen øst			X

1.5 LIMITATION AND ASSUMPTIONS

The thesis is governd by the following limitation:

- There are great uncertainties about how the Barents Sea will look like in 2030. Information regarding sizes and associated shipping traffic to each field in the future scnearios is based on the information from different companies, experts and government reports.
- Consequences of ship collisions are not considered in the risk anlysis.
- The focus of the thesis is on the Norwegian Economic Zone of the Barents Sea.
- The calculation and simulation is based on Automatical Information Source (AIS) data from 2013

The following assumptions have been considered for the thesis:

- The export traffic for each field must take the shortest route until the separation zone is reached.

- The maritime traffic, except the added offshore fields and Russian transit traffic is assumed to be the same in 2013 as in 2030
- The same amount of Inspection, Maintenance & Repair (IMR) vessels is chosen for each field, this assumption is made in collaboration with ENI Norge through a telephone meeting.
- The incoming traffic for transporting equipment to Polarbase from the marked is assumed to be by land.
- Assumes that the capacity at Polarbase is acceptable for each scenario.
- There is no WOW (Waiting on weather) in the simulations.
- Assumes that all vessels have successful operations.
- The export tankers from Hammerfest will use the same sailing route as Arctic Princess.
- The helicopter technology and capasity is improved, with respect to crew transportation. No crew boats are included in the model.

1.6 THESIS OUTLINE

This thesis consists of the 5 chapters. Chapter 1 contains background information relevant for the thesis and a description of the research problem, an overview over the three scenarios, aim, research questions, the scope, limitations and the thesis outline. Chapter 2 follows with a literature review. This chapter starts with an environmental description of the Barents Sea, with physical conditions and an overview of the existing and future fields in the Barents Sea. The two next sub chapters contains of the maritime traffic and a description of the theory of ship collisions. Chapter 3 describes the research, method and materials, how the method is conducted and the challenges connected to data collection and data analysis. Chapter 4 contains of discussion of the findings, literature and the results. This chapter starts with results of the data analysis, comparison of results, a sensitivity analysis and ends with a literature discussion. Chapter 5 presents the conclusion to the thesis and suggestions for further research.

2 LITERATURE REVIEW

This chapter presents the basic theories and knowledge that are used to answer the research questions.

2.1 DESCRIPTION OF ANALYSE AREA

2.1.1 Description of the Barents Sea

The Barents Sea (Figure 2.1) is a subarctic shallow continental shelf of approximately 1 400 000 km^2. The Barents Sea is delineated in the Norwegian Sea in the west by a line from the North Cape of Bear Island to the South Cape of Spitsbergen, the rest of Zemlja Frantsa losifa (Frans Josef Land), Novaja Zemlja in the east, the Arctic Ocean to the north and the Russian and Norwegian coast in the south. The depth varies between 200 m and 500 m, but the ocean is shallower than 50 m in the Spitsbergen Bank (SNL, 2014).

Figure 0.1: Overview over the Barents Sea (World Atlas, 2014)

There have been drilled more than 100 wells since 1980 in the Barents Sea. However it was only at the beginning of the new millennium that the Barents Sea could be termed as the third oil and gas province (SNL, 2014).

2.1.2 Physical Conditions

In this sub-chapter the physical conditions in the Barents Sea are described. All the mentioned physical conditions may have an impact on the sailing conditions, and may therefore be a contribution for increasing the risk for ship collisions.

Air Temperature

The average minimum air temperature in the Barents Sea is -7.7 ˚C with an annual range between -6.0 ˚C to -9.0 ˚C. The minimum air temperatures that can be expected in the southwest are in the range of -15˚C to -20˚C. Towards the north and east, the temperatures decrease to the range of -20˚C to -30˚C. The minimum air temperatures are shown in Figure 2.2 (Jacobsen, 2012).

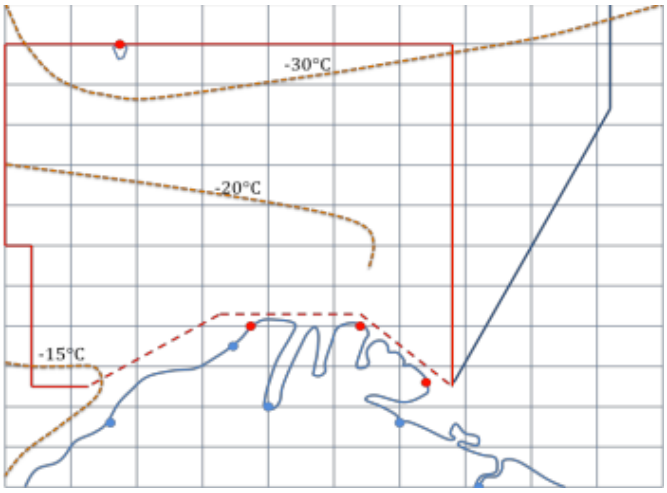


Figure 0.2: Lowest air temperature with an annual probability greater than 10^-2 (Jacobsen, 2012)

Wind

A comparison of wind conditions in the Barents Sea and the North Sea shows no major differences in wind speed. The highest wind speed have been measured at Bear Island, and then found to decrease towards the east and north. Metrological conditions in the Barents Sea are dominated by storms that forms in the North Atlantic and the wind direction during winter is typically from the southwest, except near the coast where the wind direction normally is northeast (Thelma, 2010).

Icing

Icing is a well-known hazard to traditional operations in the northern waters, where about 80 vessels capsized due to icing in the period 1955-1970 (Løset, et. al., 2006). In combination with low temperatures, icing is caused by:

- sea spray
- undercooled rain
- rain
- fog

Sea spray is the most frequent cause of icing and the factor with the biggest contribution of ice on ships, and a combination of spray and atmospheric icing can cause extreme ice loads. Icing due to sea spray is a phenomenon which occures at low temperatures combined with strong winds from the south and southeast bringing cold air masses from the east. According to the Meteorological Institute icing from sea spray will occur with temperatures below -2˚C and with wind speed in excess of 11 m/s, however the data for sea spray icing is limited. Observations of air temperatures at the Norwegian coastal stations indicate that icing will be a problem in the part of the Barents Sea which is opened for petroleum activities (Figure 2.3). The icing problem in the North Barents Sea can be extreme, and spray and mist can cause build up reaching four centimeters of ice per hour on the surface of a device (Thelma, 2010). Figure 2.3 shows the occurence (percentage) of temperature below -1.8 C and wind above 10 m/s in January from 1961 to 2010.

Ice accretion on ships and structures is a concern for operations in cold climates and can lead to a variety of problems, as even light ice accretions can lead to many operational difficulties, e.g. slippery decks, ladders and handrails. Ice accretion can be a safety hazard; if equipment such as winches, derrick, valves, life-saving and fire fighting equipment are rendered inoperable, causing delayes in operation or potentially necessitates an evacuation of the platform. For vessels, the effect are more serious, in that ice accretion increase the draught, reduces the freeboard, and moves the centre of gravity of the vessel, thereby compromising stability (Løset, et. al., 2006).

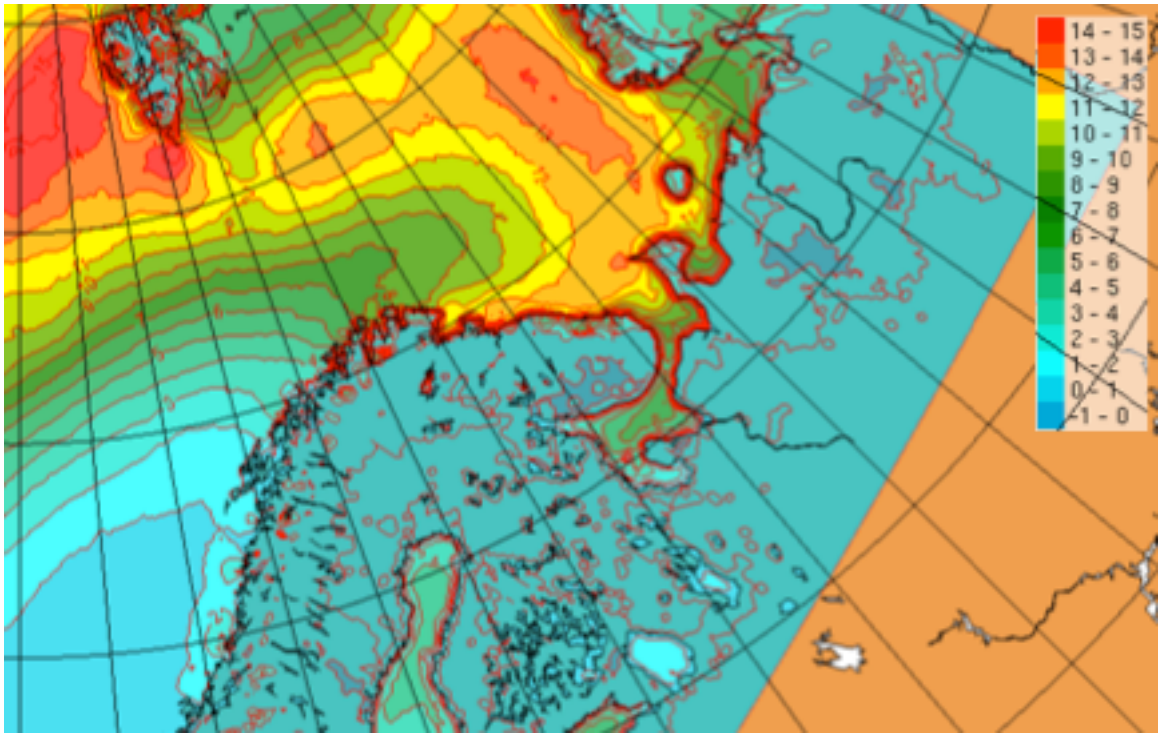


Figure 0.3: Occurence (%) of temperature below -1.8 and wind above 10m/s January 1961-2010 (Kystverket,2014)

Atmospheric icing may occure in the Barents Sea throughout the year as low air temperatures are possible at any time. For moving ships the rate of icing depends on wind speed, air temperature, sea temperature, characteristic speed and heading of the ship. Atmospheric icing occurs through fresh water precipitation, like snow, rain and super-cooled droplets. Atmospheric icing normally form when the air temperature is between 0 ˚C and – 20 ˚C and the wind speed is less than 10 m/s. As a result of atmospheric icing, the higher parts of the ship can get covered with 1-2 cm (rarely up to 6 cm) thick ice (Løset, et. al., 2006). Atmospheric icing may produce a uniform layer of ice on all exposed surfaces. This may pose various problems in operations, communication and navigation, as it also adheres to antennas and other technical aids on the deck, e.g. cranes, winches and valves. Black frost can cause a critical reduction of stability, especially for smaller vessels, if atmospheric icing occurs simultaneously as sea spray icing. Sea spray can only cause ice accumulation up to a certain height above the waterline, but atmospheric icing can occur at all heights (Løset, et. al., 2006).

Status for sea ice in the Barents Sea

The ice extent in the Barents Sea is as its greatest in April. From 1979 to 2013 there has been a negative trend in sea ice extent in April, although the yearly variations are large. The ice extent is lowest in September, and there has also been a negative trend from 1979 to 2013.

The last eight years have had yearly variations that have been more moderate compared to previous years. The lowest ice exent in April was in 2006, and in September in 1979, 2001, 2004, 2011, 2012 and 2013 the area have been nearly ice-free (Figure 2.4).

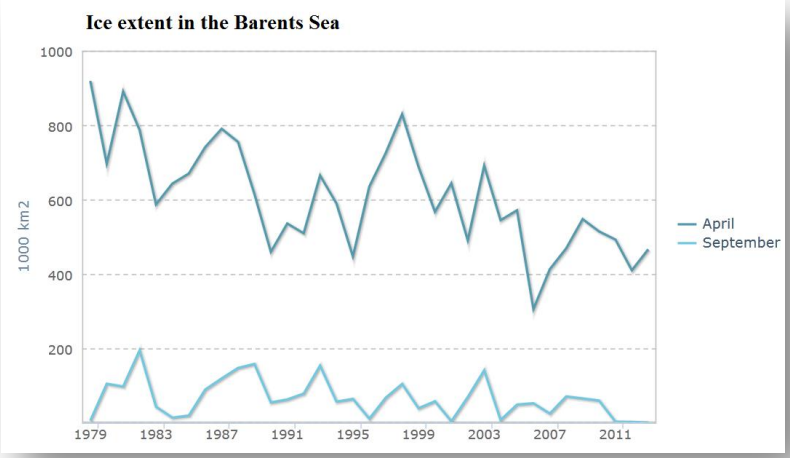


Figure 0.4: Ice extent in the Barents Sea from 1979 - 2013 (Meterologisk institutt, 2012)

Polar Lows

Polar lows are small but intense low pressure formed in the Arctic waters during the winter season from October to April. A potentially damaging aspect of polar lows are the rapid changes, as the wind can increase from breeze to storm in just a few minutes, and the wave height is observed to increase by up to 5 meters in under an hour. Generally, polar lows are difficult to forecast, since they occur in areas with few points of observations, and they are of a comparatively small scale in relation to the observation coverage (Meteorlogisk institutt, 2012).

Figure 2.5 presents the monthly distribution of polar lows in the Norwegian Sea and the Barents Sea, which is registered at the Norwegian Metrological Institute from 2000 to 2012.

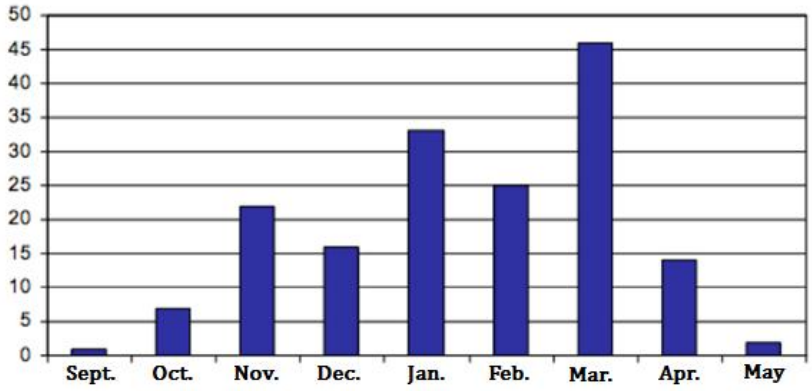


Figure 0.5: Monthly distribution of polar lows in the Norwegian Sea and the Barents Sea from 2000 to 2012 (Meterologisk institutt, 2012).

Visibility

The sight parameter is based on the assessment of an observer, and therefore only manned stations have visibility data. The nearest weather stations catering for the area are stations on the coast of Finnmark and on Bear Island. The conditions, as observed at these stations are shown in table 2.1 (Meteorologisk institutt, 2012).

Table 0.1: Visibility distribution (Meterologisk institutt, 2012)

Visibility	Sight	Bjørnøya and Hopen	Vardø Radio
Good	> 10 km	50 % (July) 60% (Rest of the year)	80-90 %
Moderate	4 - 10 km	12 – 19 %	5 – 8 %
Low	1 – 4 km	10 – 19 %	9 – 12% (Dec&Jan) 3 – 7 % (Rest of the year)

The frequency of fog at Bjørnøya and Hopen is significantly higher than in Vardø and the percentage is highest from June to September where it varies in the range 11-27 %. The frequency of fog is for the rest of the year in the range of 4-8 % at these stations. Vardø radio has the greatest frequency of fog in July-August and in February when there is fog 4-7 % of the time. The rest of the year is in the range 1 % (Meteorologisk institutt, 2012).

Darkness

The sun is below the horizon for a given period during winter. This results in total darkness, called polar night, in the middle of the winter with only limited periods of twilight during the day. The length of the daylight period decreases rapidly from the autumn equinox until the sun falls below the horizon. Similarly the daylight period increases rapidly from the return of the sun until the spring equinox. Table 2.2 shows the dates when the sun falls below the horizon and when it returns in different locations (Jacobsen, 2012).

Table 2.2: Sun activity in different locations (Jacobsen, 2012)

Location	Sun disappears	Sun returns
Vardø	23. November	19. January
Hammerfest	22. November	20. January
Nordkapp	20. November	22. January

2.1.3 Existing and future fields in the Barents Sea

The Rystad report includes planned, possible and probable offshore fields through their scenarios. Considering the uncertainties associated to the size of the future fields, some assumptions with respect to the ship traffic have been done. Table 2.3 shows a total overview of the maritime traffic for the existing and future fields in the Barents Sea, which are used in the simulations.

Table 2.3: Maritime Traffic for existing and future fields

	Field Size mill. Sm^3	Supply Vessel [75-100m]	IMR Vessel [100-125m]	Export Tankers [275-300m]
Goliat[1]	10	70	4	36
Johan Castberg[2]	100	130	4	100
Gohta[3]	10	70	4	36
Fingerdjupet	10	70	4	36
Hoop	10	70	4	36
Lopparyggen Øst	10	70	4	36
Barentshavet sydøst	10	70	4	36
Barentshavet sydøst II	50	100	4	50
Snøhvit		AIS	AIS	AIS

[1] Parameters from telephone meeting with ENI Norge
[2] Parameters are taken from the government's document for scenarios for year-round petroleum activity in the Lofoten and the Barents Sea 2005-2020
[3] The parameters for the rest of the offshore fields are reached in consultation with Project Manager in Petro Arctic, Kjell Giæver.

A location overview of the different offshore fields is shown in figure 2.6.

Figure 0.6: Overview over existing and future fields in the Barents Sea

2.2 MARITIME TRAFFIC

With the forseen increase in petroleum activity in the Norwegian and the Barents Sea an increase in the shipping traffic in the area is expected. In this context, the main goal should be that the risk of environmental damage caused by ship collisions and spills should be kept at a minimal level, while continuously striving to further reduce the risk.

Det Norske Veritas (DNV) prepared a report commissioned by the Coastal Administration where the probability of acute pollution from shipping along the Norwegian coast is analysed. The analysis is based on traffic data from 2008 and forecast for 2025. It is concluded in the DNV report that the predicted increase in Russian traffic, in combination with increased Norwegian exports of petroleum from the Barents Sea will cause the likelihood of emission to increases significantly by 2025 along most of the coast of Nordland, Troms and Finnmark (Figure 2.7) Without the introduction of further maritime safety measures, an increase in tanker traffic will result in a greater probability of a major accident in the area. Today's emission probability is low due to the relatively low level of activity and the introduction of effective maritime safety measures.

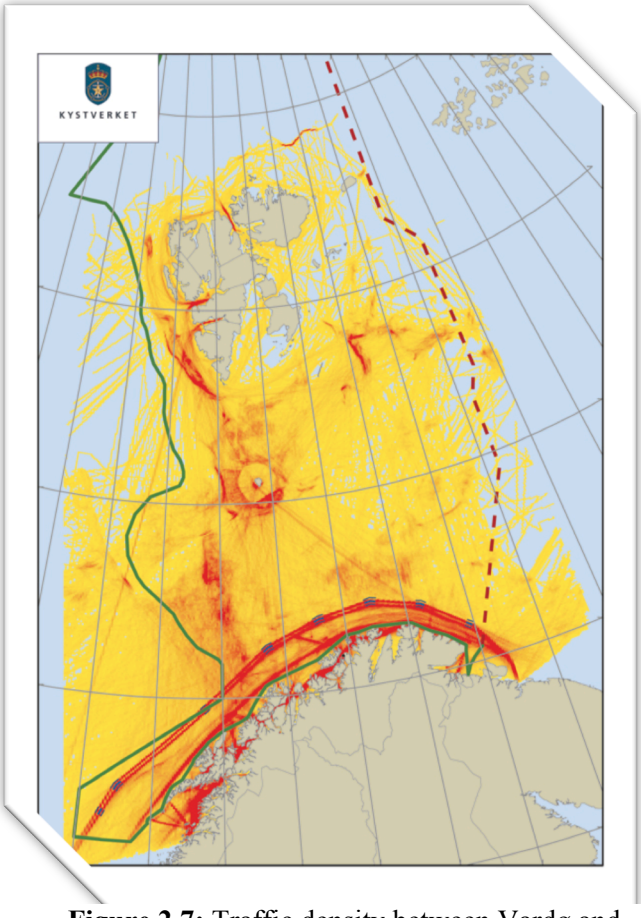


Figure 2.7: Traffic density between Vardø and Røst in the second half of 2010 (Det Kongelige Miljøverndepartement, 2011)

As of today, the same effective maritime safety measures is about to be introduced south of Lofoten (Det Kongelige Miljøverndepartement, 2011).

2.2.1 Russian Traffic

There are several reviews of the extent of the transit traffic to/from Russia. Kystverket (2003) have discussed the uncertainties of the development based on meetings with different Russians groups. It is assumed that there will be established a pipeline to Murmansk before 2015, and the total export will be approximately 80 milion tonnes crude oil. In addition, any transport of gas/condensate with ship is assumed to be approximately 6 milion tonnes of Liquefied Natural Gas (LNG) and 1 milions tonn Liquefied Petroleum Gas (LPG) (DNV, 2003).

The traffic is assumed to be of 656 ships from Russland every year with different vessel size, the total Russian traffic is presented in Table 2.4 by the length of the ship and the volume of Deadweight tonnes (DWT).

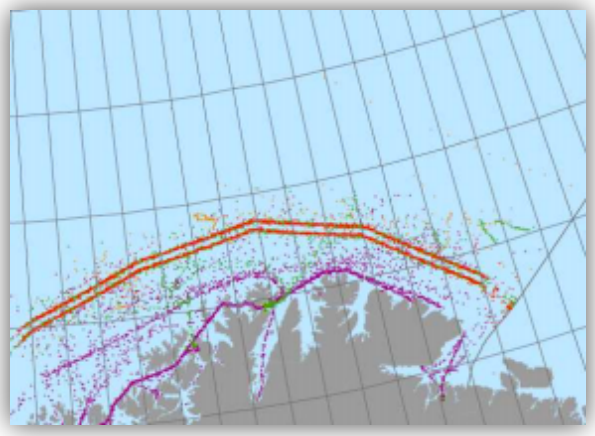
Table 2.4: Ship Traffic along the Norwegian coast linked to exports from Russia (DNV, 2013)

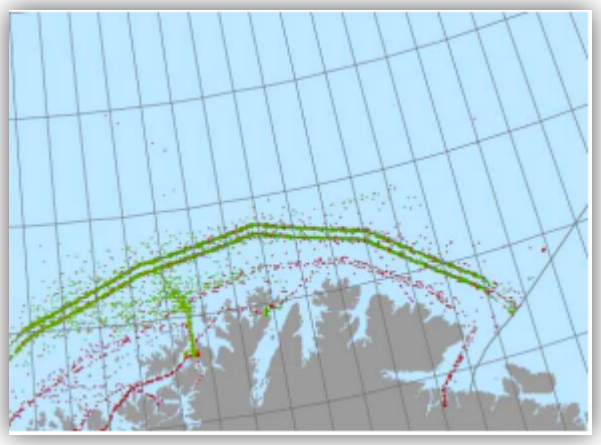
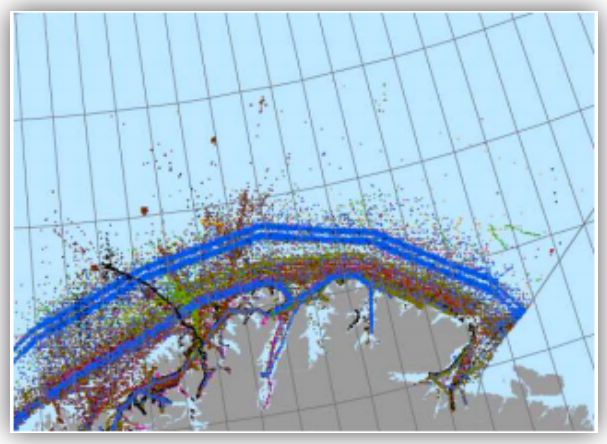
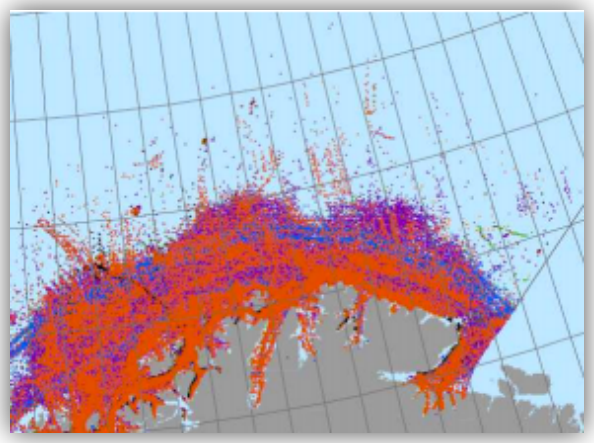
Ship Traffic in the analyze area	Total
100 000 DWT (225m - 250m)	320
180 000 DWT (300m - 325m)	150
280 000 DWT (325m - 350m)	86
100 000 DWT LNG (275m - 300 m)	60
25 000 DWT condensate (150m - 175m)	40
Total vessels	656

2.2.2 Description of Activity

There is expected to be an increase in all type of ships, but especially gas and oil tankers, except fishing boats that are expected to decline (Det Kongelige Miljøverndepartement, 2011). The reduction of fishing boats due to implementation of improved technology, better resource management and continued restructuring of the fishing fleet. The reduction of fishing boats does not necessarily mean less tons caught fish, but the fishing boats sails less to catch allocated quotas (DNV & Kystverket, 2012). Table 2.5 shows the traffic pattern for all ships except fishing ships. For 2011 represents this traffic around 61 % of 'all ship traffic, and 30-40% of these are over 5,000 DWT.

Table 2.5: Trafitic pattern for different ship types (DNV & Kystverket, 2012)

	Description
	**Oil Tankers** In 2011 oil tankers constitutes about 3,1 % of total travelled distance. More than 86% of the sailed distance, is made by vessels with a deplacement of 5000 DWT or more. These vessels are required to follow the Traffic Separation System (TSS) when traveling along the coast.

	**Gas tankers and chemical-/product tankers** In 2011 gas tankers and chemical-/product tankers constitutes about 3,4 % of total travelled distance. More than 99% of the sailed distance is made by vessels that are over 5000 DWT. These vessels are required to follow the TSS when traveling along the coast.
	**All vessels except fishing vessels** In 2011 these vessels constitute about 61 % of total travelled distance. Approximately 30-40 % of sailed distance is made by vessels that are over 5000 DWT. These vessels are required to follow the TSS when traveling along the coast.
	**All vessels** A density plot of total travelled distance for all vessels in 2011.

2.2.3 Traffic Development 2005-2009

The traffic of seismic vessels, offshore supply vessels and tankers has increased significantly more than for other groups of vessels, altough from relatively low levels. Fishing vessels accounted for most ship movements in 2008, about 58 % of the total distance travelled in the Barents Sea. Over 80 % of all distance travelled for ships with 10,000 gross tons in the planning area is now taking place in the separation system Vardø-Røst, including close to 100 % of all traffic. The remaining traffic in the area is dominated by cargo ship on 1,000-5,000 gross tons, but there are also activities with other cargo, offshore vessels and other support vessels (Det kongelige miljøverndepartement, 2011).

Transit traffic consists of large tankers and bulk carriers to/from Russian ports. Until 2008, the traffic volume was stable in terms of both cargo volume and the number of passing ships. The total cargo volume is in the range of 10 million to 12 million tonnes per year, and is taken by 200 to 240 fully laden tankers. In 2009 the volume rose significantly (Figure 2.8). There are indications that the volume transported from the transit operations will continue to increase in the coming years, and the average size of tankers carrying oil is expected to increase (Det kongelige miljøverndepartement, 2011).

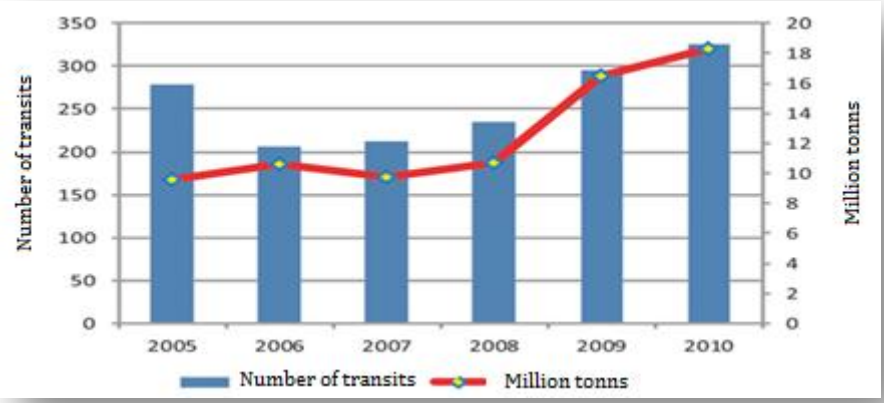


Figure 2.8: Number of passing ships versus cargo volume development (Det Kongelige Miljøverndepartement, 2011)

2.2.4 Ship Traffic In The Northeast Passage

Interest in ship traffic in the Arctic Ocean, including the Northeast Passage has increased with the rapid retreat of ice sheet in recent years. Summer ice has retreated sufficiently to create time windows in which all or part of the shipping lanes north of Russia and Canada / USA is open before freezing starts again. Today's traffic in the Arctic Ocean is low, and it is expected that the ship traffic in the Arctic Ocean over the next few years will still dominated by ships that have destinations in the area (Det kongelige miljøverndepartement, 2011).

Ships in transit through the Northeast Passage are currently at a very low number. Ship traffic through the Passage is likely to increase as global warming increases. The Northeast Passage will shorten the distance between Rotterdam and Yokohama from 11,200 nautical miles to 6,500 nautical miles, which can provide a significant cost reduction (DNV & Kystverket, 2012).

For shipping, the predictability in relation to absence of ice, especially multi-year ice, is a very important factor when the route through the Northeast Passage is chosen. Due to the annual variations, with some cold winters, multi-year ice must still be expected in the coming years. Other factors, such as the difficulty of identifying and quantifying risk factors associated with sailing in the Arctic, compared to traditional routes brings negative impact on the attractiveness of the

Northeast Passage. There are also considerable uncertainties with regards to Russian policies and particularly to the development of infrastructure. If transit through the Northeast Passage is to increase to a commercial scale, it would be more than a pure economics and logistics question (DNV & Kystverket, 2012). For liners, such as container ships, the reliability and predictability of the passage plan is the most important factor, one must know the exact date when the goods will arrive. This is challenging through the Northeast Passage due to uncertainties regarding ice, weather and politics (DNV & Kystverket, 2012).

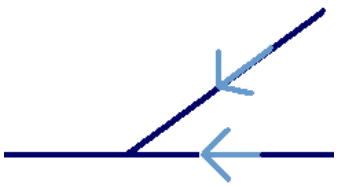
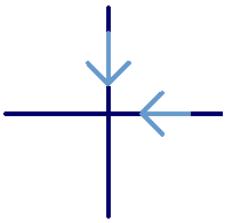
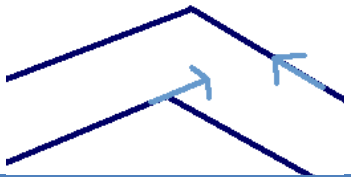
2.3 SHIP COLLISION

There can be many reasons for a ship collision to occur. Rule 7 in Farewells rules of the nautical road says this about the risk of collision: "*Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists. If there is any doubt such risk shall be deemed to exist."* (Allen, 2005).

2.3.1 Types of Accidents

Since other collision types, e.g., collision with a floating object, are not considered in this thesis, ship-ship collisions are referred as collision hereafter. A ship-ship collision occurs if a ship strikes another ship (Kristiansen, 2005). Collisions can be divided into head-on, overtaking, merging, crossing and bend collision (Table 2.6).

Table 2.6: Description of the different collisions type

Collision type	Illustration
Head-on collision	
Overtaking collision	
Merging collision	
Crossing collision	
Bend collision	

2.3.1.1 The Head-On Situation

"*When two power-driven vessels are meeting on reciprocal or nearly reciprocal courses so as to involve risk of collision each shall alter their course to starboard so that each shall pass on the port side of the other."* (Allen, 2005).

Vessels approach each other in a head-on situation at a rate equal to the sum of their individual speeds, whereas in the overtaking situation the rate of approach is, off course, the difference between the velocities of the ships involved. The closing speeds in crossing collision is somewhere in the middle. Thirty-knot closing speed are common in head-on encounters, fifty-knot relative speed are an unremarkable occurrence for container ships and naval vessels, and closing speeds for high-speed craft can approach terrestrial highway magnitudes. When vessels collide full on, even at slow speed, the result can be extremely destructive. The general rule for calculating the vessels' respective kinetic energies is (Allen, 2005):

$$Kinetic\ Energy = ½\ Mass \times Velocity^2$$

2.3.1.2 The Overtaking Situation

Of the five types of ship collisions – overtaking, head-on, merging bend and crossing – many consider the overtaking situation the least risky due to the low relative speed and reduce force of impact in the event of collision. The risks of overtaking collisions are greater in narrow channels, where increased traffic density, limited manoeuvring room, and the risk of interaction expose the vessels to the danger of grounding or collision.

Overtaking situations develop slowly, often placing the two vessels in close proximity – and exposed to crossing or meeting traffic – for considerable periods of time (Allen, 2005).

2.3.1.3 Crossing Situations

Rule 15 in "Farewells Rules of the nautical road" describes crossing situations like this:

"*When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel."* (Allen, 2005).

2.3.1.4 Merging Situations

The merging situation occur when two vessels are sailing in different directions, and meets in a waypoint connection of three legs. This in combination with ships who fails to make evasive actions in order to avoid the collision (IALA Web, 2014).

2.3.1.5 Bend Situations

The bend situtation occur when two ships are sailing in oposite directions meet in a bend (waypoint connection with two legs). One of the ships fails to change the course at the waypoint, resulting in the ships ending up on collision course. This in combination with ships who fails to make evasive actions in order to avoid the collision (IALA Web, 2014).

2.3.2 Main Causes of Ship Collision

In 2002 Liu and Wu of Dalian Maritime University studied 100 written collision reports from the maritime authorities in the UK, USA, Australia, Canada, New Zeeland and Sweden. And listed the following main causes: (Lee & Parker, 2007)

1. **Improper use of radar and ARPA** are still a common problem on board ship. The most frequently observed errors were misinterpreting the information showing on the radar screen, improper setting of the range scale of the radar and no radar plotting. The underlying human elements included lack of knowledge, experience, training and fatigue. The organisational factor also had an influence to some extent.
2. **Poor lokout** has been involved in most collisions. Factors included the lack of competent lookouts, improper looking methods, and improper use or no use of all available means. Poor lookout was usually caused by lack of experience, knowledge and training, manning problems, lack of safety culture, high workloads and inattention.
3. Error of judgement was another factor commonly found in the cause of collisions. The most probable underlying human elements were lack of knowledge, training and information processing ability. Fatigue and workload also played important roles in the navigator`s ability to make the correct judgements.
4. **Communication problems** ranked high in the list of unsafe acts. The most frequently made mistakes were lack of communication and misinterpreting received information. The major underlying human elements found were the reluctance of navigators to exchange information.
5. **Failure to take early actions** frequently appeared in collision cases. The causes of this unsafe act were poor lookout and the torpor induced by the sheer monotony of keeping watch.
6. **Apparently improper ship manoeuvring** failure to comply with good seamanship and failure to display signals had a close relationship with knowledge, skill, training and experience.
7. **Visibility** was an important influencing factor in ship collisions. Failure to sound signals, failure to arrange appropriate lookout, failure to reduce speed and failure to communicate with others frequently appeared in this situation.
8. Collisions studied were caused by a **combination of several factors** in general.

As we see, the different causes influence each other, and there is no single reason that caused a collision, but often a combination of several factors. In figure 2.9 we can se an illustration of the connection between different elements that leads to an accident. This generic model is called Model of Accident Causation Using Hierarchical Influence Network (MACHINE), and shows how the direct causes of all accidents are combinations of human errors, hardware failures and external events.

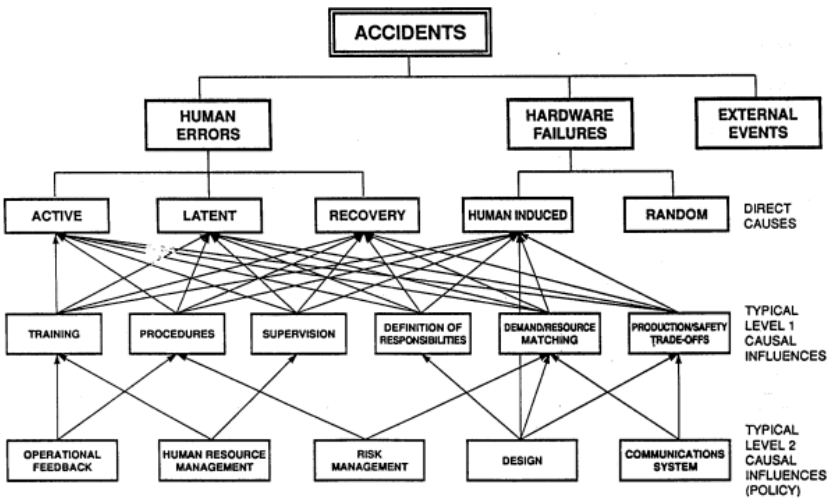


Figure 2.9: The MACHINE model reflects the relationship between human errors, hardware failures and environmental elements (Embrey, 1992)

2.3.3 Concepts of Risk and Risk Analysis

A measure of potential loss is called risk. It is defined as the product of the probability or frequency of the unwanted event and its consequences if it occurs:

$$Risk = Probability \; x \; Consequence \qquad (1)$$

This thesis will only focus on defining the probability part and identify the probabilities of ship collisions in the Barents Sea. If we can find measures which reduces the probability, the risk will also be smaller.

Typically, marine accident probabilities are modelled based on the work of Fujii et al. (1974) and Madcuff (1974). Following their first ideas, the frequency of marine accidents is generally estimated as:

$$P = N \times P_C \qquad (2)$$

Where

N *Number of accident candidates*
P_C *Causation factor*

Accident candidates are the ships that are on an accident course in the vicinity of another vessel. In other words, the number of accidents would be *N* if no evasive maneuvers were made to avoid the accident. Causation factor is the probability of failing to avoid the accident while being on an accident course. It quantifies the fraction of accident candidates that are actually colliding with another vessel (Ylitalo, 2010).

2.3.3.1 Probability of a collision

It is many different aspects in the cause of a collision, like human or organizational factor. The probability is calculated as followed: (Geijerstam & Svensson, 2008)

$$F_{cp} = F \times F_d \times P_1 \times P_2 \times P_3 \qquad (3)$$

F_{cp} – Frequency of powered passing vessel collision
F – Total traffic in the lane
F_d – Proportion of vessels that are in the part of the lane directed towards another ship
P_1 – Probability that the passage planning stage is not carried out correctly
P_2 – Probability that the vessel suffers a watch keeping failure
P_3 – Probability that a platform or stand-by vessel fails to alert the ship in time to prevent a collision

2.3.3.2 Causation factor P_C

The causation factor specifies the probability that the officer of the watch will fail to react, e.g. in case the vessel in on collision course with another vessel. *80 % of the P_C is estimated to come from Human Error* (Kystverket, 2014).

The causation factors are important for the results since they act as reduction factors on the calculated number of blind navigation collisions. In the specification on the causaution factor it should be considered if navigators exhibit extraordinary awereness; possible beacuse of two navigators being present on the bridge. For ferry routes it is typically the case that the causation factor is lower than the average due to the navigators increased situation awareness (IALA, 2012)

Table 2.7 and Table 2.8 presents the different factors which contribute to personal and organizational failures (Kystverket, 2014).

Table 2.7: Causation factor, personal

Personal:		
Physical limitations	Wishful thinking	Laziness
Inadequate communication	Ignorance	Greed
Bad judgement	Negligence	Alcohol
Fatigue	Folly	Mischief
Boredom	Panic	Violations
Inadequate training	Carelessness	Ego

Table 2.8: Causational factor, organization

Organization:		
Ineffective regulatory	Production orientation	Inequitable promotion / recognition
Poor planning / training	Cost-profit incentives	Ineffective monitoring
Poor communication	Time pressures	Ego
Low quality culture	Rejection of information	Negative incentives
Low worker morale	Complex structure	Vioaltions

2.3.3.3 How to Perform a Maritime Risk Assessment

It is described by the International Maritime Organization (IMO) that a generic model of collision risk shall not be viewed in isolation, but rather as a collection of systems, including organisational, management, operational, human, electronic and hardware aspects. The systems and functions should be broken down to an appropriate level and aspects of interaction of functions and systems. The extent of their variability should also be adressed. The human element is regarded as one of the most contributory aspects to the causation of accidents and must be incorporated in an assessment. Expert judgement is an important part of an assessment that provides proactive thoughts and ideas and is necessary where limited data exists (IMO, 2007).

During an identification of possible hazards, it is necessary to combine both creative and analytical techniques with the aim to identify all relevant hazards. Structured group reviews with experts in the various appropriate aspects such as ship design; operations and management should be undertaken followed by a ranking of hazards and scenarios with regards to their contribution to an accident (IMO, 2007).

2.3.4 Collision Avoidance

The environmental, human and economical consequences of a ship collision in the Barents Sea are large. It is therefore important to have good and reliable systems on ship collision avoidance. From a theoretical point of view ship avoidance can be describes as easy as: "*Collisions avoidance involves two or more seagoing vessels that have to cooperate and coordinate their individual operations to avoid ending up in the same place at the same time*." (Nielsen & Petersen (2004).

The central problem facing the mariner in selecting the appropriate collision avoidance action is the absence of mutual cognition – understanding not only the conduct required of the mariner´s own vessel, but of the other vessel as well. In short, what is that other vessel going to do? Regimes aimed at fostering coordinated action by approaching vessel seek to ameliorate the problem. A coordinated system for collision avoidance requires three elements. Each approaching vessel must mutually perceive: (Allen, 2005)

1. The risk of collision
2. The strategy to be applied in avoiding collision

3. The point in distance and/or time at which manoeuvres are to be made.

Since 2002 new ships and later all larger sea-going vessels (>300 Gross Tonn (GT)) and all passenger vessels are required to carry AIS on board. Through dedicated VHF frequencies, AIS information is transmitted between vessels, from vessels to shore, or vice versa. In simple terms AIS is a technology to make ships "visible" to each other. As an aid to collision avoidance, it records the information of ship behaviour, including the effects of human action and ship manoeuvrability. The information includes the vessel's name, its particulars, ship type, registration numbers, and destination as well as the vessel's position, speed, and heading (Mou, Tak & Ligteringen, 2010).

"Even with this technology on ship collision avoidance, ship collisions still occures. It has, in fact, become commonplace to hear that human factors are involved to a considerable degree (some say as much as 80 %) in most collisions. But such obvious conclusions should not distract us from searching out the true root causes of human failures. The errors may be in risk detection, communication, assessment, or management" (Allen, 2005).

After approval by the IMO, a sailing led-system was established in the Norwegian economic zone from Vardø to Røst on July 1st 2007. The system requires all tankers and cargo ships over 5000 gross tons in transit to stay at least 30 nautical miles from land. By moving the risk further away from the coast the likelihood of accidents and spills are reduced. The increased distance gives the authorities more time to intervene if the ships are having problems and requires assistance, and opportunities to prevent accident is improved. Vardø Vessel Traffic Service (VTS) was established in 2007 and monitors all tankers and other risks along the Norwegian coast. Vardø VTS also monitors the vessels compliance with rules of the sail lead system from Vardø to Røst. If a vessel departs form the lead, the VTS call up and guide vessels on the wrong course and requisition assistance when needed (Det Kongelige Miljøverndepartement, 2011).

Measures to improve safety at sea conducted after 2005 (Det kongelige miljøverndepartement, 2011).

- Automatic Identification System (AIS) for ships (information, tracking and collision prevention) have been introduced. This is estimated to reduce the risk of collsion by 20%
- The satellite-based monitoring of sea areas has been developed.
- Vardø VTS was established in 2007 and monitors the risk of traffic along the Norwegian coast, including Svalbard
- Tow preparedness has been improved and three new tugs have been chartered on short-term contracts.
- New harbour act came into force in 2010. The harbour act became effective on Svalbard in 2008 through a separate regulation
- Norwegian Coastal Administration (NCA) has developed a procedure for the government´s overall handling of situations where it is necessary for a vessel to seek a port of refuge.
- To limit the potential for damage by oil spills, a requirement was introduced in 2007 that ships calling at nature reserves in East Svalbard shall not bring or use other fuel than light marine diesel. From 1st January 2010, a similar claim made applicable to the three major national parks on the west coast of Svalbard. It made temporary exemption for the approach to Ny-Ålesund and Magdalenefjorden until 2015

2.3.4.1 VVTS – Vardø Vessel Traffic Service

The main task of the VTS is monitoring risk traffic and enables alert actions if necessary, and to coordinate vessels in *Norwegian tugboat prepardeness*. The traffic control center is a part of of the coastal administrations line of preparedness against acute pollution (Kystverket, 2012).

The responsibility of Vardø VTS was expanded on July 1st 2008 to cover the entire Norwegian Economic Zone, from the Swedish border in the south to the border between Norwegian and Russian economic zone in the north, Svalbard and Jan Mayen included. Within the scope of monitoring, the VTS monitor tankers and other risk traffic in the coverage area (Kystverket, 2012).

Vardø VTS has recently helped to avert a series of incidents that could have resulted in a major accident. Their ability to quickly get an overwiev of potential hazardous and risk situations has undoubtedly helped to increase maritime safety throughout the Norwegian economic zone (Kystverket, 2012).

2.3.4.2 Automatic Identification System

Automatic Identification System (AIS) in an international aid to avert ship collisions and to identify and monitoring the ships (Figure 2.10). AIS is made applicable to vessels over 300 GT in international traffic and 500 GT engaged in domestic voyages, and all tankers and passenger ships irrespective of size. Excempt from the requirement to be equipped with AIS are special categories such as warships, naval auxiliaries and state-owned or state-operated vessels and small craft yacht. Since the AIS system has a limited range from the coast there will be traffic that is not captured by the system, such as fishing vessels, Svalbard traffic (including coal transport and cruise/passenger accounts for the largest magnitude) and parts of the transatlantic move (including to/from Russia). The coverage area is still deemed to be sufficient to capture all matarial aspects of shipping in Barents Sea (Kystverket, 2010).

Figure 2.10: The AIS-Sat I in orbit (SNL, 2014)

3 RESEARCH, METHODS AND MATERIAL

The aim of this chapter is to present and discuss the applied research approach and methodologies used in this research.

3.1 METHOD

Figure 3.1 presents an overview of the used methods from start to the conclusion. It started with a literature review about the analysis area before the basis for the thesis was ready. From the simulation tool IWRAP, the results from the different scenarios achieved.

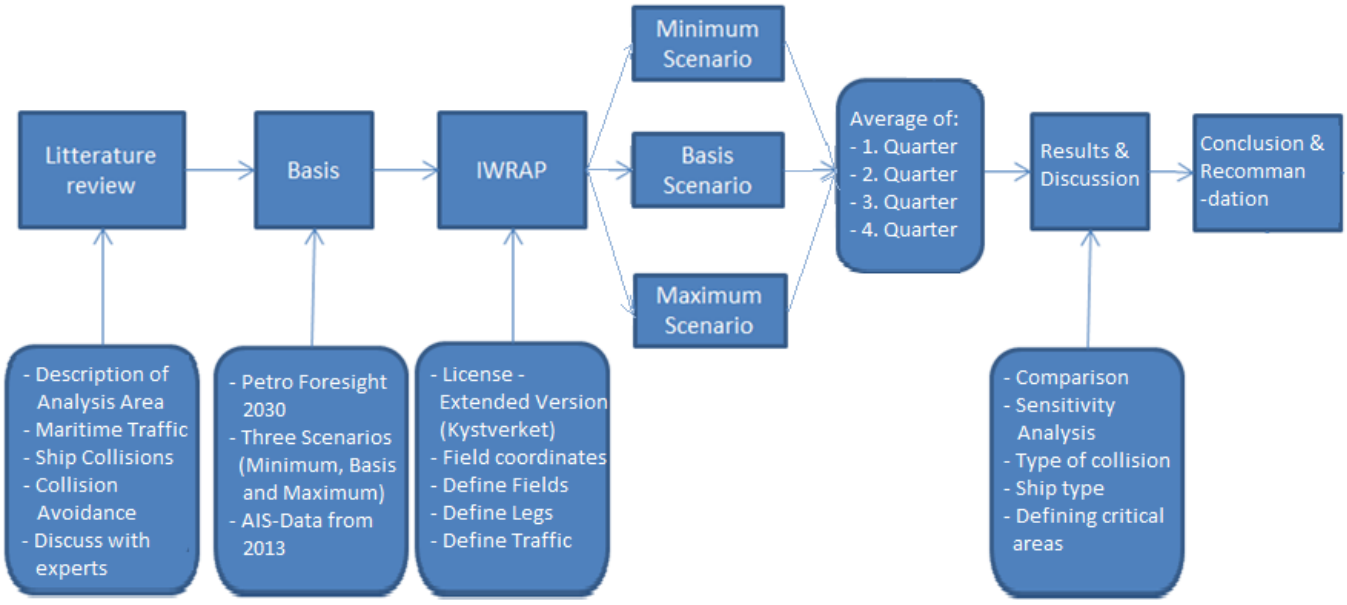


Figure 3.1: Methodology used in the thesis

3.2 DATA COLLECTION

To acquire knowledge regarding the subject in this thesis, an extensive data collection was required. In order to substantiate the theory chapters it has been performed research in various government documents developed by DNV and Kystverket. This is considered as very reliable source for this thesis. These documents were handed to me personally after a meeting with DNV here in Tromsø. Øyvind Persson in DNV was also a contributing part in the definition part of the thesis. The library at UiT – The Arctic University of Norway was invaluable to attain basic knowledge about ship collisions, collision avoidance and the reasons for why ship collisions occur. The amount of literature concering these issues were huge, but there were little specific literature on ship collisions in the Barents Sea. Therefore was it a challenge to separate information that would be relevant for this thesis.

When a basic knowledge of the analysis area and theory behind ship collsions was achieved, contact was established with senior advisor Trond Langemyr in Kystverket. He was very engaged in the topic of this thesis and gave access to even more government documents unavailable on the Internet. He proposed using IWRAP Mk2 to simulate the frequency of ship collisions, and gave access to the extended version for free. To make the simulations realistic, he sent a complete sample of AIS data for 2013. These data are not for distribution.

Contact with professionals within the industry has been leading the work. As mentioned there where early-established contact with specialists in DNV and Kystverket, but also specialists at Aker Solutions, ENI Norge, Petro Arctic and UiT – The Arctic University of Norway. By participating in

a workshop at Hurtigruta by OPLOG (OPerational Logistics and business process management high north Oil & Gas operations), I had the opportunity to discuss and brainstorm about this subject with specialist in the industry further valuable data and insight was achieved. It has been very helpful to discus this subject with specialists through the whole process in order to be able to make the required assumptions. The exact locations of the various fields are defined in an ongoing project of Aker Solutions. The sailing routes for each facility are assumption made in consultation with supervisor Øystein Mikelborg, where the ships sail the shortest route from A to B.

3.3 DATA ANALYSIS

IWRAP has the function to load AIS data for a particular area and create a density plot for this traffic. After the density plot is made, your own sailing routes should be defined with desired traffic. This was done for each field in the scenarios, for supply vessels, IMR vessels, exports vessels and the Russian transit traffic. IWRAP calculate the frequency of accidents in each predefined leg and connects the results with the chosen AIS data.

The simulation program was not able to process the all the AIS data at once, and it was therefore decided to split the AIS data into quarters. In practice, each scenario had four simulations, with its associated result. The relevant results from each quarter were added together to get the average result that the figures in the result chapter are based on.

It is possible to get vast amount information about the traffic, accident types and locations through this program. It was therefore a challenge to find the most relevant information and effective methods of presentate it. It was decided to get statistics for all legs for each offshore field, type of collisions and an overview over which ship types that involved in the collisions.

IWRAP does not include tools for estimating the uncertainties of the results, so this was performed manually. All scenarios have a sensitivity analysis with a difference in traffic with plus minus ten percent. The sensitivity analysis is included to predict the outcome if the basis predictions turns out to be different.

3.3.1 IWRAP Mk2

The objective of IWRAP is to provide the user with a tool that assists to quantifying the risks involved with vessel traffic in specific geograpichal areas. On the basis of a specified traffic intensity and composition the tool allows the user to efficiently evaluate and estimate the annual number of collisions in the specified navigational area (IWRAP, 2014).

IWRAP gives results as the frequency of head-on, overtaking, merging, crossing and bend collisions. The relative risk of each waterway and waypoint is marked on the map. It is also possible to evaluate collision frequencies at certain waterway or waypoint. In addition, overall collision frequencies, frequencies at certain location or of certain collision type are presented by ship type (Ylitalo, 2010). The following section discuss different equations which are used to calculate the risk of the different collision types in IWRAP 8 (IALA Web, 2014)

i) Head-on Collisions

The relative speed of two ships approaching each other is expressed as:

$$V_{ij} = V_i^{(1)} + V_j^{(2)} \qquad (4)$$

Where:

$V_i^{(1)}$ is the speed of the ship of the ship class *i* moving in the direction *1*

$V_j^{(2)}$ is the speed of the ship of the ship class *j* moving in the direction *2*

The number of collision candidates for head-on collisions on a waterway is evaluated as

$$N_G^{head-on} = L_W \sum_{i,j} P_{G_{i,j}}^{head-on} \frac{V_{ij}}{V_i^{(1)} V_j^{(2)}} \left(Q_i^{(1)} Q_j^{(2)} \right) \quad (5)$$

Where:

L_W	is the length of the segment
$Q_{i,j}^{(n)}$, (1,2)	is the number of passages per time unit for each ship type and size, in each direction, (1) and (2),
$f_i^{(1)}(y)$ and $f_j^{(2)}(y)$	is the geometrical probability distribution of the lateral traffic spread on the route. The traffic spread is typically defined by a Normal Distribution but may in principle be of any type.

$P_{G_{i,j}}^{head-on}$ depends on traffic distributions across the waterway, $f_i^{(1)}(y)$ and $f_j^{(2)}(y)$. Typically, traffic spread across a waterway is defined by a normal distribution but any distribution may be used. Distributions have to be assumed to be independent. When traffic is normally distributed with parameters ($\mu_i^{(1)}$, $\sigma_i^{(1)}$) and ($\mu_j^{(2)}$, $\sigma_j^{(2)}$), the mean sailing distance between vessels headon to opposite direction is

$$\mu_{ij} = \mu_i^{(1)} + \mu_j^{(2)} \quad (6)$$

The standard deviation of the joint distribution is

$$\sigma_{ij} = \sqrt{(\sigma^{(1)})^2 + (\sigma^{(2)})^2} \quad (7)$$

In the case of normal distribution, $P_{G\,i,j}$ can be calculated as

$$P_{G_{i,j}}^{head-on} = \Phi\left(\frac{\bar{B}_{ij} - \mu_{ij}}{\sigma_{ij}}\right) - \Phi\left(-\frac{\bar{B}_{ij} + \mu_{ij}}{\sigma_{ij}}\right) \quad (8)$$

Where

Φ is the standard normal distribution function and

$\bar{B}ij$ is the average vessel breadth:

$$\bar{B}_{ij} = \frac{B_i^{(1)} + B_j^{(2)}}{2} \quad (9)$$

Where B_i is the average breadth of vessel of ship class *i*.

ii) Overtaking Collisions

When estimating the number of overtaking collisions, the relative speed in equation (4) is replaced by

$$V_{ij} = V_i^{(1)} - V_j^{(2)} \quad (10)$$

Where $V_{ij} > 0$ otherwise no overtaking will occur. The geometric probability of meeting (5) is replaced by

$$P_{G_{i,j}}^{overtaking} = P\left[y_i^{(1)} - y_j^{(1)} < \frac{B_i^{(1)}+B_j^{(1)}}{2}\right] - P\left[y_i^{(1)} - y_j^{(2)} < -\frac{B_i^{(1)}+B_j^{(1)}}{2}\right] \qquad (11)$$

For normally distributed traffic, μ in equation (6) is now

$$\mu_{ij} = \mu_i{}^{(1)} - \mu_j{}^{(2)} \qquad (12)$$

Thus, the number of overtaking collision candidates is calculated as in the case of head-on collision (equation (6)). (Friis-Hansen, 2008)

iii) Crossing Collisions

The frequency of crossing collisions depends on the angle between two lanes. Figure 2.6 shows two crossing waterways for which the ship traffic also is given. The geometric number of crossing collision for crossing waterway can similarly to equation (5) be expressed as,

$$N_G^{crossing} = \sum_{i,j} \frac{Q_i^{(1)} Q_j^{(2)}}{V_i^{(1)} V_j^{(2)}} D_{ij} V_{ij} \frac{1}{\sin\theta} \qquad for\ 10° < |\theta| < 170°$$

Where

$$V_{ij} = \sqrt{(V_i^{(1)})^2 + (V_j^{(2)})^2 - 2V_i^{(1)}V_j^{(2)}\cos\theta}$$

gives the relative speed between the vessels.

iv) Merging and Bend Collisions

Merging collision is considered as crossing collision. A bend collision may occur if a ship does not turn at a bend of a waterway and as a result is on a collision course with another vessel (Friis-Hansen, 2008).

v) Crossing Collisions with Small Vessels

In IWRAP, it is also possible to include the small vessels that do not carry AIS equipment by inserting "area traffic". However, area traffic is assumed to be uniformly distributed to the analysis area around the year.

3.3.2 Causation Factor, P_c

"*The causation factor P_c is the reduction factor with which the number of accident candidates has to be multiplied to get the estimated frequency of marine accidents. Causation factor quantifies the probability of failing to avoid the accident while being on an accident course." (Ylitalo, 2010)*

The most traditional and most exact way to estime the value of the causation factor is to use historical data from the wanted area. The traditional approach for calculation of P_C is to formulate a fault tree or an event tree analysis, see figure 3.2.

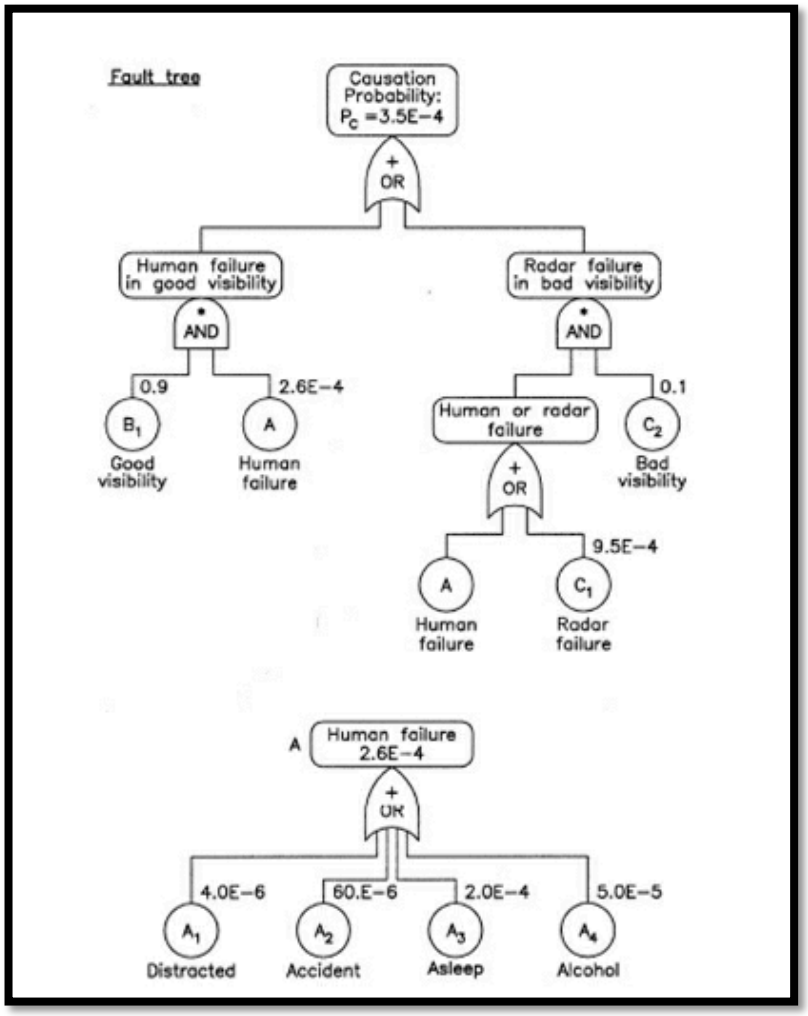


Figure 3.2: Fault three for calculating the causastion probability P_C for collision (IALA Web, 2014)

The default causation factor (Table 3.1) for collisions is adopted from IWRAP, these numbers are the "IALA defintions" which are predefined in the program. No work has been published about adjusting the causation factor for the Barents Sea, so the default value is used to get an estimate of collision frequency. To get exact values for the causation factor, more research in the Barent Sea region must be done.

Table3.1: Causation Factors used in the analysis

Type of collision	Value
Merging	1,300E-04
Crossing	1,300E-04
Bend	1,300E-04
Headon	0,500E-04
Overtaking	1,100E-04

3.3.3 Operating Vessels and Size

For the analysis of vessel traffic in the planning area and close to the coast area are the identified vessels divided into 12 ship types and 7 size categories. Table 3.2 presents the ship types and size categories, which are used in the analysis.

Table 3.2: Operating vessels and size

Ship type	Size category (Gross tonn)
Oil tankers	< 1000 GT 1000 – 5000 GT 5000 – 10 000 GT 10 000 – 25 000 GT 25 000 – 50 000 GT 50 000 – 100 000 GT > 100 000 GT
Chemical-/Prod tanker[4]	
Gas tanker	
Bulk carrier	
General cargo	
Container ships	
RoRo	
Reefer	
Passenger	
Offshore supply vessel	
Other offshore service vessel	
Other activities	
Fishing vessel	All sizes

[4] Only a small proportion of the vessels in the group is registered as pure chemical-/product tankers, the rest are combined. Although the distribution of load types on these ships are not known, from experience different types of refined oil products may be a typical load.

4 RESULTS OF ANALYSIS AND DISCUSSION

This chapter will presents the results of the data analysis of the three scenarios, and study the uncertainties in the results through a sensitivity analysis. The available data were analysed using IWRAP Mk2 software. Due to the capacity of the program/computer the simulations containing AIS data for 2013 is separated into four quarters. The average of the results for each quarter is presented in this chapter. It presents an overview picture of the routes in the scenario, note that the density plot for the historical data is not shown, but included in the calculations. The different color at the legs indicates the likelihood of a collision, where deeper color means higher likelihood of collisions.

4.1 MINIMUM SCENARIO

The minimum scenario consists the Russian transit traffic and two offshore installations; Goliat and Johan Castberg. Figure 4.1 presents an overview of where the fields are located and how the ship traffic in the area is. The presented likelihood of ship collisions includes traffic to/from Polarbase and its associated export tankers.

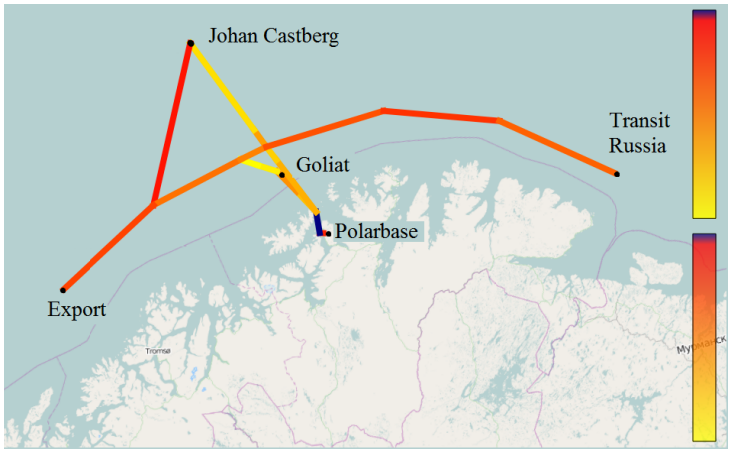


Figure 4.1: Minimum scenario in IWRAP

By studying Figure 4.1 and the color of the legs, we can identify where the likelihood of ship collision is greatest, which in this scenario will be the leg into Polarbase. With regards to Table 2.3, by adding the supply and IMR vessels for Johan Castberg and Goliat, 200 supply vessels and 8 IMR vessels will sail in that waterway a year, in addition to the existing traffic in the area.

The presented results for example Johan Castberg will include the legs for export to the separation zone, while the supply vessels which sails the legs to Polarbase. The leg to Polarbase is taken separately, and will be in addition for all the fields connected to Polarbase.

Figure 4.2 presents which fields and waterways that generate most incidents per year in the minimum scenario. In total, the Russian transit traffic will be the biggest contribution for the likelihood of incidents per year. This waterway will include all the traffic in the separation zone, included the export tankers in this zone. The waterway in to Polarbase has higher level of probability for incident compare to Goliat and Johan Castberg which can be considered as most critical because of the high amount of traffic in the short length of the leg.

Through calculations in IWRAP, the result shows that the waterway into Polarbase will have 1.6E-04 incidents per year. The Russian transit traffic will have likelihood on 3.1E-04 incidents per year, this is roughly twis as likely compared with the likelihood of a collision on the leg into Polarbase.

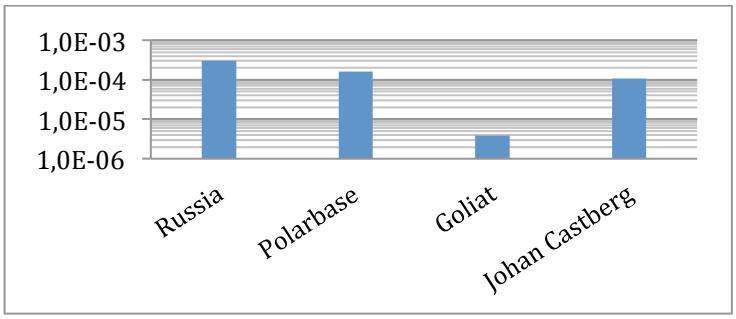


Figure 4.2: Incidents per year for each facility in the minimum scenario.

Table 4.1 presents how often each collision type will occur per year for minimum scenario, the results is given in incidents per year.

The result indicates that the probability for head on collision is the most common collision type. Head on collisions will occure 4.1E-04 per year, while overtaking collisions will have 1.7E-04 incidents per year. The total number incident per year in this scenario is 5.80E-04.

Table 4.1: Collision type in minimum scenario

Minimum Scenario	Total [Incidents/Year]
HeadOn	4.1E-04
Overtaking	1.7E-04
Crossing	0
Merging	2.0E-09
Bend	8.0E-09
Sum	**5.80E-04**

Figure 4.3 presents an overview of how many incidents per year the different ship types will be involved in. The results indicate that the crude oil tankers and support ship will have the largest contribution to the frequency of collisions. The support ships will in this scenario only go back and forth between the offshore installation and Polarbase, while the crude oil tankers will export the oil from the fields and be a big part of the Russian transit. Crude oil tankers will have 3.9E-04 incidents per year, while support ships have 1.5E-04 incidents per year.

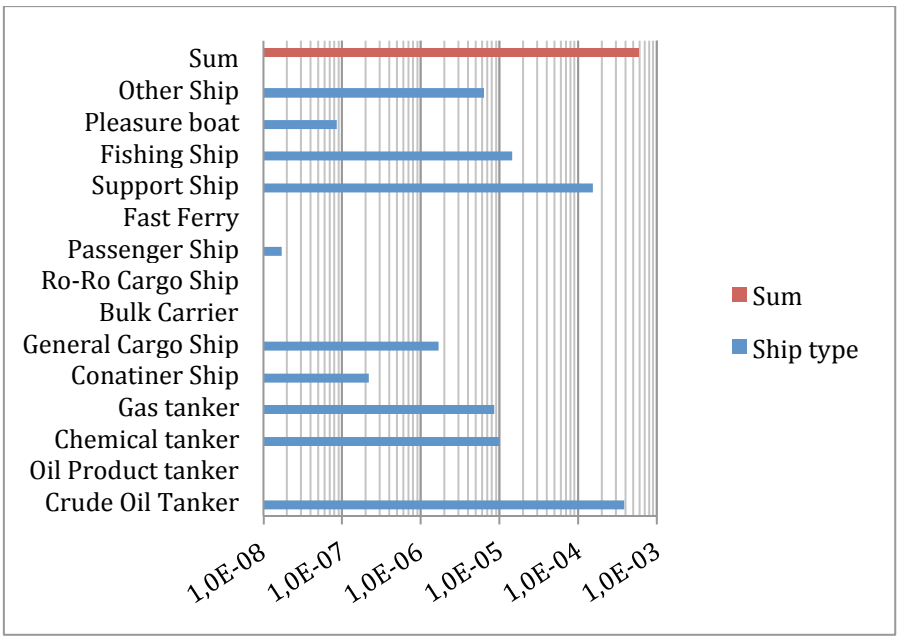


Figure 4.3: Incidents per year, per ship type in minimum scenario

Figure 4.4 presents the frequency of the different types of collisions decribed in *chapter 2.3.1 Types of Accidents*. The results indicates that the probability of head on and overtaking collsion by crude oil tankers will be the most frequent collision type, while head on and overtaking collisions by support ship will be the second largest contributer in this scenario.

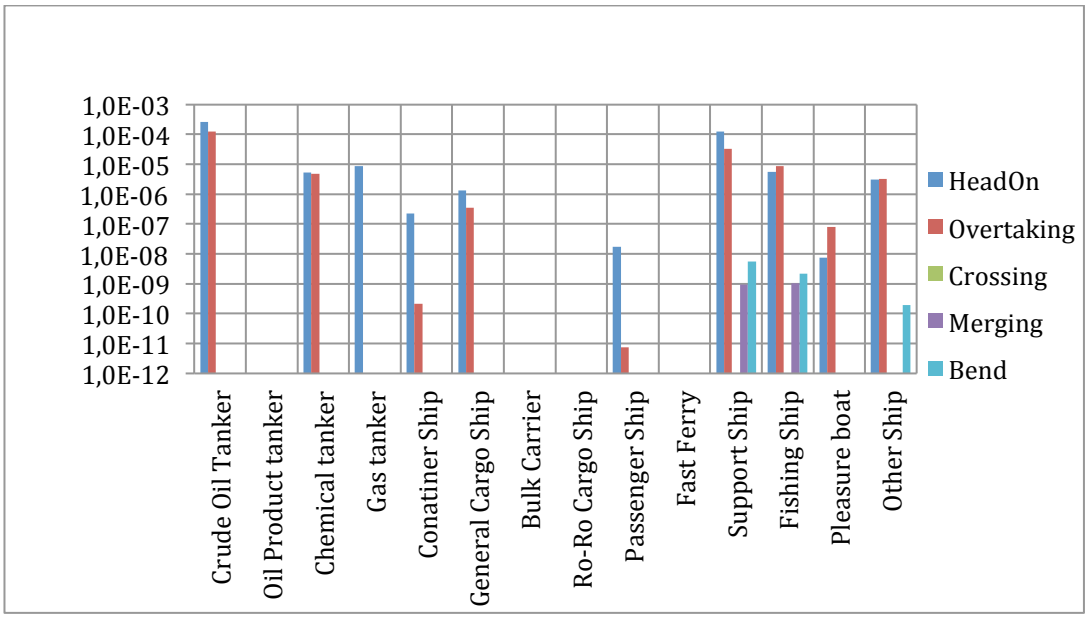


Figure 4.4: An Overview on how the different ship collides in Minimum Scenario

Figure 4.4 shows that the crude oil tankers and the bigger ship doesnt have any contribution from the collision type; crossing, merging and bend collision. This may caused by that these ships are following the separations zone, and they sail back and forth to their destination, which in this case is the offshore facility.

A summary of the minimum scenario:

- The largest likelihood of collision in one leg is the traffic in the separation zone with the Russian traffic.
- The most critical leg is Polarbase because the high amount of traffic in its short length.
- Head on and overtaking collision is the most common collision type
- Crude oil tankers will have the biggest contribution to the frequency of collisions

4.2 BASIS SCENARIO

The basis scenario consists of the Russian transit traffic and six offshore installations; Goliat, Gohta, Johan Castberg, Hoop, Lopparyggen and Barentshavet Sydøst. Figure 4.5 presents an overview of where the fields are located and how the ship traffic in the area is distributed. The presented likelihood of ship collisions includes traffic to/from Polarbase andassociated export tankers. The supply vessels connected to Barentshavet Sydøst, will go back and forth to the intended onshore facility in Vardø, while the export tankers will go the shortest way to the separations zone.

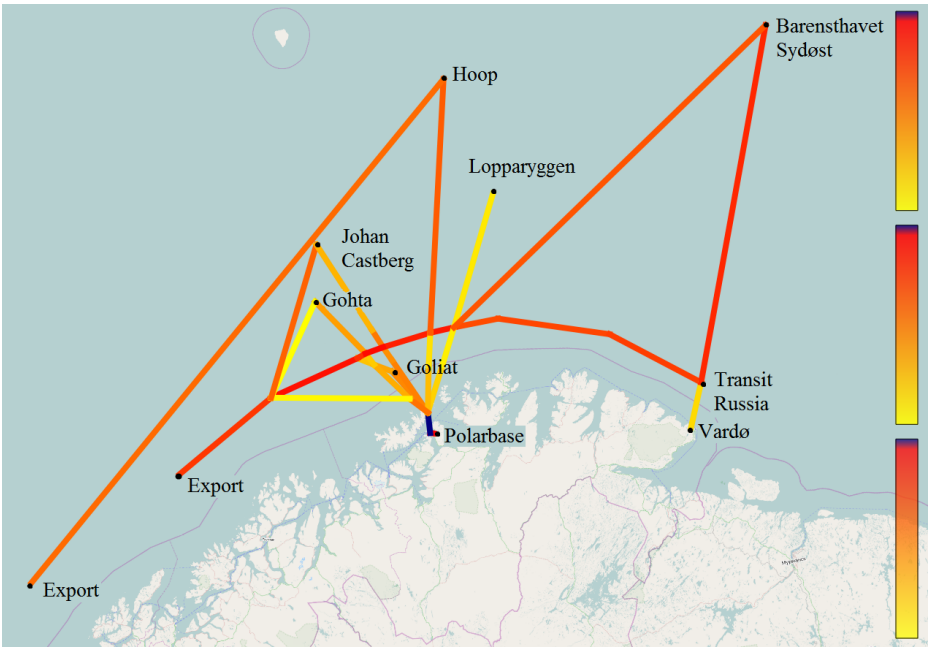


Figure 4.5: Basis scenario in IWRAP

By studying figure 4.5 and the color of the legs, we can identify where the likelihood is greatest of ship collision, which in this scenario will be the leg into Polarbase. With regards to table 2.3, by adding the supply and IMR vessels for which is sailing into Polarbase, it will be 410 supply vessel trips and 20 IMR vessels in that waterway a year, in addition to the existing traffic in the area. Note that the leg for Polarbase is taken separately, and will be in addition for all fields.

Figure 4.6 present which field and waterway that will have the highest likelihood of incidents per year in basis scenario. By looking at the color of the legs, it shows that the number of incidents will be highest into Polarbase. Through calculations in IWRAP, the waterway in to Polarbase will have

1,1E-04 incidents per year. The second largest contributer to the total probability is the russian transit traffic were we have likelihood of 2,4E-04 incidents per year.

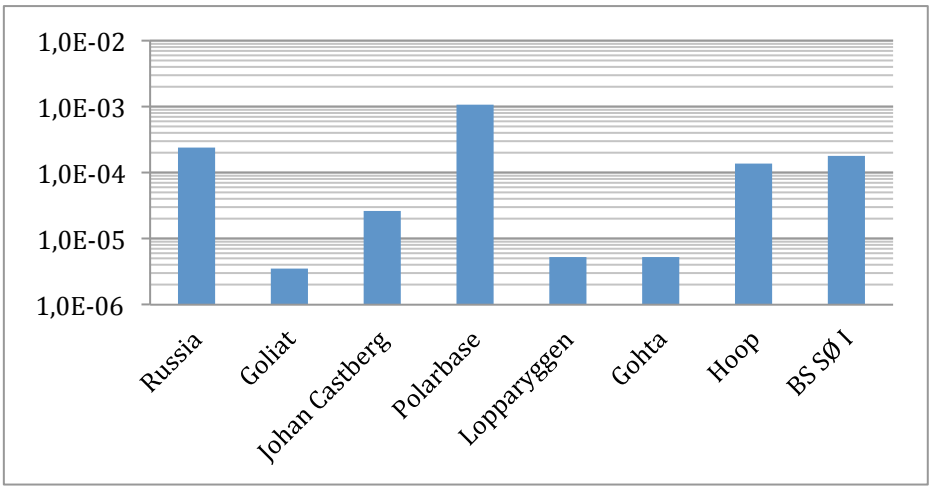


Figure 4.6: Incidents per year for each facility in the basis scenario

Table 4.2 present how often each collision type will occur per year for basis scenario, the results is given in incidents per year.

The result indicates that the probability for head on collision is the most common collision type in this scenario. Head on collision will occure 1,1E-03 times per year, while overtaking collisions will have 5,9E-04 incidents per year. The total incident per year in this scenario is 1,8e-03. Table 4.2 presents the frequency of the different collision types in Basis Scenario.

Table 4.2: Collision type in basis scenario

Basis Scenario [Indicent/year]	**Total**
HeadOn	1,1E-03
Overtaking	5,9E-04
Crossing	2,0E-09
Merging	3,0E-09
Bend	9,0E-09
Sum	**1,8E-03**

Figure 4.7 presents an overview of how many incidents per year the different ship types will have. The results indicatess that crude oil tankers and support ship will have the largest contribution to the frequency of collisions. The support ships will in this scenario only sail back and forth between the offshore installation and to the associated onshore facility, while the crude oil tankers will export the oil from the fields and be a big part of the Russian transit, exept from the export tankers from Lopparyggen which will go from Hammerfest and in to the separation zone. Crude oil tankers will have 1,0E-04 incidents per year, while the support ships will have 1,8E-04 incidents per year.

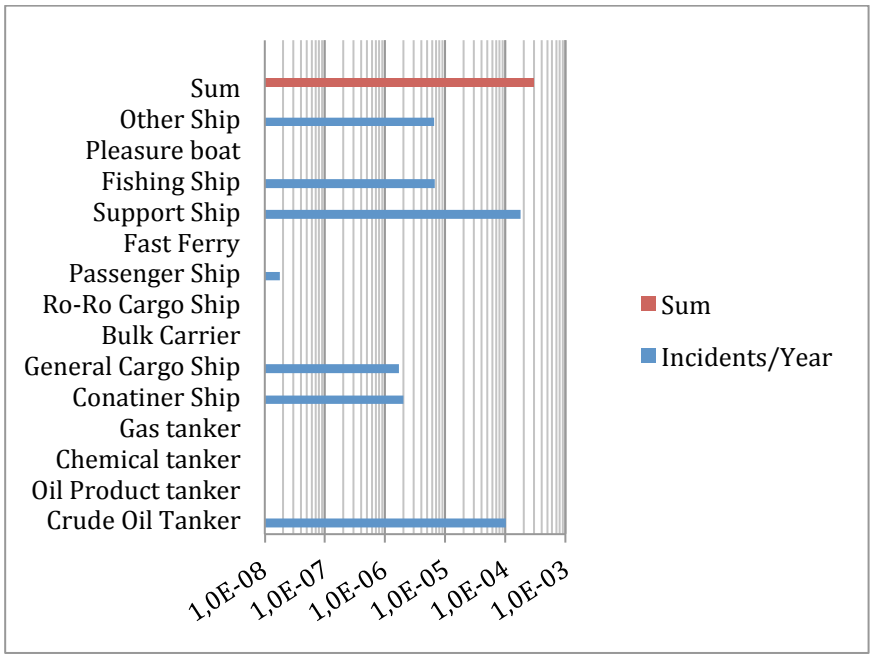


Figure 4.7: Incidents per year, per ship type in basis scenario

Figure 4.8 presents the frequency of how the different ships will collide. The results indicates that the probability of head on and overtaking collision by support ship will be the most frequent collision type, while head on and overtaking collisions by crude oil tankers will be the second largest contributer in this scenario.

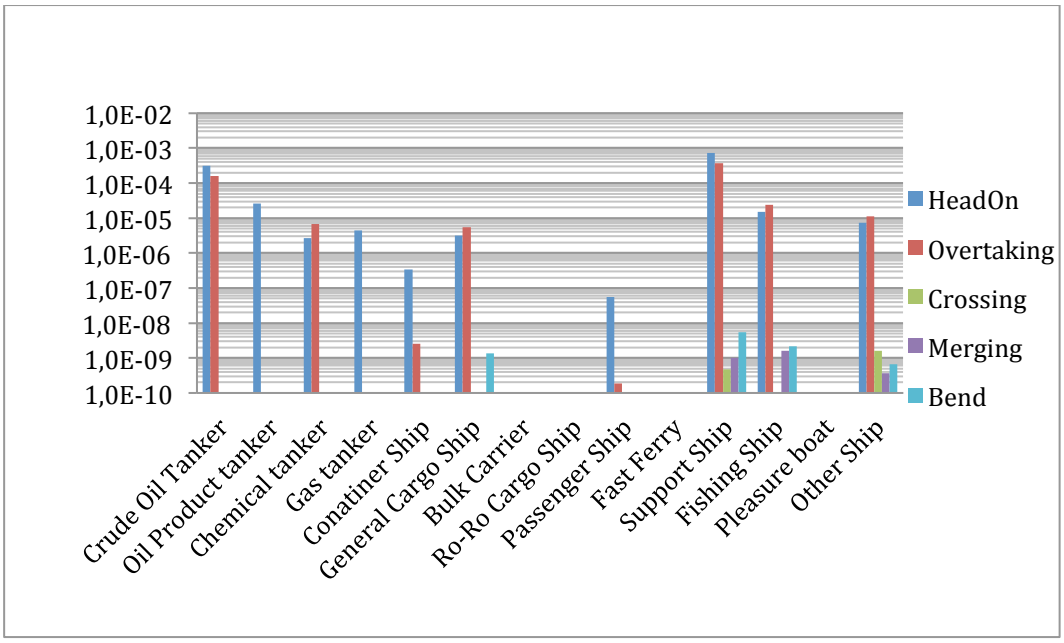


Figure 4.8: An Overview on how the different ship collides in basis Scenario

A summary of the basis scenario:

- The largest likelihood of collision in a leg will be in the waterway into Polarbase
- Head on collision is the most common collision type
- Support ships will have the biggest contribution to the frequency of collisions
- The most common way for the support ships to collide, is by head on and overtaking.

4.3 MAXIMUM SCENARIO

The maximum scenario consists of the Russian transit traffic and eight offshore installations; Goliat, Gohta, Johan Castberg, Hoop, Lopparyggen, Fingerdjupet, Barentshavet Sydøst and Barentshavet sydøst II. Figure 4.9 presents an overview of where the fields are located and how the ship traffic in the area is. The presented likelihood of ship collisions includes traffic to/from Polarbase and its associated export tankers. Barentshavet sydøst and Barentshavet Sydøst II supply vessels will be located in Vardø. The export from Johan Castberg and Gohta will in this scenario be from Veidnes, the associated supply vessels will still go to Polarbase. Export from Barentshavet sydøst II and from Lopparyggen will be transported in pipelines.

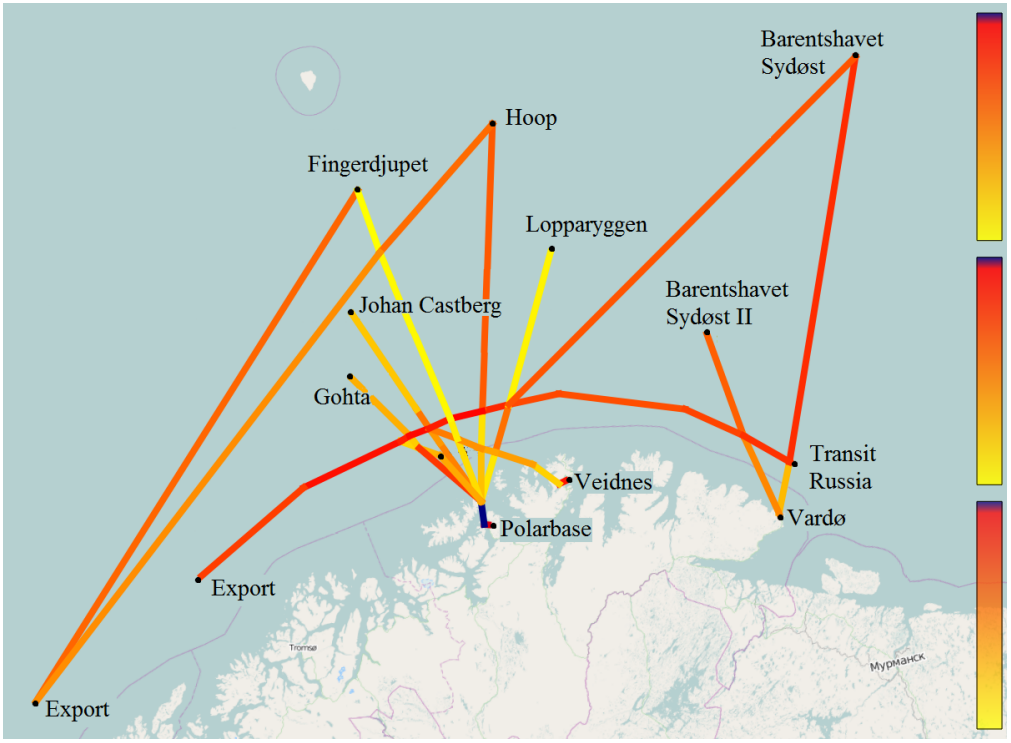


Figure 4.9: Maximum Scenario IWRAP

By studying figure 4.9 and the color of the legs, we can identify where the likelihood is greatest of ship collision, which in this scenario will be the leg into Polarbase. With regards to Table 2.3, by adding the supply and IMR vessels for which is sailing into Polarbase, it will be 480 supply vessel trips and 24 IMR vessels in that waterway a year, in addition to the existing traffic in the area. Note that the leg for Polarbase is taken separately, and will be in addition for all fields.

Figure 4.10 presents which field and waterway have the most incidents per year in Maximum scenario. The results of the analysis show that the number of incidents will be highest into Polarbase. The graph of total incidents per year is presented in red. Through calculations in IWRAP, the result shows that the waterway in to Polarbase will have 1,0E-03 incidents per year. The second biggest contributer to the probability is the Russian transit traffic were we have likelihood on 2,9E-04 incidents per year. The highest probability for collision is through the waterway into Polarbase.

Figure 4.10 shows which field and waterway that generates most incidents per year in maximum scenario. The graph of total incidents per year is presented in red.

The leg for Polarbase is taken separately, and will be in addition to all fields heading for Polarbase. The result of analysis shows that the number of incident will be highest into Polarbase. The waterway in to Polarbase will have 1,0E-03 incidents per year.

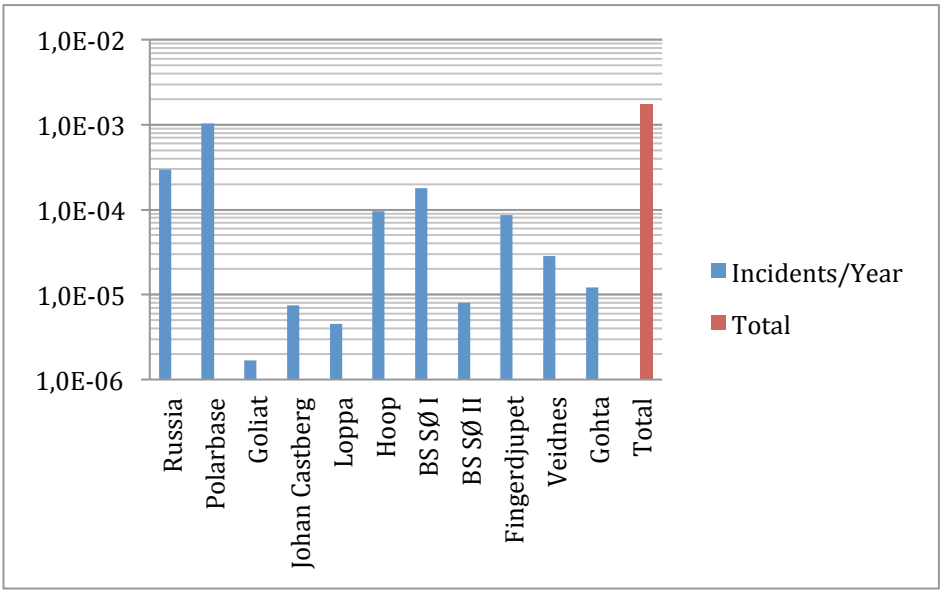


Figure 4.10: Incidents per year for each facility in the maximum Scenario.

Table 4.3 present how often each collision type will occur per year for maximum scenario, the results is given in incidents per year.

The result indicates that the probability for head on collision is the most common collision type in this scenario. Head on collision will occure 1,3E-03 times per year, while overtaking collisions will have the value of 4,5E-04 incidents per year. The total incident per year in this scenario is 1,75E-03. By comparing figure 4.10 and table 4.3 one can observere that the greatest likelihood for head on collisions will occure in in the leg to/from Polarbase.

Table 4.3: Collision type in maximum scenario

Maximum Scnerio	Total [Incidents/Year]
HeadOn	1,3E-03
Overtaking	4,5E-04
Crossing	5,0E-09
Merging	6,0E-10
Bend	9,0E-09
Sum	**1,75E-03**

Figure 4.11 presents an overview of how many incidents per year the different ship types will have. The results indicate that crude oil tankers and support ship will have the biggest contribution to the frequency of collisions. The support ships will in this scenario only sail back and forth between the offshore installation and to the associated onshore facility. Crude oil tankers will have 5,5E-04 incidents per year, while the support ships will have 1,1E-04 incidents per year.

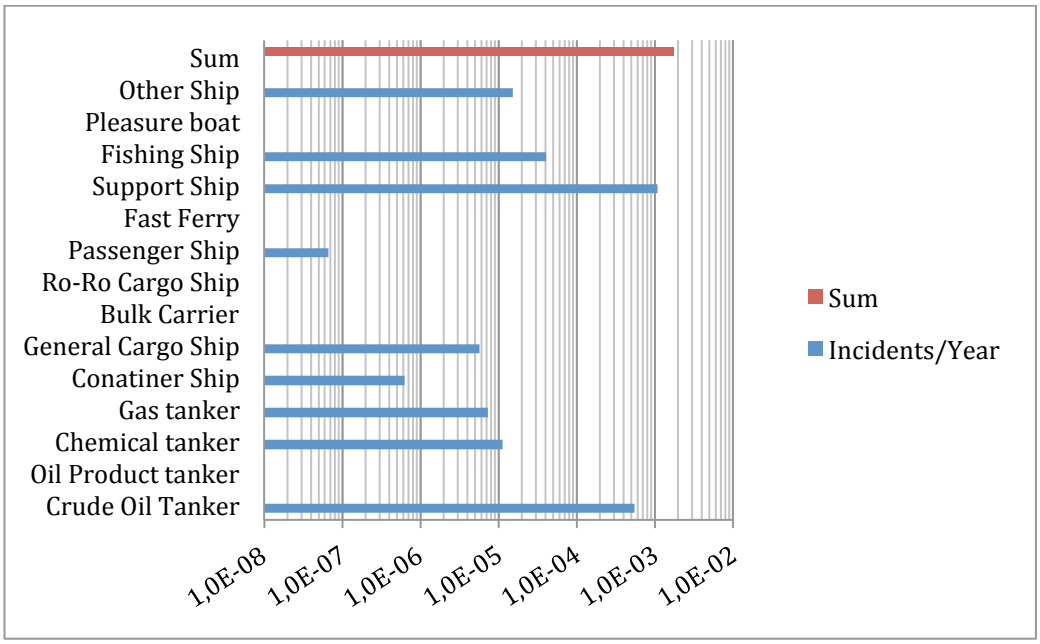


Figure 4.11: Incidents per year, per ship type in maximum scenario

Figure 4.12 presents the frequency of how the different ships will collide. The results indicates that the probability of head on and overtaking collision by support ship will be the most frequent type of collision, while head on and overtaking collisions by crude oil tankers will be the second largest contributer in this scenario.

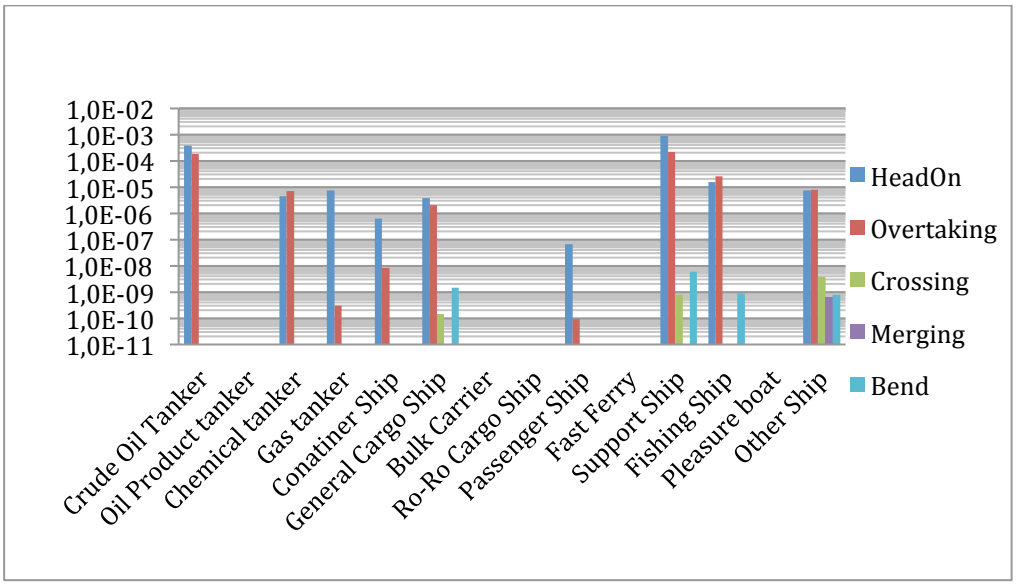


Figure 4.12: An Overview on how the different ships collide in Maximum Scenario.

A summary of the maximum scenario:

- The largest likelihood of collision in a leg will be in the waterway into Polarbase
- Head on collision is the most common collision type
- Support ships will have the biggest contribution to the frequency of collisions
- The most common way for the support ships to collide, is by head on and overtaking.

4.4 COMPARISON OF RESULTS

By comparing the results for each scenario we observes a big gap between minimum scenario with 5,8E-04 incidents per year, compared with basis scenario which had 1,8E-03 incidents per year (Table 4.4). This has a natural explanation since minimum scenario only added two offshore facilties (Goliat and Johan Castberg) with its associated traffic, while the basis scenario added six facilities.

Figure 4.13 presents the incidents per year for each scenario. The difference between basis scenario and maximum scenario (1,75E-03 incidents per year) is a more interesting case. One might have assumed that it would be significantly a higher frequency of collision in the maximum scenario than in the basis scenario, since the maximum scenario has added eight offshore facilities compared with basis´ six. This may be explained in the installed pipeline from east of the Barents Sea which goes to southern Norway. By inserting this pipeline, the export tankers connected to Barentshavet Sydøst II and Lopparyggen will be exclucded. This means that it would be 36 less crude oil tankers to Lopparyggen in the basis scenario. The pipeline from Johan Castberg and Gohta in maximum scenario redirects their associated export tankers into Veidnes, this is 136 export tankers which will go for loading at Veidnes.

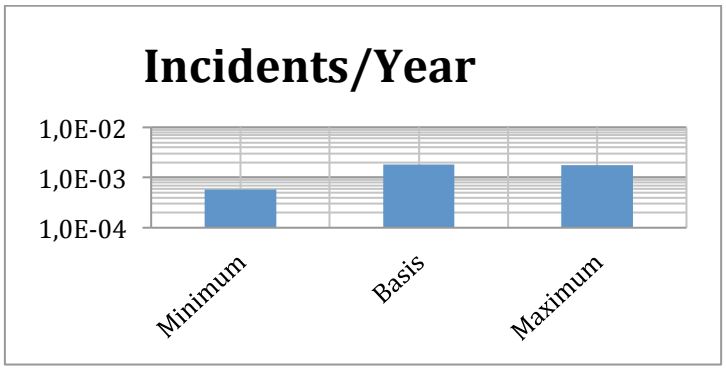


Figure 4.13: Comparison of Incidents per year for all scenarios, graphical

Table 4.4: Comparison of incidents per year for all scenarios, values

[Incidents/Year]	Minimum Scenario	Basis Scenario	Maximum Scenario
Total	**5,8E-04**	**1,8E-03**	**1,75E-03**

Figure 4.14 presents the difference in incidents per year for each offshore facility between the three scenarios. We observe that the highest likelihood of collisions is located in the leg to/from Polarbase. There could have been made some further measures with respect of this traffic. This could be:

1) Separate in and outgoing traffic from VTS in this area.
2) Establish an additional base in another location

The first measure will separate the traffic and release the pressure at the narrow waterway into Polarbase, which would reduce the likelihood of collision on this leg. Introducing traffic lanes the distances from A to B will be increased, and it still needs to cross other traffic lanes. A measure from VTS by introducing a “separation zone” here would be an option.

The second measure would have a positive ripple effect both to the infrastructure and increased population to the districts with more workplaces. This would be an important political issue, as chosing the coastal city to locate the new base in would cause a high level of interest from the local communities. This measure will further more create challenges for the existing infrastructure at the coast of Finnmark, since there are no existing infrastructure today that would be able to receive the

amount of supply vessels that is required for the extent described in this scenario. The infrastructure will not only require a major upgrade at the chosen location, but the road network in Finnmark will require a major update to implement this measure. The existing roads in Finnmark are bound together by a larger number of bridges, tunnels and ferry crossings. All these elements must be considered and taken into account in the planning stage. The many high number of fjords can make things complicated to get equipments and personnel to where it is needed. The relocation of the main base for some of the installations would however undoubtedly be a positive measure with respect to ship collisions.

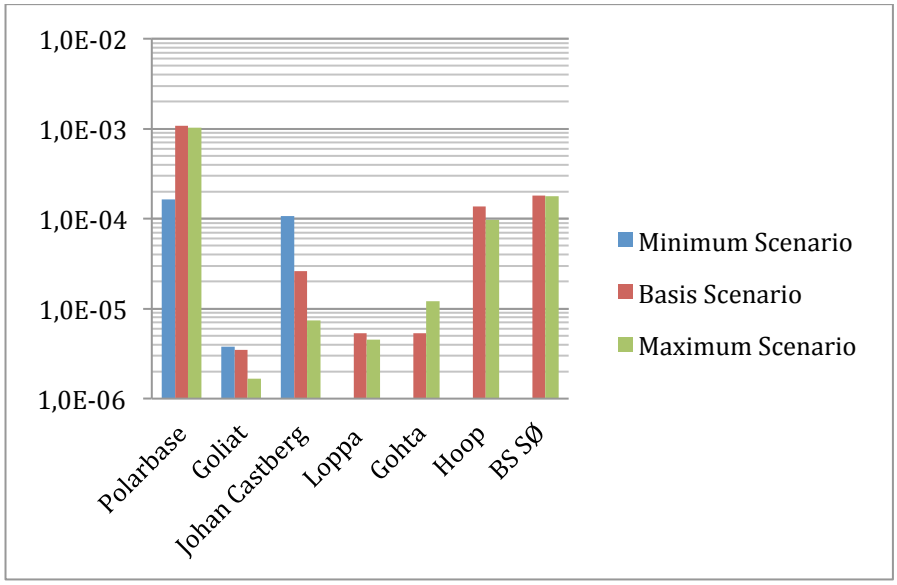


Figure 4.14: Comparisson of all scenarios of likelihood for ship collision for the different offshore fields

Figure 4.15 presents which kind of ships that is colliding in each scenario. The results are based on the average value for the quarters in the scenario.

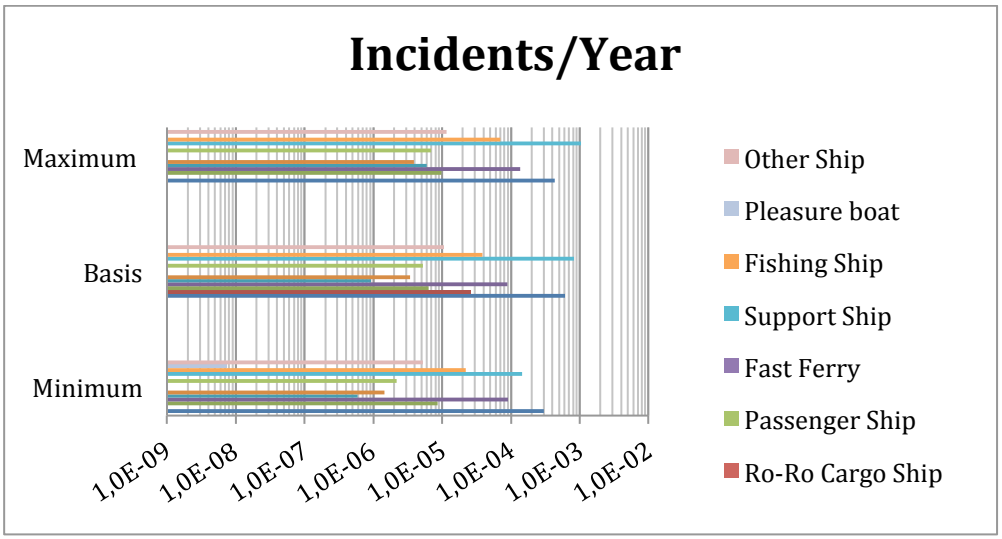


Figure 4.15: Comparison of the different scenarios of the likelihood of ship collision for each ship type.

Figure 4.16 presents an comparison of the different collision types in each scenario. Head on and overtaking collisions will have the largest contribution for all scenarios. By analyzing the figure we observes that the highest amount of head on collisions is in the maximum scenario, while the overtaking collisions has the highest amount in the basis scenario.

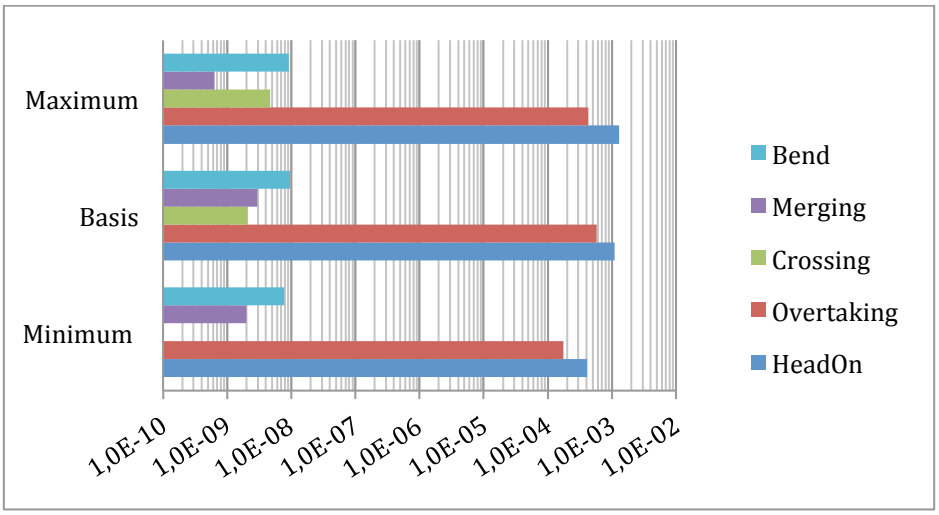


Figure 4.16: Comparison of collision type for each scenario.

4.5 SENSITIVITY ANALYSIS

The aim of sensitivity analysis is to study the relative influence of the inputs and their uncertainty to the results. The analysis for each scenario is conducted with an increment and decrement of the ship traffic with 10%, the results are presented in table 4.5, 4.6 and 4.7.

The sensitivity analysis is only conducted for the 1st quarter in each scenario. This is because of the large amount of data needed to complete one simulation. It is the change in percentage which is interesting to identify. The 1st Quarter is chosen since the probability was greatest in this quarter for all the scenarios, and will therefore be "worst case scenario".

Table 4.5: Sensitivitiy Analysis of Minimum Scenario

1. Quarter	**Minimum Scenario**	**Minimum Scenario -10%**	**Minimum Scenario +10%**
	Incident/Year	***Incident/Year***	***Incident/Year***
Overtaking	2,5E-04	2,32E-04 [-7,6%]	3,1E-04 [23,4%]
HeadOn	6,65e-04	5,42E-04 [-18,6%]	8,21E-04 [23,5%]
Crossing	0	9,77e-09	9,77E-09
Merging	0	2,79e-09	2,79E-09
Bend	5,50E-09	1,52E-08 [175,7%]	1,52E-08 [175,7%]
Total Collision	**9,16E-04**	**7,74E-04 [-15,6%]**	**1,13E03 [23,46%]**

Table 4.6: Sensitivitiy Analysis of Basis Scenario

1. Quarter	**Basis Scenario**	**Basis Scenario -10%**	**Basis Scenario +10%**
	Incident/Year	***Incident/Year***	***Incident/Year***
Overtaking	1,30E-03	6,23E-04 [-51,9%]	7,64E-04 [-41%]
HeadOn	2,42E-03	2,82E-03 [16,8%]	3,70E-03 [53,3%]
Crossing	0	0	0
Merging	2,12E-09	0	0
Bend	5,50E-09	1,52E-08 [175,7%]	1,52E-08 [175,7%]
Total Collision	**3,71E-03**	**3,44E-03 [-7,16%]**	**4,47E-03 [20,4%]**

Table 4.7: Sensitivitiy Analysis of Maximum Scenario

1. Quarter	**Maximum Scenario**	**Maximum Scenario -10%**	**Maximum Scenario +10%**
	Incident/Year	***Incident/Year***	***Incident/Year***
Overtaking	8,29E-04	7,3E-0,4 [-12%]	9,24E-04 [11,5%]
HeadOn	2,81E-03	2,31E-03 [-17,9%]	3,36E-03 [19,5%]
Crossing	0	0	0
Merging	0	0	0
Bend	1,19E-08	1,19E-08 [0%]	1,19E-08 [0%]
Total Collision	**3,64E-03**	**3,04E-03 [-16,6%]**	**4,29E-03 [17,7%]**

By studying the results in the minimum scenario, we observe that the probability of ship collisions will decrease with -15,6% with a reduction of ten percent on the totalt traffic. By increasing the total traffic, it will then be an increasment of the probability by 24,5%. The minimum scenario will be the scenario with the greatest difference in the probability of ship collision in percent. The reason for this may be that the amount of the traffic in this scenario is initially small, and a change in the number of ships will have a greater effect.

The collision type, bend collision will increase 175,7% in both minimum and basis scenario for both of the sensitivity analysis. This increment of likelihood of collision will find place in the waypoint where the support vessels from each field will enter the legs to Polarbase. The biggest contributor her will be collisions between support ship against support ships which will have a likelihood of collsions 1,3E-08.

By analyzing the sensitivity results we can conclude that the effect of increasing the total ship traffic with 10%, the likelihood of collisions will increase more than it will decrease by decreasing the traffic with 10%. Figure 4.17 presents the results of the sensitivity analysis graphically.

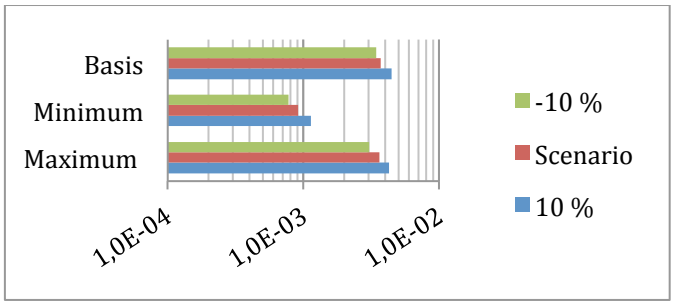


Figure 4.17: Comparison of the sensitivity analysis for each scenario

4.6 FURTHER DISCUSSION

In 2002 Liu and WU of Dalian Maritime University studied 100 written collision reports from the maritime authorities in the UKS, USA, Australia, Canada, New Zealand and Sweden, and listed the following main causes: Poor lookout, Improper use of radar and ARPA, Error of judgement, Communication problems, Failure to take early action, apparently improper ship manoeuvring, visibility and the last was a combination of several factors. All these factors must be considered when sailing in the Barents Sea. Some factors will have a larger role than others in terms of the cold climate.

Icing on a vessel will take place by either atmospheric icing or spray icing and may cause that some components of the boat will lose its functionality partly or completely. As a consequence, it will have a direct role in several of the points mentioned as causes for incidents. Icing may lead to poor lookout, radar trouble and therefore improper ship manoeuvring. The icing will be most extreme when the weather phenomena “Polar Lows” occures. The sudden change in weather, with a drop in temperature and pressure will lead to icing on vessels. This weather phenomenon is difficult to predict, so the vessel must be designed for to handle icing and the crew must always be aware of icing while operating in the Barents Sea.

There are still som uncertainties associated with the future of shipping in the Barents Sea, but the traffic will most likely increase significantly in the coming years, given the increased interest in oil and gas development in the Barents Sea. As seen in table 2.5, chemical, product and oil tankers constitute about 61% of total travelled distance. It is expected an increase of all ship types until 2030, but especially gas and oil tankers, fishing vessels are however expected a reduction (Det kongelige Miljøverndepartement, 2011). The reduction of fishing boats is due to the implementintation of improved technology, better resource management and continued

restructuring of the fishing vessel. The reduces of fishing vessel does not necessarily mean less tons caught fish, but the fishing boats sails less to catch allocated quotas (DNV & Kystverket, 2012).

There are also still some uncertainties with regards to the possible opening of traffic in the north easth passage, but if the passage opens in the coming years, the transit between Europe and Asia will most likely pass through this passage. This will lead to a big increment of the ship traffic in the Barents Sea, and there will be a proportional increasement in the Russian transit aswell, it should then be considered a separation zone even further north than today.

There are some actions with respect to ship collision avoidance made, since 2002. All new ships and later all large seagoing vessels and all passenger vessels are required to carry an AIS on board. After approval by the International Maritime Organization (IMO) there was 1st of July 2008 established a sailing led-system in the Norwegian economic zone from Vardø to Røst.

If a ship collision finds place in the Barents Sea in the coming year due to the increased ship activity in this area, it will have a large impact on the vulnerable environment. There are done several studies of the effects of oil spill in the Barents Sea, and how it will affect the environment; this is because the Barents Sea has many vulnerable components, as sea and birdlife. Especially with respect to the long response time for fields that are far from land. This can be critical in relation to the large spread of the oil before the collection gets started. A thorough and professional assessment must be made in relation to the upgrading of the emergency preparedness in the analyse area to reduce the response time to a minimum.

By looking at figure 3.2, we observers how the causation probability is calculated, and how the special wind and weather conditions will affect the values of the causation factor used in this thesis. With greater values at for example the visibility in the faul tree, would have led to greater likelihood of the probability of ship collision regard to equation 2. This applies for all of the environmental contributors in the Barents Sea. By having historical data on all of the environmental contributors, an exact causation factor for the Barents Sea could have been calculated for use in IWRAP.

5 CONCLUSION AND RECOMMENDATIONS

To ensure a high level of safety, and continously work towards a lower probability of incidents requirements must be made that shipping crews which operates in the Barents Sea shall have knowledge and training in operating in arctic and subarctic environment, as well as programs to report near-incidents and incidents for future reference and added learning.

Main conclusions about the environmental coniditions in the Barents Sea

- The Barents Sea is a clean and rich sea
- The area has mainly a low contamination level, and improvement will be difficult and costly.
- The environmental conditions in the Barents Sea will have a great impact on calculating the causastion factor values.

If we look at the equation at that presents the likelihood for a ship collision to occur, we can immediately conclude that the likelihood will increase in the coming year with respect to the increasing numbers of vessels in the area. Total traffic in the lane, N, will increase and as a consequence of that, the likelihood will increase. The remaining components in the equation are more general, and are not specified especially for our area.

$$F_{cp} = N \times F_d \times P_1 \times P_2 \times P_3 \quad (3)$$

Conclusion of the results:

- The leg that will be the most critical is the leg to/from Polarbase, this applies for all scenarios.
- For future measures with respect to the traffic routes, the fjord into Polarbase/Hammerfest should be considered.
- The scenario that have the highest likelihood for collisions is the basis scenario
- Crude oil tankers and supply vessels will be the ship type with the highest likelihood of ship collisions in all scenarios
- The most common collision type is head on and overtaking collision in all scenarios.
- By using pipelines to export gas from the Barents Sea, the amount of ship traffic, N, regarding to equation (3) will be reduced, and therefor reduce the probability of ship collisions.
- By analyzing the sensitivity results we can conclude that the effect of increasing the total ship traffic with 10% will have a greater effect then decreasing it.

Based on the research conlusion and issues, I purpose the following points for future research:

- Do the same calculations, with including the consequences of a ship collision in different locations in the Barents Sea.
- Reviewing data from other areas which have experienced an increase in ship traffic with to ensure a proper handling of the added numbers of ships passing through Polarbase especially
- Try to add a TSS into polarbasen; by changing the distribution of the traffic direction.

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