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Norwegian University of
Science and Technology

Assessment of Helicopter Emergency Response Capacity in the Barents Sea

Marion F Jakobsen

Marine Technology
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Supervisor: Soren Ehlers, IMT

Norwegian University of Science and Technology
Department of Marine Technology

NTNU
Norges teknisk-naturvitenskapelige universitet
Institutt for marin teknikk

Master thesis task description

For

Marion F. Jakobsen

Assessment of Helicopter Emergency Response Capacity in the Barents Sea

The lack of infrastructure both onshore and offshore in the Barents Sea will impose challenges for search and rescue operations. Oil and gas activities are moving further north on the Norwegian Continental Shelf and new challenges are met. Arctic-specific environmental conditions, and long distances from onshore bases are some of the challenges faced.

The aim of this thesis is to develop a simulation model framework for mapping the rescue capacity of the Barents Sea. With the intention to assess the probability of a successful rescue within given time requirements. The purpose of the model is to assess to what extent the wind conditions affect the search and rescue helicopter operations in the Barents Sea.

Literature studies of specific topics relevant to the thesis work may be included. The work scope may prove to be larger than initially anticipated. Subject to approval from the supervisors, topics may be deleted from the list above or reduced in extent.

In the thesis the candidate shall present his personal contribution to the resolution of problems within the scope of the thesis work. Theories and conclusions should be based on mathematical derivations and/or logic reasoning identifying the various steps in the deduction. The candidate should utilise the existing possibilities for obtaining relevant literature.

Thesis format

The thesis should be organised in a rational manner to give a clear exposition of results, assessments, and conclusions. The text should be brief and to the point, with a clear language and the objective to be published in a conference article and/or scientific journal. Telegraphic language should be avoided.

The thesis shall contain the following elements: An executive summary, list of symbols and acronyms, followed by the main body of the thesis consisting of a brief background introduction, a state of the art defining the knowledge gaps defining the scope or work and limitations, the actual contribution chapters, conclusions with recommendations for further work, references and (optional) appendices. All figures, tables and equations shall be numerated.

The supervisors may require that the candidate, in an early stage of the work, presents a written plan for the completion of the work. The plan may include a budget for the use of computer and laboratory resources if applicable, which will be charged to the department. Overruns shall be reported to the supervisors.

The original contribution of the candidate and material taken from other sources shall be clearly defined following basic academic principles and an acknowledged referencing system, which includes the name of the referred authors followed by the publication year in the text. The subsequent reference list can thus be alphabetical.

The report shall be submitted in two copies:

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- The text defining the scope included
- In bound volume(s)
- Drawings and/or computer prints, which cannot be bound should be organised in a separate folder.
- The report shall also be submitted in PDF along with essential input files for computer analysis, spread sheets, MATLAB files etc. in digital format.

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Thesis supervisor

Professor Sören Ehlers

Deadline: 10 June 2015

Preface

This thesis has been written during the spring of 2015 and is the finalization of the Master of Science degree in Marine Systems Design at the Norwegian University of Science and Technology, NTNU. The thesis is weighted as 30 credits.

The purpose of this master thesis is to assess helicopter emergency response capacity in the Barents Sea and identify the effect of wind conditions on helicopter rescue operations. A model that simulates the rescue operations has been developed in the Matlab toolbox SimEvents.

I would like to express my gratitude to my thesis supervisor Professor Sören Ehlers for being available at all times to answer questions and providing valuable input to the thesis. I would also like to thank Ph.D. candidate Aleksandar-Saša Milaković for his assistance, good advice, and constructive feedback throughout the thesis work. In addition, I would like to thank fellow master student Knut Støwer for helping with SimEvents related questions.

Trondheim, 10th June, 2015

Marion

Marion Fjällstrøm Jakobsen

Stud. Techn.

Abstract

As the global demand for energy is increasing, oil and gas exploration is moving further north to more remote areas. Offshore activity in these areas is challenging. Arctic-specific environmental conditions, and long distances from existing infrastructure are some of the challenges faced. Therefore, new and more robust solutions on technological and operational side are required before commencing operations in the area.

The challenges that search and rescue operations encounter in the High North includes huge distances and areas to cover, time critical operations, and harsh environmental conditions. The vast distances and lack of infrastructure are challenging for evacuation and rescue operations. In this thesis, the helicopter emergency response capacity of operations in the Barents Sea is studied.

The purpose of this thesis is to develop a simulation model framework for mapping the rescue capacity in the Barents Sea. The intention is to assess the probability of a successful rescue at different locations and with given time requirements. The aim of the simulation model is to assess how the wind speed and direction affect the search and rescue helicopter operations in the Barents Sea.

Firstly, a single potential oil field is studied. Secondly, a larger area of the Barents Sea is considered. For the larger area the model establishes the probability of successfully rescuing 1, 5, 15, and 21 people from the sea within the performance requirement of 120 minutes at different locations. This information can be used to evaluate the required level of emergency preparedness at the field of interest.

The evaluated single field is located approximately 200 nautical miles from Hammerfest. A report on this subject was written by the author of this thesis in the fall of 2014. Previous calculations based on deterministically assumed conditions have proved that it was possible to rescue six persons from the sea, at this location (Jakobsen, 2014). The results from the simulation identify that, depending on the wind conditions it is possible to rescue between zero and eleven persons within 120 minutes. However, no consistency in the wind directions is found.

The results from the larger area of the Barents Sea identify little variation in the results in the months evaluated. The effect of the weather is considered to be similar in both summer and winter months. The results show that the distance is the main contribution to the results and that the weather along the route induces some variance in the number of rescued persons. Compared to the result from the single field, there is less variation in the number of people rescued. The variation could be because wind conditions are kept constant along the route for the single field, compared to the larger area where the wind conditions varies along the route.

Based on these results it is suggested that before helicopter transportation, thorough weather observations should be made. The number of passengers should be based on the number found possible to rescue at the given location in the given wind conditions.

Sammendrag

Den globale etterspørselen etter energi er økende, og leting etter olje og gass beveger nordover til mer fjerntliggende områder enn før. Offshorevirksomhet i Barentshavet er utfordrende. Lave temperaturer, stummende mørke i vintermånedene og lange avstander fra eksisterende infrastruktur krever nye og robuste løsninger før oljefelt i Barentshavet blir innført.

Utfordringene i nordområdene for søk- og redningsoperasjoner er blant annet de store avstandene, tidskritiske operasjoner, det lave antallet ressurser med lav kapasitet og de tøffe klimatiske forholdene. De store avstandene og den manglende infrastrukturen er en utfordring for evakuerings- og redningsoperasjoner i Barentshavet. I denne oppgaven er helikopterets beredskapskapasitet for operasjoner i Barentshavet vurdert.

Formålet med denne avhandlingen er å utvikle en simuleringsmodell som kartlegger redningskapasiteten i Barentshavet, med den hensikt å evaluere ulike steder for å vurdere sannsynligheten for en vellykket redning innen de gitte tidskravene.

Målet med simuleringsmodellen er å vurdere hvordan værforholdene påvirker operasjoner utført av søk- og redningshelikoptre i Barentshavet. Modellen etablerer sannsynligheten for en vellykket redning av 1, 5, 15 og 21 personer fra sjøen innenfor ytelseskravet til 120 minutter for ulike steder i Barentshavet. Når effekten av været er kjent, etablerer modellen sannsynligheten for en vellykket redning. Denne informasjonen kan videre brukes til å vurdere det nødvendige nivået av beredskap på feltet av interesse.

Simuleringsmodellen vurderer først ett enkelt felt, omtrent 200 nautiske mil fra Hammerfest. Tidligere beregninger har vist at det var mulig å redde seks personer fra sjøen på dette feltet. Resultatene fra simuleringen identifiserer at det, avhengig av værforholdene, er mulig å redde mellom null og elleve personer i løpet av 120 minutter. Dette viser at værforholdene påvirker redningsoperasjonen, men det er ikke funnet noen trend i vindretningen, altså er det like sannsynlig at den gir medvind som motvind.

Resultatene fra vurderingen av en større del av Barentshavet angir at det er liten variasjon i resultatene evaluert i de forskjellige månedene. Det betyr at effekten av været anses å være lik i både sommer- og vintermånedene. Resultatene viser at avstanden er avgjørende for resultatene, været langs ruten viser lite variasjon i antall reddede personer. Sammenlignet med resultatene fra det ene feltet ser man mindre variasjon i antallet personer som er reddet. Dette kan være på grunn av at værforholdene til det enkelte feltet er holdt konstant langs ruten, sammenlignet med at det varierer langs hele ruten.

Basert på resultatene i denne oppgaven, er det foreslått at antall passasjerer om bord i ett helikopter, bør ikke overskride det antallet som er beregnet mulig å redde innen 120 minutter. Beregningene som angir antall passasjerer om bord bør ta hensyn til vindtilstand, da effekten av denne kan være betydelig.

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1 Introduction

1.1 Background and motivation

As oil and gas activities are moving further north on the Norwegian continental shelf, new challenges arise connected with the vast distances from shore and the challenging weather conditions. The main challenges with operations in the Barents Sea are the lack of infrastructure in the region and the large distances (Borch et al., 2012). As oil and gas activities are moving further north, the distance from shore increases and new challenges regarding emergency evacuation emerge.

Accidents around the world have demonstrated that it is important to have sufficient emergency preparedness resources available in areas close to offshore installations. This is to ensure that survivors are taken care of, whether they are injured or not. Having sufficient resources for rescue and evacuation is essential for operations in remote areas such as the Barents Sea.

The vast distances and lack of infrastructure are challenging for evacuation and rescue operations in the Barents Sea. Search and rescue (SAR) helicopters have limited range and fuel capacity. The Norwegian Oil and Gas Association has identified a performance requirement of 120 minutes to rescue 21 people from the sea when wearing survival suits designed for the conditions on the Norwegian Continental Shelf (2012). The time requirement applies within the 500 meter safety zone of an offshore facility. Potential offshore installations located far from shore will challenge this time requirement. In addition, wind conditions may affect the helicopter response time.

With the increased activity level in the Barents Sea, it is important to identify the required level of emergency preparedness, to ensure that the requirements for search and rescue operations are met.

In 2013, Sigurd R. Jacobsen and Ove T. Gudmestad wrote a paper “Long-range rescue capability for operations in the Barents Sea”. The purpose of their work was to examine the feasibility of long-range search and rescue of personnel in the Barents Sea. They propose to use a combination of an emergency response vessel and a search and rescue helicopter to improve the search and rescue capability. They reflected on the challenges connected to the large distances and limited recourses to assist accidents at sea and on general rescue operations in Northern Norway and The Barents Sea. They stated that numerous parties from the industry have expressed concern about this issue.

Jacobsen and Gudmestad (2013) further suggested that factors such as sea state, wind speed and direction, temperature of air and sea, visibility, polar lows, helicopter stability with floatation devices deployed, and availability of rescue resources should all be evaluated when considering the probability of survival and rescue. They further suggested that all the listed issues should be evaluated before helicopter's departure. In their work, they proposed a rescue capacity of a search and rescue helicopter and an emergency response vessel, and then the rescue capacity combined. They assessed the rescue capacity of the search and rescue helicopter based on the time to mobilise the helicopter, flying time to the scene of the incident, and the number of persons to be rescued within a 120 minutes performance requirement. Based on this, they presented the following graph, shown in Figure 1.

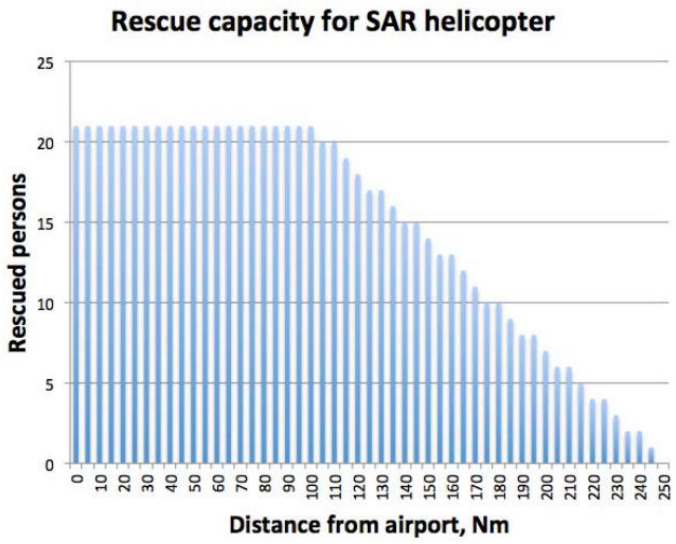


Figure 1 Recue capacity for a search and rescue helicopter at different distances from airport (Jacobsen and Gudmestad, 2013)

Based on the paper "Long-range rescue capability for operations in the Barents Sea", a seminar paper was written in the fall of 2014 by the author of this thesis. The paper presented the rescue capacity of a potential offshore installation 200 nm north of Hammerfest (Jakobsen, 2014). Search and rescue helicopters have a limited operational range due to fuel consumption and capacity onboard. The current range is approximately 175 nm, see Figure 2. This can be extended if it is possible to refuel en-route (Røsok, 2011).

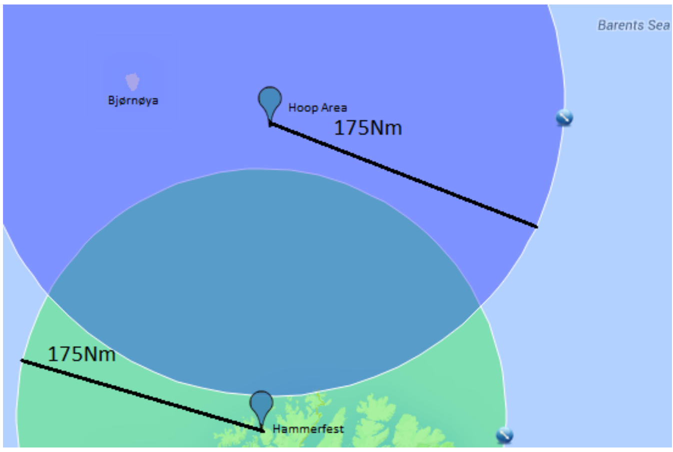


Figure 2 Radius visualizing the helicopter's range and the location of a potential oil field

Deterministic calculations of a rescue scenario at the Hoop area (Hoop area, 2014) were performed, to evaluate if the performance requirement could be met at this location. The calculations showed that with a SAR helicopter located in Hammerfest, with a mobilisation time of 15 minutes, it was possible to recover six persons from the water within 120 minutes. These calculations were performed using deterministic values for all parameters. The study showed that at this distance, it was not possible to meet the performance criterion of rescuing 21 persons within 120 minutes.

1.2 Scope and objectives

There is limited literature on the topic of rescue capacity, and how to establish the sufficient level of rescue capacity when planning a potential new oil field. The studies above consider search and rescue helicopter operations, and limitations regarding distance. However, the studies do not consider weather conditions or other factors which might affect the rescue operations. Therefore, the aim of this thesis is to study the following:

- How does the wind conditions affect the search and rescue helicopter operations?
- What is the number of persons that can be rescued within the performance requirement of 120 minutes, for different locations in the Barents Sea?
- How does varying the mobilisation time, flying time, and recovery time affect the number of rescued persons?

To evaluate the questions above, a simulation model is developed which implements stochastic parameters such as wind conditions, and variance in mobilisation time and pick up time. The purpose of the simulation model is to investigate the rescue capacity of a search and rescue helicopter for the Barents Sea. In this thesis, the rescue capacity is evaluated for two cases:

- A single field in the Barents Sea,
- Several locations in a larger area of the Barents Sea.

The single field which is located approximately 360 km (200 nm) north of Hammerfest, is previously studied, and the large distance proved to impose challenges to search and rescue operations (Jakobsen, 2014). The weather is a limiting factor when it comes to search and rescue operations by helicopter. Helicopter search cannot be performed in winds excess of 55 knots, and recovery of personnel may prove difficult or impossible in high levels of fog.

1.3 Structure of Thesis

This thesis contains six main chapters, the contents of which are described below.

Chapter 1 includes a general introduction to the topic of the thesis, the scope, and objectives. General background information is presented in chapter 2. The framework for the simulation model and the methodology used is presented in chapter 3. The results are presented in Chapter 4, and further discussed in Chapter 5. Finally, conclusions and further work are given in Chapter 6. Additional information, Matlab code, and figures are found in the appendices, and is referred to when required.

2 Helicopter rescuing operations in the Barents Sea

A growing demand for energy, and recent oil and gas discoveries, have established the Barents Sea as a potential area for oil and gas exploration and production. Estimates from 2012 (Schenk, 2012) predict that 22 % of the world's undiscovered recoverable oil and gas resources are located in the Arctic. 37 % of this is expected to be located in the Barents Sea region.

The Barents Sea borders the Arctic Ocean in the north, Greenland and Norwegian Seas in the west, Kara Sea in the east and the Kola Peninsula in the south, as shown in Figure 3. The Barents Sea is a subarctic area with a size of 1 400 000 km^2. The greatest water depths found in the Barents Sea are at 600 m, and the average water depth is approximately 222 m (ISO 19906, 2010). The Barents Sea has great potential for oil and gas exploration.

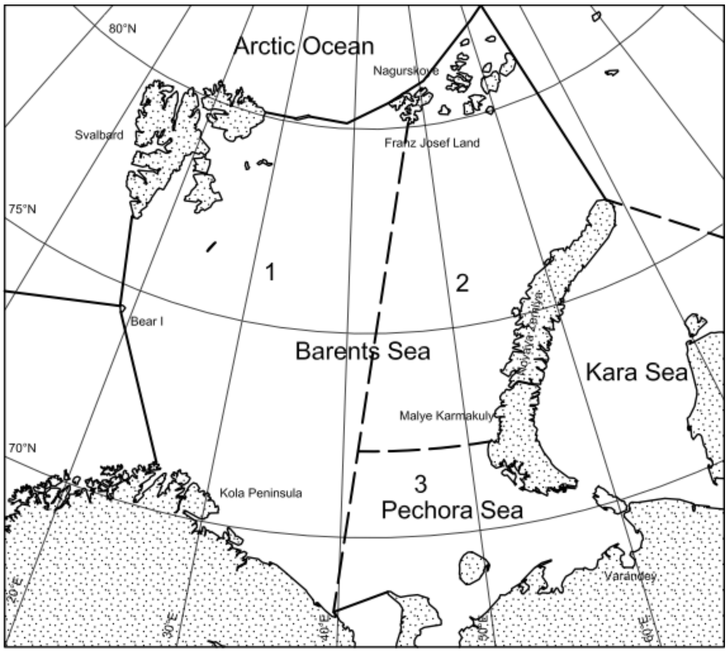


Figure 3 Regions of the Barents Sea (ISO 19906:2010(E))

There are several challenges related to operations in the Barents Sea. Borch et al. (2012) have defined the main differences compared to the North Sea, as shown in Figure 4.

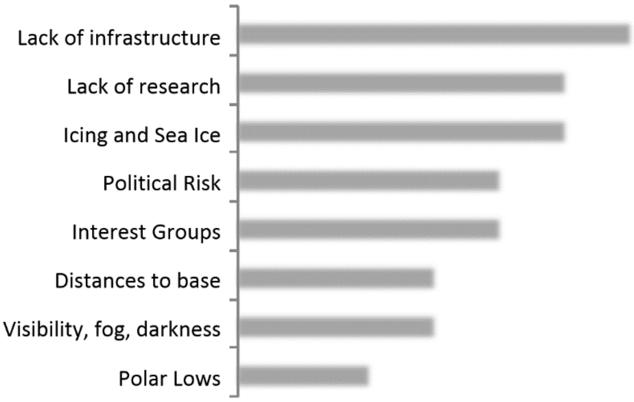


Figure 4 Operational challenges in the Arctic, compared to the North Sea. (Borch et al., 2012)

This chapter includes background information on relevant challenges related to the Barents Sea region, such as environmental conditions, and infrastructure. Further, it includes discussion on previous work, existing regulations, and current state of helicopter operations.

2.1 Environmental conditions

The conditions in the Barents Sea region can be challenging for operations. Whether it is the effect of low temperatures or icing on equipment, the Barents Sea region introduces new challenges regarding the environmental conditions. In the following sections, some of the challenges are listed.

2.1.1 Low temperatures

Low air and water temperature increase the risk of a possible emergency evacuation and the need for higher level of thermal insulation of life rafts, survival suits, etc. (Larsen and Markeset, 2007). The sub-arctic area is prone to low temperatures. The expected air temperature in the Barents Sea is at average between -9 and +7 °C (Jacobsen and Gudmestad, 2012).

Low temperatures may also affect materials and equipment, as many materials become brittle when exposed to low temperatures. This makes them disposed to the possibility of cracking due to thermal stress. This has to be considered in the design of the SAR helicopters and equipment (Gao et al., 2010);(Løset, 1995); (Freitag and McFadden, 1997).

The temperature of the sea water range between +2 °C and -1.9 °C during winter time. Sea water freezes at around -1.9 °C and surface ice can develop (Jacobsen and Gudmestad, 2012). The 120 minutes performance requirement is based on the design of survival suits worn during helicopter transportation. In the case of helicopter ditching, and the passengers end up in the water, the regulation states that there should be a safety factor of 1.5 for the response time of 120 minutes. This implies that the suits have to be verified for at least 180 minutes in the water. The suits worn on the Norwegian Continental Shelf have been tested for six hours against hypothermia. However, the water temperature in the North Sea is never lower than 2 °C. With the low water temperatures in the Barents Sea, the insulation level in the rescue suits may be insufficient.

2.1.2 Wind

The wind affects the flying time to the offshore facility depending on wind speed and direction in relation to the helicopter's direction and speed. This is further discussed in the methodology chapter, section 3.1. The average wind speed at Bjørnøya in the months January, February, and March is 14.37 m/s (Norwegian metrological institute, 2013). Wind speeds in the Barents Sea can reach higher values, and extreme winds can occur during polar lows, which can be considered as intense maritime cyclones. If the temperature is low and the wind speed is high, this gives conditions for ice accretion. The wind is also a limiting factor for helicopter's operational capability, as the general rule is that helicopter transport should not be carried out if the wind speed is exceeding 55 knots (Norwegian Oil and Gas, 2013).

2.1.3 Polar lows

Polar lows have a relative short life span, high travel speed and are hard to predict. This makes them a challenge for operations in the area (Pakkan et al., 2013). The following definition from Rasmussen and Turner describes the phenomenon:

"A Polar low is a small, but fairly intense maritime cyclone that forms poleward of the main baroclinic zone (the polar front or other major baroclinic zone). The horizontal scale of the polar low is approximately between 200 and 1000 kilometres and surface winds near gale force" (Rasmussen and Turner, 2003).

Polar lows are well-known phenomenon in the Barents Sea and are hard to predict as they appear quickly with wind speeds up to 28.4 m/s and at Beaufort force of 10. They develop when cold winds come from ice-covered regions and pass over warmer sea.

Distributions in Figure 5 shows the yearly number of polar low events, having an average of 15 polar lows every year, with seasonal character. November to April are the months with the highest probability of polar low occurrence. The summer months are polar low free (Pakkan et al., 2013).

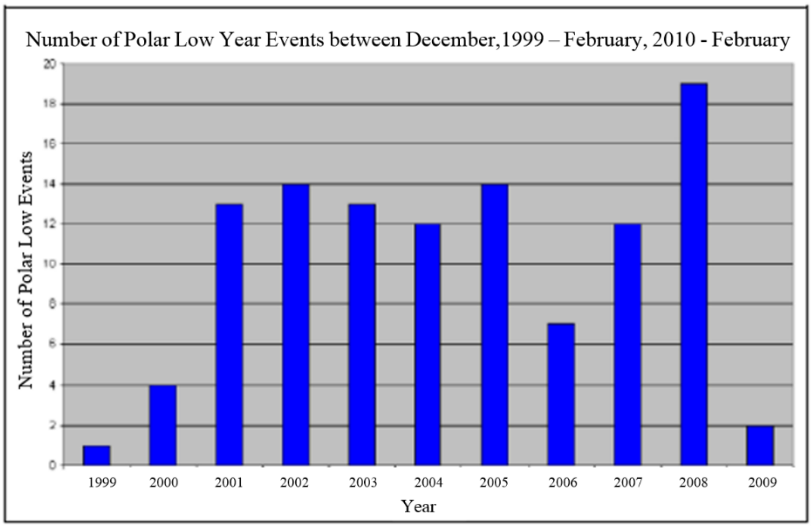


Figure 5 Yearly distribution of polar low events from 1999 to 2010 (Pakkan et al., 2013).

2.1.4 Sea states

High sea states will affect the recovery time of personnel, but it has proved difficult to establish to what extent. The effect of wave height on recovery time depends on the experience of the helicopter crew, but the time increases with increasing sea state (KV Njord, Pers. Comm., 2015).

The sea states are similar to the conditions in the North Sea. Information from the NORSOK standard (NORSOK N-003), in Figure 5, shows that the significant wave height in the south-west of the Barents Sea is 14 m, with a probability of exceedance of 0.1. Stormy weather can occur, and can be a threat to the operations.

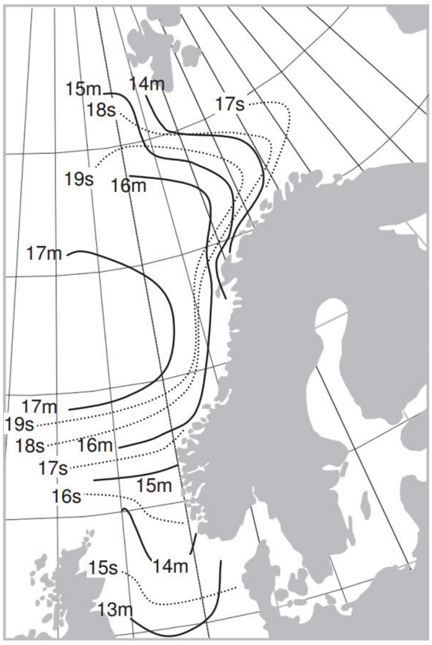


Figure 6 Significant wave height Hs and related maximum peak period Tp

The lines mark sea states with an annual probability of exceedance of 0.1 of 3 hours duration. ISO curves marking wave height are solid lines while wave periods are dotted. (NORSOK N-003, 2007)

2.1.5 Sea ice and icebergs

For arctic operations, sea ice is an important environmental factor that can threaten operations. Ice affects several aspects of oil and gas activities, from the design of the facilities to the emergency evacuation and rescue (Gudmestad and Quale, 2011).

The surface of the Barents Sea is never completely ice covered. April and March are the months with the highest density of ice. In these months ice covers approximately 55-60 % of the surface area. During the spring, the ice along the eastern shore of Svalbard can be a mix of multi-year and first-year ice. This is, however, not the main ice type found in the area. The ice cover also contains icebergs from the glaciers of Svalbard. Icebergs drift with influence from the wind and ocean currents. The ice conditions vary throughout the Barents Sea area, with the risk of drifting ice during the winter and spring months (ISO19906:2010, Annex B). Sea ice is disregarded in this thesis, and it is assumed that the people requireing rescue are located in the water.

2.1.6 Ice accretion

Icing is a weather phenomenon caused by several factors such as snow, freezing rain, low temperatures and high air humidity, or sea spray. Icing on helicopters and equipment can impose threats, such as loss of stability, decreased operability of equipment, and increased fatigue rate (Løset et al., 2006).

2.1.7 Visibility

Low visibility can affect the recovery time and locating persons in the water can prove to be difficult. Total darkness during the winter months also challenges search and rescue operations.

Fog and snow can impair the visibility. Fog occurs a large number of days of the year. There are statistically 64 days during a year where the visibility in the Barents Sea is less than 2 km, and 76 days during a year where the visibility is less than 1 km due to fog (Jacobsen and Gudmestad, 2012). The low visibility affects helicopter transport.

During the winter months, the sun is below the horizon all day. This results in total darkness, called polar night. The period of daylight during the autumn decreases rapidly towards the winter equinox. Similarly, the period of daylight increases rapidly towards the summer equinox (Polar nights and midnight sun, 2011)

Polar darkness will affect the time it takes to recover personnel from the water, due to the fact that it will be more difficult to locate persons in the water in the dark. Another effect the darkness has on helicopter operations is the increased risk when landing on helicopter decks, which are affected by the motion of the sea. To reduce the risk connected to landing on helicopter decks offshore, a regulation was implemented on the Norwegian Continental Shelf, requiring that the size of the helicopter landing decks are increased by 25%.

The low visibility due to darkness and fog will increase the time it takes to recover persons from the water. The design of survival suits take conditions of the Barents Sea into account and are equipped with connected personal beacon senders, reflective material, and a light, which will ease the search process.

2.1.8 Weather forecasting

Before commencing helicopter transportation, it is important to have weather forecasts available for the route. When planning these operations, consideration to operational limits should be assessed so that one can evaluate if it is feasible to complete the transportation. The North region has poor coverage of weather observations, and in the Arctic, reliable weather forecasts can be a challenge (Larsen and Markeset, 2007).

2.2 Infrastructure, facilities, and resources

One of the main challenges in the Barents Sea region is the lack infrastructure (Borch et al., 2012). The following section will cover the current situation in the Barents Sea region and some related challenges.

2.2.1 Search and rescue resources

The main resources for search and rescue in the Barents Sea region are helicopters, coast guard vessels, and vessels that are operated by the Norwegian Sea Rescue. The coast guard vessels operated by the Norwegian Navy may have helicopters onboard (KV Njord, Pers. Comm., 2015). There are two Sea King helicopters stationed in Banak, Finnmark operated by the Norwegian Royal Air Force. While drilling and exploration operations are in progress in the Barents Sea, a transport helicopter and an All Weather Search and Rescue (AWSAR) helicopter are operated by the petroleum industry. (Jacobsen, 2012)

2.2.2 Offshore facilities

Compared to the North Sea, there are few active oil fields in the Barents Sea region. The first floating offshore facility to be located on the Norwegian continental shelf of the Barents Sea is the Goliat FPSO, planned to be installed during the summer of 2015. The field is approximate 85 km north-west of Hammerfest.

Another facility in planning is Johan Castberg, 240 km north-west of Hammerfest, which has a planned production start in 2018. There are occasionally drilling facilities in the area. With few or no neighbouring facilities, there is less activity in the area, and fewer potential operators to cooperate with regarding emergency preparedness.

2.2.2.1 Vessel operations in close proximity

To identify the level of vessel operations in close proximity to the possible oil fields in the Barents Sea at a random point in time, Marine Traffic (Live Ships Map, 2015) was used. This is done by a visualisation of the number of vessels appearing on the live map. The vessels on the map are equipped with AIS transponders, and they sail within the range from the AIS receiver onshore. There are several reasons that vessels might not appear on the map, such as:

- Not having an AIS transponder, or having a fault on the transporter.
- Sailing in an area with no receiving AIS station nearby.
- Weak signals from the transponder due to low transmission power.
- Restriction in reception range between Class A and Class B transponders.
- Incorrectly configured to transport the correct information.

The images from Marine Traffic, Figure 7, show that there is far less vessel activity in the Barents Sea region compared to the North Sea. Peter Schütz from DNV GL mentioned that the rescue capacity is not an issue in the same way for the North Sea as the Barents Sea region. This is due to the fact that when considering a new installation, there is a sufficient amount of vessels and transport helicopters in the area nearby. Looking back to the beginning of the oil industry in the North Sea on the Norwegian continental shelf, the regulations were not well established, and higher levels of risk were most likely taken. (2015, Pers. comm., 29. January)

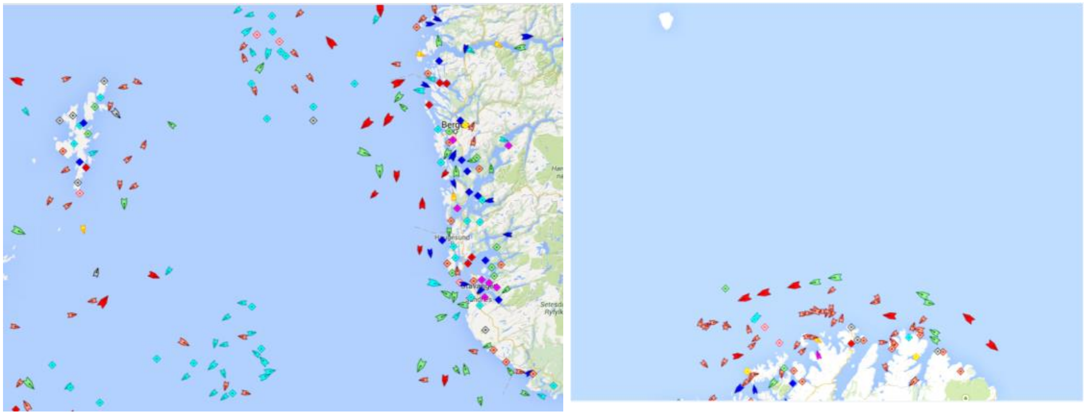


Figure 7 Marine Traffic 17.33, 17.02.15, North Sea and the Barents Sea (Live Ships Map, 2015)

2.2.3 Distances

As mentioned in the introduction, the rescue capacity at a single field located 200 nautical miles from Hammerfest has previously been evaluated (Jakobsen, 2014). It was established that the distance to the field was too large to manage a complete rescue of 21 persons, and only six could be recovered within the performance requirement of 120 minutes.

One of the main challenges regarding search and rescue operations in the Barents Sea is the vast distances from base hubs, where helicopter are located. Long distances between base hubs and facilities are the limiting factor for SAR helicopter and emergency response vessels.

2.3 Existing regulations

Several of the existing regulations in the maritime industry have been developed as a response to larger accidents. The Titanic accident was a catalyst for the first international convention for the Safety of Life at Sea (SOLAS). Accidents such as Scandinavian Star raised a number of issues regarding fire protection and evacuation, and in 1992, the International Maritime Organization (IMO) adopted a widespread set of amendments regarding fire protection. The lessons learned from large accidents are implemented into the regulations to avoid similar accidents from reoccurring. Historically, when a large accident occurs, gaps in the regulations have had a tendency to reveal themselves.

There are several regulations that apply to safe evacuation, escape, and rescue. Some of the requirements are included here to give an overview of what requires consideration for search and rescue operations.

2.3.1 Area-based emergency preparedness on the Norwegian Continental Shelf

The Norwegian regulations from the Norwegian Oil and Gas Association state that planning for emergency actions is required for:

- Major accidents scenarios
- Less comprehensive accidents scenarios
- Scenarios that temporarily increases the risk

The provisions further imply that the level of emergency response actions shall not be based on the level of risk. Scenarios with low risk levels shall still have planned corresponding emergency response actions. It is essential that the emergency response actions are not excluded due to low probabilities of a scenario. However, some parameters, such as response time and capacity, are proposed to follow a risk-based approach.

Norwegian Oil and Gas Association published recommendations for area based emergency response (2012). The publication suggests resource planning based on the following scenarios:

- Man over board as a result of working over sea
- Personnel in the sea after helicopter ditching
- Personnel in the sea after emergency evacuation
- Collision hazard
- Acute oil spill
- The need of external firefighting due to installation fire
- Acute injury or illness, requiring external medical response
- Helicopter crash on installation, severely injured personnel

2.3.2 Time requirement for rescue

The petroleum industry and the Norwegian Oil and Gas Association have identified a performance requirement of rescuing 21 persons from the water within 120 minutes inside the 500 meter safety zone of an offshore facility. This time requirement is based on the insulation level of the immersion suits worn while transported by a helicopter. (2012)

2.3.3 Survival suit requirements

"*The Norwegian Oil and Gas, 094 - Recommended guidelines for requirement specifications for survival suits*" establishes the minimum design and performance requirements for the offshore survival suits used on the Norwegian Continental Shelf (2004). The requirement includes the suits worn while being transported to the field in helicopters, and the survival suits stationed on offshore facilities. The requirements build upon the international regulations and standards for survival suits, with an emphasize on ergonomic design, thermal protection, breathing systems for underwater escape, equipment for search and rescue, as well as securing suitability for the regions in which the offshore facility is located. “ISO 15027-1, Immersion suits – Part 1” covers the safety and performance requirements for constant wear immersion suits for work and leisure to protect from hypothermia and effects of cold-water immersion.

2.3.4 Survival in cold water

The sea water temperature in the Barents Sea can be as low as -1.9 °C, which is the freezing temperature of sea water. The survival suits used in the North Sea are tested in waters with a temperature of 2 °C. Low sea temperatures in the Barents Sea will impose challenges to the evacuation, and the survival suits used in the Barents Sea should be designed for the extreme low temperatures.

The guide to survival in cold water from International Maritime Organisation (2012) explains the effects of cold water on the body and informs about insulation and hypothermia. It is a guide on how to prolong life in case of evacuation into water. It describes in steps what to do in case of evacuation and how to prepare for an evacuation in advance. Reading this guideline before going on board a vessel can save lives, by informing personnel of behaviour in case of an emergency evacuation. The guideline includes a checklist for both rescuers and people evacuating.

2.3.5 NORSOK Z-013 Risk and emergency preparedness assessment

This NORSOK standard has a purpose to establish requirements for planning, risk, and emergency preparedness assessment. The standard emphasises the requirements that are related to ensuring that the emergency preparedness assessments are suitable for their purpose, rather than ensuring that the requirements are detailed descriptions of how the assessment and the related hazards are included and analysed.

2.3.6 The Petroleum Safety Authority Norway

2.3.6.1 Act 29 November 1996 No. 72 relating to petroleum activities

This act includes the Ministry’s requirements for emergency preparedness. Section 9.2 states that licence owners and other parties involved in petroleum activities shall at all times maintain efficient preparedness towards defined hazard and accident conditions that potentially may lead to loss of lives, injury to personnel, pollution, or major damage to material assets. The licence owner is obliged to ensure that necessary measures are in place to prevent or minimize any potential harmful effects, including measures required to return the environment to the state it had before the occurrence of the accident. The Ministry may issue rules regarding emergency preparedness and its connected measures, and order that co-operation between licence owners takes place when planning emergency preparedness.

The Ministry may also decide that other parties shall make necessary contingency resources available for the account of the licensee, in the case of an emergency or accident.

2.3.6.2 The Framework regulations

The purpose of the framework is to promote high standards for health, safety, and environment in activities, achieve systematic implementation of measures that comply with the requirements, and achieve the goals stated in the work environment and safety legislation. Section 29 and 30 cover co-operation and partnership regarding emergency preparedness and oil spill. Including regulations stating that the Operator shall coordinate the emergency resources in hazard and accident situations. The Petroleum Safety Authority Norway together with Norwegian Directorate for Civil Protection may determine regulations stating that emergency vessels, including aircrafts, shall be present at installations or vessels in petroleum actvities.

2.3.6.3 The Management regulations

These regulations state that emergency preparedness analyses shall be carried out and be part of the basis for making decisions when:

- Defining hazard and accident situations,
- Requiring performance requirements for the emergency preparedness,
- Selecting and dimensioning emergency preparedness measures.

The management regulations do not include any materialistic regulations towards emergency preparedness but includes extensive regulations regarding emergency preparedness analyses for personnel and for oil spill.

2.3.6.4 The Facilities regulations

The following sections cover emergency preparedness:

§41	Equipment for rescue of personnel
§43	Emergency preparedness vessels
§44	Means of evacuation
§45	Survival suits and life jackets, etc.
§46	Manual fire-fighting and firefighters’ equipment

A summary of the regulations coverage follows below:

It is required that all offshore installations at all times shall predispose equipment to utilize rapid and gentle rescue of personnel from the water. Diving facilities shall at all times predispose equipment such that personnel in diving bells, chambers, chambers subsea, and subsea vessels can be rescued in the case of an emergency. Personnel on an offshore facility shall be able to evacuate rapidly and efficiently to a safe area under any weather conditions. Free-fall lifeboats, supplemented by rescue chutes and life rafts, shall be used for evacuation to sea. It shall be possible to store personal survival suits in the cabins. The life rafts onboard shall be located where they are easily accessed. The installation shall be equipped with a sufficient level of manual firefighting and firefighter equipment to efficiently fight fire and prevent further escalation.

2.3.6.5 The Activities regulations

The regulations cover general requirements regarding emergency preparedness, preparedness regarding hazard and accident situations. The relevant paragraphs are listed below:

§73 Establishment of emergency preparedness
§74 Shared use of emergency preparedness resources
§75 Emergency preparedness organisation
§76 Handling hazard and accident situations

These regulations include that the responsible party of an operating facility shall prepare a strategy for emergency preparedness and accident situations. The emergency preparedness level shall be based on the results from risk and emergency preparedness analyses. Also, it is stated that parties shall co-operate on shared use of emergency preparedness resources, where the co-operation shall be regulated by an agreement and based on emergency preparedness analyses.

The operator shall ensure that emergency preparedness is in cooperation with the public rescue service and other health services in the country, in such a way that rescued, injured and sick personnel will be taken care of in a proper way. The emergency preparedness organisation shall be robust, to manage efficient handling of hazards and accident situations.

The responsible party shall ensure that necessary measures are taken during hazard and accident situations as soon as possible so that the right notification is given straight away.

2.4 Helicopter operations

The following section covers the helicopter operations and their operational limitations.

Helicopters are the main mean of personnel transportation to and from the offshore facilities on the Norwegian Continental Shelf. Stakeholders in the industry, together with SINTEF, have conducted studies regarding helicopter safety (SINTEF, 2010). An extensive amount of work has been put into the studies, aiming to improve the safety of helicopter operations. The report gives the following recommendations and observations to reduce the risk of the helicopter operations:

- Reducing the number of flights during the night, in the dark, or in conditions with low visibility, especially when approaching moving helicopter decks.
- Requirements regarding improved weather observations, with a focus on remote areas.
- Continuation and replacement of tracking devices used to track helicopters at all time during the flight.
- To improve the safety of operations, a requirement for a hangar on offshore facilities to accommodate SAR helicopters is implemented.
- Requirement to increase the area of helicopter decks on the Norwegian Continental Shelf by 25 %.

Reducing number of flights in darkness on the Norwegian continental shelf is difficult due to the polar nights in the north during the winter season. In the Barents Sea, close to Bjørnøya, the sun leaves early in November and returns in early February, resulting in three months of total darkness. A report from the Ministry of Petroleum and Energy, regarding infrastructure and logistics in the petroleum industry in the south-east Barents Sea, showed that out of 147 operations performed by Sea King helicopters in the Barents Sea, one third of the missions were executed in darkness. (Jacobsen, 2012)

2.4.1 Operational limitations/Resource limitations

Search and rescue helicopters are limited in capacity, range, and operational conditions. The major limitation for search and rescue helicopters is their range, due to limited fuel capacity. The requirement regarding fuel is calculated based on the distance to the destination, time to perform the approach, and sufficient amount of fuel to return to base and still have fuel for 30 minutes further flying time. These regulations can be found in full in BSL D 2-2 (1976). Transport helicopters normally carry fuel for 3.5 hours flying time, which includes the extra half hour reserve fuel. The guideline 066 from Norwegian Oil and Gas Association states that an offshore facility cannot be utilised as an alternate airport (2011). The approximate range of a transport helicopter is 175 nm.

Carrying additional fuel on board the helicopter, and refuelling on an installation offshore could be solutions to extend the helicopter range capacity. However, the increased weight of the helicopter will reduce the capacity of personnel that the helicopter can transport. The helicopter may also land on offshore facilities for refuelling if the facility has a fuel depot. Helicopter in flight refuelling is also an alternative, and such equipment is available on some coast guard vessels. This does not involve landing on a facility (Jacobsen, 2012).

Certain environmental conditions are limiting to helicopter operations:

- The probability of lightning.
- Air turbulence and the wind speed on deck.
- Low visibility, fog or snow.
- Wind speed and direction, which reduces headway significantly.
- Icing, if the helicopter is not correctly equipped with de-icing equipment.

It is stated in the 064 guidelines from Norwegian Oil and Gas Association that helicopter transportation should not take place when the wind speed exceeds 55 knots. The weather conditions will affect the recovery time of personnel in the water. The 064 guidelines states that it takes approximately 3 minutes to recover a person from the water using a SAR helicopter. Statoil has stated in their own regulations that it shall not take longer than 3 minutes to recover persons from the water; based on the 064 Guideline (Nina Skjegstad, 2015, Pers. Comm., 23 March).

2.4.2 Current state of helicopter response in the Barents Sea

To this date, the author has not succeeded in finding literature on how a sufficient level of emergency preparedness is determined for new oil fields.

Peter Schütz from DNV GL mentioned that it has not been a relevant problem when establishing new fields in the North Sea, due to the constant flow of vessels and helicopters around already established oil fields (2015, Pers. comm., 29. January). Skjegstad from Statoil mentioned that since there are no other shareholders in the area around Johan Castberg, the guidelines from Norwegian Oil and Gas *064 – Area Emergency Preparedness* are not utilised (2015, Pers. Comm., 23 March). Therefore, no area emergency preparedness is planned for at this stage. However, field emergency response is planned for, using the same defined situations of hazards and accidents listed in the 064 guidelines. Ms. Skjegstad refers to the guidelines and the section which refers to the Barents Sea and similar areas. The guidelines state that the area emergency preparedness in areas such as the Barents Sea, are justified special attention regarding the efficiency requirements. Still, there is not considered to be any scientific basis to establish extraordinary requirements in these areas.

Skjegstad mentions that it is important to establish if the SAR helicopter has sufficient reach to be based onshore, or if it is required to have a helicopter in a hangar offshore. It is mentioned that the number of passengers onboard the transportation helicopter depends on the distance between the field and the onshore helicopter base. If the helicopter hangar solution turns out to be too costly or not technically feasible, the number of passengers onboard the transportation helicopter is required to be reduced to the number of personnel that has been evaluated possible to recover within the time requirement of 120 minutes. For example, if it is only possible to recover six persons within the 120 minutes time requirement, the transport helicopter can only transport up to six persons when transporting personnel between onshore base and the installation. Skjegstad also mentions that the supply vessels that serve the installations could have emergency preparedness functions, such as oil spill.

To establish the required level of field emergency preparedness, the *064 – Area Emergency Preparedness* guidelines are adapted into Statoil’s own guidelines and requirements. The calculations are based on deterministic values for helicopter travel speed, pick up rate and mobilisation time.

2.4.3 Weather conditions’ effect on recovery time from water

Visibility, wave height, and wind will affect the recovery operation, but data on this topic is sparse. To evaluate the effect these conditions have on recovery of personnel, information is collected from relevant persons involved in search and rescue operations and from relevant literature. This information is evaluated and used in the simulation model, which simulates the recovery of persons from the water.

2.5 Seminar paper written on the helicopter rescue capacity in the Barents Sea

In the fall of 2014, a seminar paper was written by the author of this thesis, the content of which is extended in this thesis.

To evaluate the challenging distances in the Barents Sea and its effect on rescue operations and performance requirements, a study was performed in the fall of 2014 (Jakobsen, 2014). The findings of the study were the initial motivation for this thesis. The case and its results are presented in the following sections.

2.5.1 Rescue capacity of a search and rescue helicopter

For these calculations, it is assumed that the helicopter is on stand-by and spends 20 minutes from being notified until take off. The search and rescue helicopter is assumed to be located in Hammerfest, with a distance of 197 nautical miles from the evaluated area. The average time it takes to locate and recover a person from the sea is 3 minutes (*064 - Area Emergency Preparedness*). A search and rescue helicopter travels at a speed of 145 knots (Jacobsen and Gudmestad, 2013). It is assumed that the personnel in the water are wearing survival suits appropriate for the conditions in the Barents Sea, with a connected personal beacon sender, reflective material and a light, which will ease the search process.

With a SAR helicopter located in Hammerfest, which is approximately 200 nm from the field, and the given travel speed, this gives 83 minutes in transit time to the field. Including 20 minutes to mobilise the helicopter, there are 18 minutes left for rescue of personnel. With the recovery time per person of 3 minutes, this gives a rescue capacity of 6 people from the water within the time limit of 120 minutes. (Jakobsen, 2014)

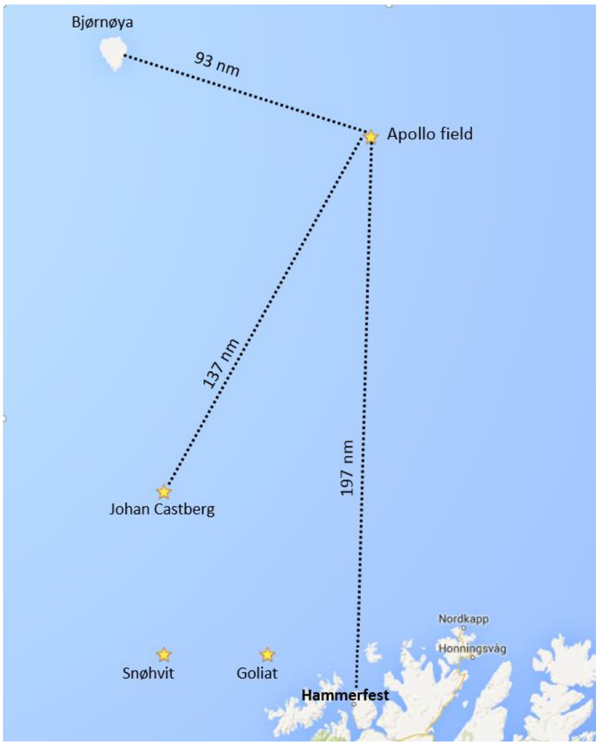


Figure 8 Distances to different possible SAR helicopter locations

This information shows that new solutions and options for search and rescue should be considered. Investing in a multipurpose emergency response vessel (ERV) at the field could be an option. However, the rescue capacity of an ERV is also limited by the distance to the field.

2.5.2 Considerations of other options for a helicopter base

Using deterministic values for the calculations of search and rescue calculations shows that the distance between Hammerfest and the field location is too far to manage a complete rescue using a general recovery time of 3 minutes per person.

One option could be to have a stand-by helicopter at a neighbouring field, such as Johan Castberg or at Bjørnøya. Johan Castberg is located 137 nm from the Hoop area, giving helicopter transit time of 57 minutes. With the including 20 minutes for preparing take off, the total time until arrival at the rescue location will then be 77 minutes, leaving 43 minutes for search and rescue. This allows for rescue of 16 persons within the 120 min requirement.

Bjørnøya is another option located 93 nm east of the Hoop area. Having a SAR rescue helicopter at this location gives a transit time of 38 minutes and a total time to arrive at the area of 59 minutes. This gives 61 minutes for search and rescue, giving time to recover 20 persons from the water.

Table 1 SAR helicopter location and corresponding rescue capacity

SAR Helicopter location	Distance from Hoop Area	Rescue capacity within 120 min
Hammerfest	197 nm	6
Johan Castberg	137 nm	14
Bjørnøya	93 nm	20

These calculations show that with a helicopter based in Hammerfest, it is possible to recover six persons within the time requirement of 120 minutes. These calculations are based on deterministic values throughout, and may not be representative for an actual rescue operation where weather conditions affect the operation. To consider the effect of the wind conditions during the rescue operation, a simulation model developed in this thesis will simulate the helicopter operations, taking in the effect from observed wind data. The required time to mobilise the helicopter for the rescue operation, transit time, and the time it takes to recover personnel will vary in each simulation run.

3 Methodology

In the following sections, the development of the model as well as relevant theory and physical effects will be described.

The simulation model is developed using the Matlab toolbox SimEvents. The toolbox design allows SimEvents to take advantage of large collections of data, processing, visualization and computations tools from both Simulink and Matlab while operating as a discrete event system simulator. Matlab is used to simulate the helicopter operations, and to evaluate how many persons can be recovered from the water at different areas in the Barents Sea within the 120 min time requirement.

3.1 Simulation in general

A simulation can be described as an imitation of a real problem over time (Cassandras and Lafortune, 2008). One can think of computer simulation as a laboratory experiment, but using computers instead of physical devices, and the software captures the interactions in the system. Randomness in the system is generated by the software using “random number generators”. Simulation can still not be considered to be the “real thing”, but is considered next best compared to building expensive and complicated systems for experimenting (Cassandras and Lafortune, 2008). The performance of the real system is imitated by using probability distributions to generate various random events that occur in the system. The model runs the simulation to obtain statistical observations of the performance which is a result of the randomly generated events.

A simulation model consists of mathematical equations, which describe the behaviour of the system. The goal of such model is to obtain information about quantities of interest, such as the response time studied in this thesis.

Stochastic values, such as weather data, can be implemented in the simulation model, giving a more realistic solution compared to using deterministic values only. In this thesis, parameters such as wind speed, wind direction, and variation of response times are implemented to consider their effect on the rescue capacity.

In the following sections discrete event simulation, SimEvents and simulation used in similar applications are described.

3.1.1 Discrete event simulation

The following definition of discrete event simulation is used in Introduction to Discrete Event Systems: “A discrete event system is a discrete state, event driven system, that is its state evolution depends entirely on the occurrence of asynchronous discrete events over time." (Cassandras and Lafortune, 2008).

Simulation can be used for discrete event systems such as manufacturing, airport design, road networks and traffic loads. Building a laboratory for testing and experimenting is unrealistic, both due to cost and complexity. Discrete event simulation is therefore a useful tool for testing a systems viability prior to executing a project.

Discrete event simulation is driven by changes of states in the system that occur instantaneously at different points in time due to the occurrence of a discrete event. One event occurring may trigger new events and processes. An example of typical change in system state is the delivery of cargo in a port.

Law et al. (1991) described discrete event simulation as the modelling of a system which changes over time, where the state variables change instantaneously at different points in time. When we experiment in a simulation model, the input data may be changed to consider different cases and to study changes in the model output.

3.1.1.1 The process-oriented simulation scheme

In discrete event simulation, it is possible to consider entities (such as persons requiring rescue) as undergoing a process as they go through the discrete event system. The process is considered as an order of events divided by time intervals. During the time intervals, entities are either receiving service or waiting to receive service. Process-oriented simulation scheme includes several processes for the different entities. All the entities in the system undergo the following process:

1. Initial Event - Personnel in the water.
2. Enters queue - Waiting for helicopter in the water.
3. Entities requesting service - If the helicopter is available, the person (the entity) receives service, if not the person remains in the queue.
4. Server - Once the person (the entity) is being picked up (receiving service), it remains in service for some time, corresponding to the pickup time (service time).
5. After service is complete, it releases the server.
6. Entity leaves the system.

Step 3 above forces the entity to remain in the queue if the server (helicopter) is busy rescuing another person from the water. The amount of time that the person is required to wait depends on the state of the system, meaning the number of other entities already in the queue and the corresponding time they require service. The time that an entity spends in the queue depends on the system state. The time delay in step 4 corresponds to the entities' service time. This time delay depends on externally provided numbers of service time, from a random number generator.

Process-oriented simulation scheme is well suited for queuing systems, such as in this case where one considers the persons in the water as entities flowing through a network of interconnected servers and queues. The main components of a process-oriented simulation scheme include:

- Entities: Users, in this case, persons and helicopters, requesting service.
- Attributes: Information connected to the individual entities.
- Process Functions: The actions or time delays that the entities experience.
- Resources: Objects, providing service to the entities.
- Queues: A set of entities waiting to utilize the same resource.

3.1.2 SimEvents

SimEvents is designed to simulate discrete event systems. It is embedded in Matlab, operating within Simulink, which is a traditional time-driven simulator. SimEvents is equipped with functionality which enables co-existence of event-driven and time-driven components in hybrid systems (Clune et al., 2006). The design allows SimEvents to take advantage of a large collection of data processing, visualization and computations tools from both Simulink and Matlab. While operating purely as a discrete event system simulator in the case where no time-driven system components are involved.

SimEvents is based on signals and entities. The term entity is taken from the discrete event system description as an environment consisting of “users” and “resources”. As previously described, the entities request resources to perform a task. The resources are occupied for a certain amount of time, and hand over the resources so that other users may use them. SimEvents consists of different sets of libraries containing blocks with different system functionalities. The main libraries in SimEvents are as follows:

- Generators: Blocks generating entities, function calls or random varieties
- Queues: Blocks where entities are stored while waiting for resources
- Servers: Blocks that model different types of resources
- Routing: Blocks controlling the movement of entities as they access servers and queues
- Gates: Blocks controlling the flow of entities by enabling/disabling access to certain blocks
- Event Translation: Blocks enabling communication between SimEvents and Simulink by translating events into function calls
- Attributes: Blocks assigning and modifying data to entities
- Subsystems: Allowing a combination of blocks to be performed when a specific event occurs
- Timers and Counters: Blocks that measure the time occurrence of events or the time elapsing between events

3.1.3 Simulation application areas

The use of simulation modelling for decision-making in emergency preparedness offshore is limited. It has proven difficult to obtain relevant literature on this topic. The work referred to in this chapter therefore includes articles that, to some extent, have resembling problem descriptions.

It is stated that the only applicable tool for modelling of complex systems is simulation (Fu et al., 2000). Simulation involves developing a model for an operation of a stochastic system. Probability distributions, are used to generate random events, with the main intention to imitate the system performance (Law et al., 1991).

Simulation is a widely used tool in transportation and logistics. Some examples of areas that use simulation as a decision tool are presented below.

Simulation is commonly used in the airline industry. Yau et al. (1993) have described the use of simulation for short term airline planning, as a decision support tool. Before the use of simulation tools, schedule analysts had to prepare the flight schedules manually. This required continuous communication and often led to problems.

The simulation model SimAir simulates daily operations of an airline company, to evaluate schedules, delays and recovery. To implement delay in operations, an event generator implements an aggregate distribution for additional flying time and ground time, representing the delay (Rosenberger et al., 2000).

Yang et al. (1991) use simulation to consider factors such as reliability and maintainability, weather conditions, management, spare part supply and the effect on the commercial airline industry. This is established using Monte Carlo simulation. The method in the article is used to conduct the reliability simulation for an airline fleet, comparing the results with actual statistical data of the same fleet. The results of the simulation proved to be useful in decision-making processes for manufacturers improving the products reliability and maintainability and such that airline companies can make changes to flight schedules, management and logistic support.

Carson et al. (1997) discussed several issues regarding simulation and optimization in transportation and logistics in a panel discussion. They discussed when to use simulation versus optimization and heuristic models, features in simulation software relevant for transportation modelling, combining simulation and optimization, and how to convince management of the advantages of simulation. Mark Brazier from CSX Transportation has expressed in the panel that problems best suited for simulations are generally large problems with dynamic nature with stochastic parameters which do not require real-time solutions.

Simulation is also widely used to study fleet size problems. Shyshou et al. (2010) developed a discrete-event simulation model which evaluates alternative anchor handling and tug supply vessels’ fleet size configurations. The uncertainty in weather conditions and the unpredictability of vessel rates add stochastic complexity to the problem. The article presents a prototype for a simulation-based decision support tool that evaluates the number of anchor handling vessels that are cost-optimal on long time hire.

Fagerholt et al. (2010) have combined the use of simulation and optimization for a decision support methodology for strategic planning in liner tramp and industrial shipping. One major advantage using this methodology is the possibility of dealing with stochastic aspects while considering routing and scheduling simultaneously. An other advantage is the flexibility, meaning that the problem can be configured to supply decision support for different strategic planning problems.

Another area where simulation is widely used is the emergency preparedness onshore, such as ambulance dispatching and locations. Savas (1969) developed a simulation model evaluating cost efficient improvements to ambulance services in New York. A more recent study by Andersson et al. (2007) developed a decision support tool for ambulance dispatching and relocation. The aim of the model is to find which ambulance to send to which patient, and where to relocate the ambulances to continuously maintain, or increase the preparedness in the area.

3.2 Effect of wind speed on helicopter ground speed

To find the actual helicopter speed as a result of the wind conditions, the ground speed of the helicopter is calculated.

The ground speed is the actual speed at which the helicopter travels over ground. It is directly connected to the wind speed and direction, and air speed of the helicopter. To obtain the ground speed, one needs to establish some values that are found using some known parameters.

The values needed to establish the ground speed are:

- Air speed [kn]
- Wind speed [kn]
- Wind direction [deg]
- Heading [deg]

To establish the heading, of the route the model finds the great circle distance between the two points of interest. Knowing the distance between the two points, it finds the course angle.

3.2.1 Great circle distance between two points

To obtain the great circle distance between the two points (points 1 and 2) of interest the following formula (Williams, 2015) is used:

$$d = 2\, arcsin \sqrt{\left(\sin\left(\frac{lat1 - lat2}{2}\right)\right)^2 + \cos(lat1) * \cos(lat2) * \left(\sin\left(\frac{(lon1 - lon2)}{2}\right)\right)^2} \qquad (1)$$

Where:

lat1 = latitude coordinate of point 1,

lon1 = longitude coordinate of point 1,

lat2 = latitude coordinate of point 2,

lon2 = longitude coordinate of point 2

3.2.2 Course heading

To establish the effect of the wind on the helicopter ground speed, the model obtains the course angle between the two points of interest, relative to north. To obtain the course between the two points of interest the following formula (Williams, 2015) is used:

$$course = 2\pi - \arccos(\frac{\sin(lat2) - \sin(lat1) \cdot \cos(d)}{\sin(d) \cdot \cos(lat1)}) \qquad (2)$$

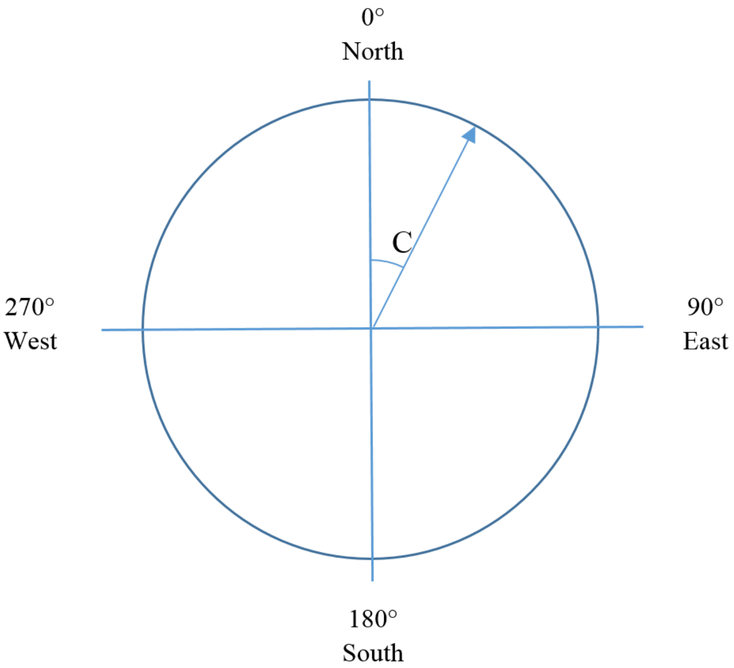


Figure 9 Heading course in degrees, relative to north.

The course angle (*C*) is defined as the angle between north and the heading of the helicopter. The angle of north is 0°, and the angles increase clockwise as shown in Figure 9.

3.2.3 Ground speed calculations

The course and speed of the helicopter in relation to the direction and speed of the wind affects the transit time and needs consideration when simulating a rescue operation. The ground speed vector is the sum of the air speed vector and wind speed vector. Vectors shown in Figure 10.

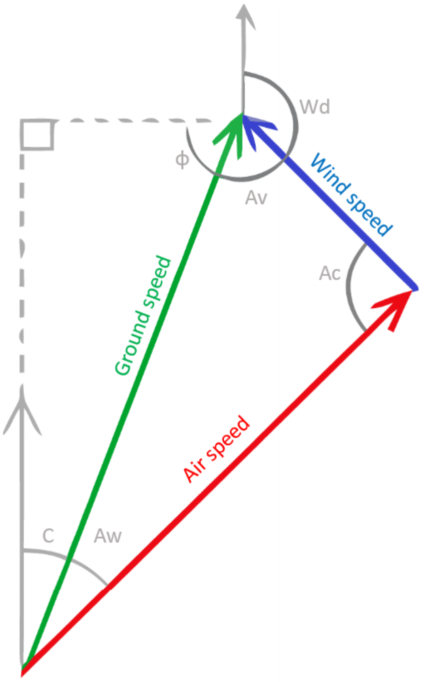


Figure 10 Relation of airspeed, wind speed and ground speed

Air speed is the speed that the helicopter is maintaining in the air. The wind speed is the actual speed that the wind is measured at. The course, *C*, is the wanted direction that the pilot wants to achieve over the ground, to reach the wanted destination.

The angle, *Aw*, is the angle between the desired course and heading of the helicopter when compensating for the wind effect, generally referred to as drift. To compensate for the drift, the pilot must steer a course equal to the sum of the course, *C*, and compensating angle, *Aw*.

Ac is the angle between the air speed and wind speed. *Av* is the angle between wind speed and ground speed.

The wind direction, *Wd*, is given in degrees, and is expressed as the direction, which the wind is blowing from. 0° represents wind blowing from the north, 90° the wind blows from the east, and so on. This is indicated in Figure 11.

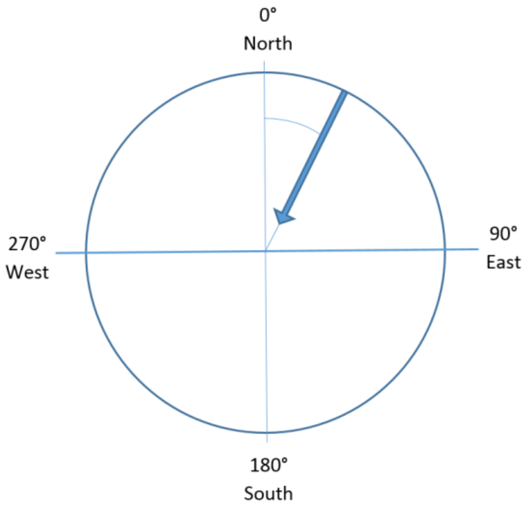


Figure 11 Wind direction in degrees

To establish the relationship between the wind speed and ground speed, general sine laws are used to describing the relationship between angles and sides in a triangle (Rottmann, 2003)

The following parameters are known:

- *C*, The course heading of the ground speed vector, in degrees.
- *AS*, The helicopter airspeed.
- *WS*, The wind speed.
- *Wd*, The wind direction in degrees.

The following equations are used:

$$Av + Wd + \phi + 90° = 360° \tag{3}$$
$$Av = 360° - Wd - \phi - 90° = 270° - Wd - \phi$$

From Figure 10 ϕ can be expressed as a function of *C*:

$$\phi = 180° - 90° - C = 90° - C \tag{4}$$

Substituting for ϕ in equation 1:

$$Av = 270° - Wd - (90° - C) = 180° - Wd + C \tag{5}$$

Using sine-laws, *Aw* can be expressed as:

$$Aw = \arcsin(\sin(Av) \cdot \frac{WS}{AS}) \tag{6}$$

To find the angle between the wind speed and the drift heading, *Ac*, the known angles are subtracted from the total sum of 180°.

$$Ac = 180° - Aw - Av \tag{7}$$

The ground speed can then be found:

$$GS = AS \cdot \frac{\sin(Ac)}{\sin(Av)} \tag{8}$$

The ground speed is used to find the total time it takes to fly to a site for rescuing personnel:

$$flying\ time = \frac{Distance\ to\ field}{Ground\ speed} \tag{9}$$

The Matlab code can be found in Appendix II.

3.3 Input data

The simulation model takes in different parameters of interest. Wind speed and direction are used in the simulation model.

The wind data is supplied from BMT Argoss. Wind observations are collected every three hours, between 1992 and 2012. To implement the data into the simulation model, the observations are transformed into stochastic distributions.

The data is divided into monthly distributions. Using the dfittool toolbox in Matlab, suitable distributions of the data are found. The wind data is fitted with a Gaussian/Normal distribution.

The mathematical equation of a normal distribution depends on the parameters mean μ and variance σ^2. The normal distribution can be described using the following equations:

$$f(x,\mu,\sigma) = \begin{cases} \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2\sigma^2}[x-\mu]^2}, & x < 0 \\ x, & x \geq 0 \end{cases} \tag{10}$$

3.4 Simulation of rescue capacity for a single field and larger region

Two cases are evaluated in this thesis. Firstly, the rescue capacity of a single field where the model collects weather data from a single field assuming constant weather between Hammerfest and the field. Secondly, the rescue capacity of a larger area in the Barents Sea is evaluated. When evaluating the rescue capacity of the larger region, the model collects weather data from multiple locations in the Barents Sea. For the second case, the model considers that the weather changes along the route and establishes the rescue capacity of the different locations.

The first case evaluates the exact position which is previously studied (Jakobsen, 2014), so that the results can be compared. The second case is an extension of the first model, adding complexity to the simulation model, and giving a larger collection of results.

3.4.1 Simulation of rescue capacity of single field

The purpose of the model is to calculate the number of persons that can be rescued from a single field, the Apollo field, using stochastic variables such as wind data, mobilisation time, and recovery time in order to evaluate if a rescue is feasible within 120 minutes. At the initiation of the simulation, a series of events occur in a certain order, which are simulated in SimEvents. For this case, the wind data used is from the Apollo field. It is assumed that the wind conditions are constant along the route from Hammerfest. An overview of the SimEvents submodel is shown in Figure 12.

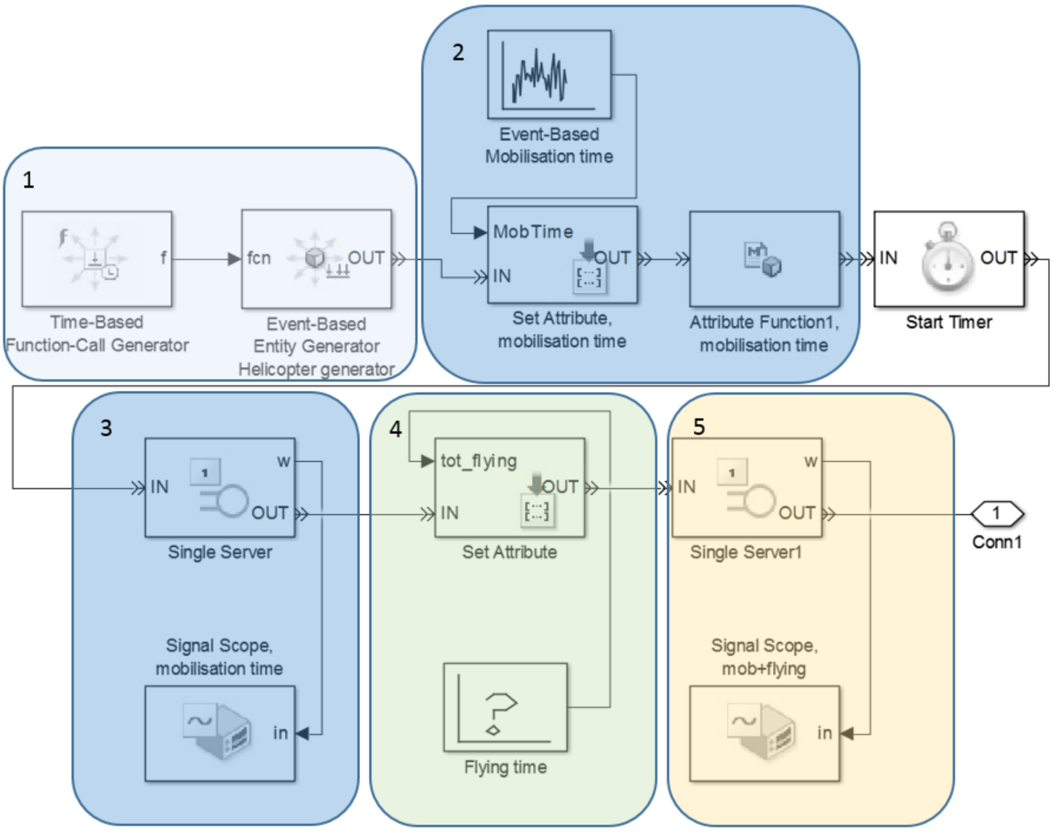


Figure 12 SimEvents submodel overview

When initiating the simulation, the model will generate a random month, and obtain a random value for the wind speed and wind direction for the same month. By inputing the wind speed and direction into the ground speed calculations, the model establishes how much the wind affects the helicopter’s travel speed.

The simulation start is triggered by the event of a helicopter ditching offshore. The model generates an entity at the simulation start, representing the helicopter. This is done in box number 1 in Figure 12.

From the instant that the helicopter crew are notified of the ditching they need between 15 and 20 minutes to mobilise the helicopter. The mobilisation time is set as an attribute to the helicopter. An attribute assigns data to the entitiy. The mobilisation time is generated using an “Event-Based Random Number” signal generator. Using a uniform distribution generates a random number between 15 and 20 minutes for every simulation run.

Further, the weather conditions on the specific day will affect the transit time to the accident site. The flying time calculated each simulation run is assigned as an attribute into the SimEvents model using an “Event-Based Sequence” signal generator, as shown in box 4 in Figure 12. The model calculates the flying time based on the effect the wind conditions will have on the transit time, see section 3.2. By creating a subsystem in SimEvents it is possible to mask parameters from the Matlab script. Using masks allows the simulation model to assign the calculated value from the script for the flying time into the simulation model. See Appendix III for further information about mask parameters. The servers in boxes 3 and 5 model the assigned attributes.

The simulation is prompted from a Matlab script. The following parameters are found:

- The course between the two points relative to north
- The distance between the base and accident site, using great circle calculations
- Random wind conditions for the simulation run and the connected month is used for the distribution of the results
- The effect of wind on the flying time

The time required to recover one person from the water will depend on the weather conditions such as wind and waves. To evaluate the variance in recovery time, the model varies the time with a normal distribution with a mean value of 3 minutes, and standard deviation of 1 minute. These values were used due to the lack of data of the effect of waves and wind on the recovery time.

Finally, to evaluate how many persons can be rescued within 120 minutes, the model finds the time it takes to arrive at the accident site, which is the sum of the mobilisation time and transit time. The signal scope block in box 5 in Figure 12, shows the time the entity has used to arrive at the accident location. This is used to evaluate the remaining time to recover personnel. An overview of the rescue operation is shown in Figure 13. As an example, if the total time it takes to arrive at the accident location is 100 minutes, there are 20 minutes left to recover personnel.

The model generates random pick-up times and establishes the number of personnel which is rescued within 120 minutes.

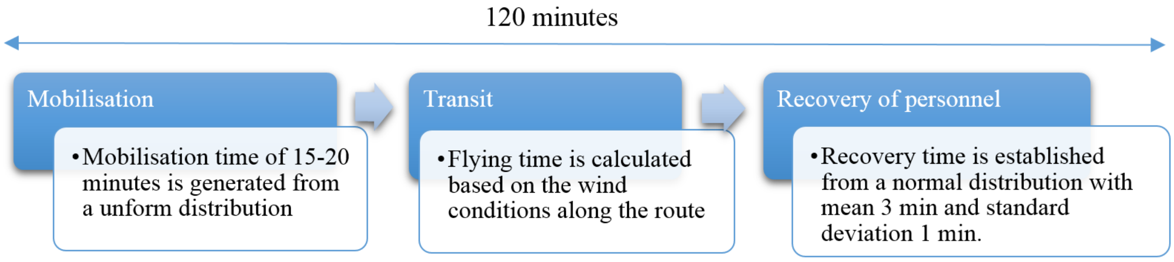


Figure 13, Overview of the rescue operation

The results from the simulation runs are plotted as a probability density function, where the number of people rescued is connected with the probability of managing to rescue that number. From this, one can evaluate the probability of rescuing a certain amount of people throughout the year, or for a specific month. The simulation is run two thousand runs to account for stochastic nature of wind conditions along the route. Checking for convergence established that two thousand runs were sufficient.

3.4.2 Simulating the Rescue Capacity for a Larger Region

To evaluate the rescue capacity in different regions of the Barents Sea, weather data from different regions is collected from the European Centre for Medium-Range Weather Forecasts (ECMRWF). The data is downloaded in a NetCDF format, which stands for Network Common Data Form. This is a binary format for storing arrays of data. The data contained u- and v-components of the wind speed 10 meters above sea level. As helicopters fly at minimum 150 meters height (Flysikkerhetsforum, 2015), the wind speed at 10 meters above sea level may not be applicable. It is however used as an approximation in this thesis.

The u-component gives the wind speed in the x-direction, and the v-component is the speed in the y-direction. To find the wind speed and direction standard vector calculus is used, see Figure 14. See Appendix II, function uwind.m for matlab code.

$$wind\ speed = \sqrt{u^2 + v^2} \tag{11}$$

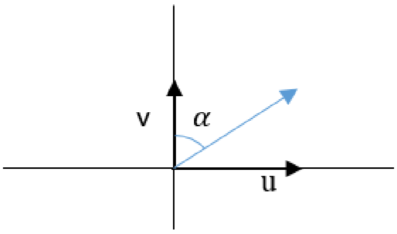


Figure 14 wind speed vector

Positive v-component indicates wind heading north while positive u-component indicates heading east. This is opposite from what is defined in Figure 11, where the wind direction in degrees indicates where the wind is blowing from. To compensate for this, 180° are added to the wind direction angle from the data set. This will then enable the wind direction to be suitable for the ground speed calculations.

Further, the weather data is divided into the areas of concern, for this case the area is divided into 16 weather “windows”. To simplify, it is assumed that the wind conditions are constant within one weather “window”. Surrounding these weather “windows” are the locations of potential offshore installtions that are considered in the case. 4 x 4 weather “windows”, results in twenty five points to evaluate.

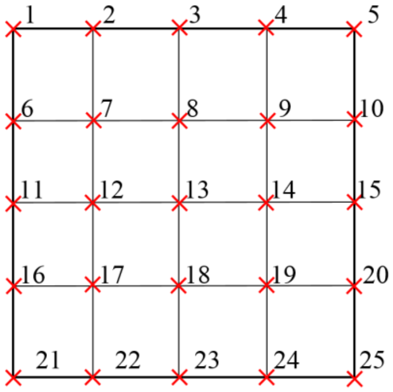


Figure 15 Grid showing the numbering of points of interest. Number 1 on the frame is area 1 etc. The 16 squares within the frame are the weather “windows”.

To obtain the distance between two points on a sphere, great circle calculations are used. Matlab has a built-in function, distance.m, which finds the distance between two points on the earth’s surface, using their coordinates. This function also establishes the course heading between the two coordinates. The course heading and distance between the base point and the point of interest are used to find the effect of the wind on the helicopter’s travel speed. When the helicopter travels through several weather “windows”, it calculates the effect of the wind based on the distance the helicopter flies through one “window” and sums up to find the total flying time.

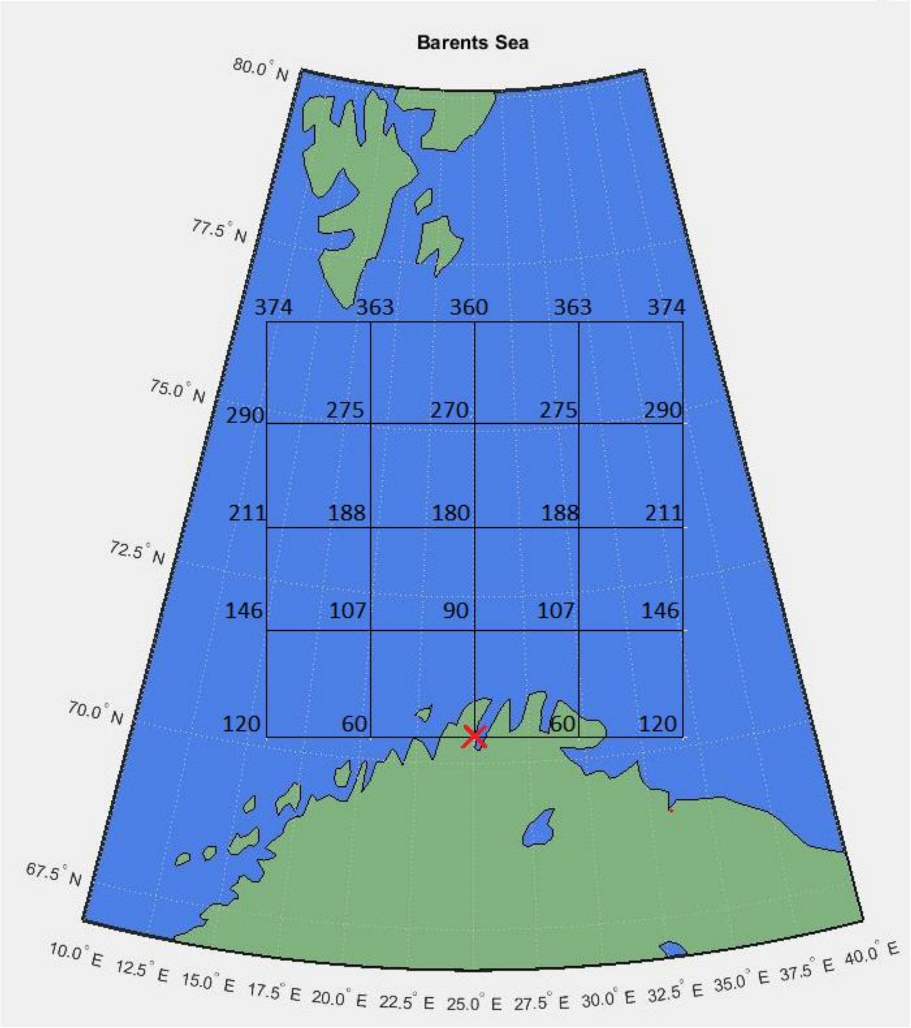


Figure 16 The distances, in nautical miles, for which the grid is scaled up to. The figure shows the approximate position of the points and is not absolute.

Figure 16 shows the distances between Hammerfest and the locations of interest. The map is only an approximation, it does not indicate exact positions of the locations, but the distance which is the main contributor in the calculations. The reason the model is built using a grid is so that it can be used for any region, as long as one implements the correct weather data from the area of interest.

As an example, in Figure 17 the point of interest is in the far North East of the grid. We can see that to get there, the helicopter travels through four weather windows on its path. To establish the length of each of these legs, and the connected ground speed over that distance, sine and cosine calculations are used. The grid is assumed to be square, the sides of the square being four units long, where one “window” is 1x1 unit large. This is then scaled to represent the actual distances evaluated, shown in Figure 16.

$$leg\ distance = \frac{1\ unit}{\sin(course\ heading)} \tag{12}$$

When the angle α to a point in the grid is known, the model finds the different leg distances to that point using sine and cosine laws. Considering Figure 17 with a known angle α , the leg 1 and leg 2 distances are easily found, then the model calculates the flying time through each leg, based on the given weather data for that area.

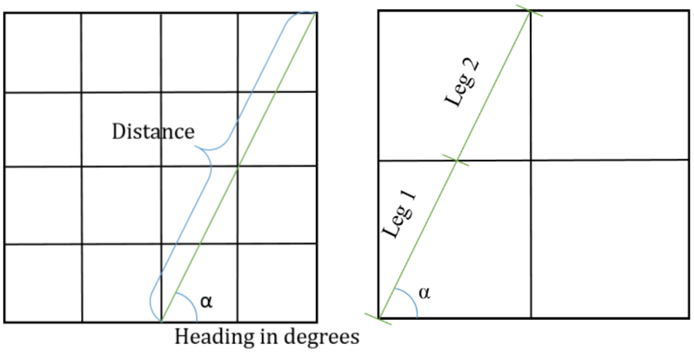


Figure 17 Grid showing distance and course angle from origin base

When the course angle is known, the model calculates the distance the helicopter travels within one weather "window". From the distance and ground speed, the model establishes the flying time. The flying time is established for each leg and summarized, to find the total flying time for a specific route. This procedure is then repeated for all the points in the grid. Matlab code for this is found is Appendix II.

$$flying\ time = \sum_{1}^{n} \frac{leg1}{groundspeed\ 1} + \frac{leg2}{groundspeed2} + \cdots + \frac{legn}{groundspeedn} \qquad (13)$$

After the model establishes the flying time, the simulation starts in SimEvents. The simulation model in SimEvents is identical as shown in Figure 12. The difference is the calculations implemented into the model. The flying time is implemented as an attribute, similar to what is described in the previous section. For one iteration of the ground speed calculations, the flying time is established for the 25 different locations, and the simulation model in SimEvents is run 25 times. This ensures that model gathers information of the rescue capacity in the Barents Sea throughout the same time measurement. One iteration of the simulation gives results of the rescue capacity of 25 locations in the Barents Sea for one specific day. The main script in the model runs 500 times and outputs a list of the number of people that are rescued in the different locations. With less wind data than for the single field, it is found sufficient to run the simulation 500 times.

The month from which the model collects weather data is random. As an example, running the simulation one iteration gives results stating that in a random day in April, it is possible rescue a certain number of people at location 1. The model runs several times, and finds the number of people that the helicopter will manage to rescue. The information is divided into monthly distributions. The model then finds the probability of a successful rescue of a defined number of persons. Matlab code is found in Appendix II.

3.4.2.1 Interpolation between points in the grid

For each simulation run, the model calculates the probability of managing to rescue a certain number of persons from the water within the time requirement. The model only gives the probability at the exact point of the grid intersection, and to evaluate the range of probabilities, interpolation is used. To find the probability between the two points, the following equation is used:

$$y = y_0 + (y_1 - y_0)\frac{(x-x_0)}{(x_1-x_0)} \tag{14}$$

Where x_0 and x_1 are the known probabilities of the two points, and y_0 and y_1 are the known positions in the vertical direction of the grid. The positions of y in the grid is calculated using certain x-values. From this, the iso-lines of the different probabilities are established. The y-values are calculated using the following x-values: [0.9, 0.6, 0.3, 0], see Appendix IV for interpolation plot. The plot was adjusted to fit the grid, and a drawing program was used to visualize the results on a map of the Barents Sea.

4 Results

This chapter includes the results from the two cases simulated in this thesis, in addition to results from deterministic calculations of a larger area of the Barents Sea. The deterministic results included will be used for comparison.

The results from the simulation model are found in sections 4.1-4.3. For the single field, located 200 nautical miles from Hammerfest, the results include distributions of the number of people that the helicopter manages to rescue within 120 minutes presented as density functions. For the larger area of the Barents Sea, the results include the probability of successfully rescuing different numbers of people.

The results are presented in this chapter, and are further discussed in Chapter 5.

4.1 Rescue from a single field

The distribution in Figure 18 shows the probability of successfully rescuing a specific number of persons from the water at a single field in the Barents Sea, namely the Apollo field. The distribution includes weather data from all year round.

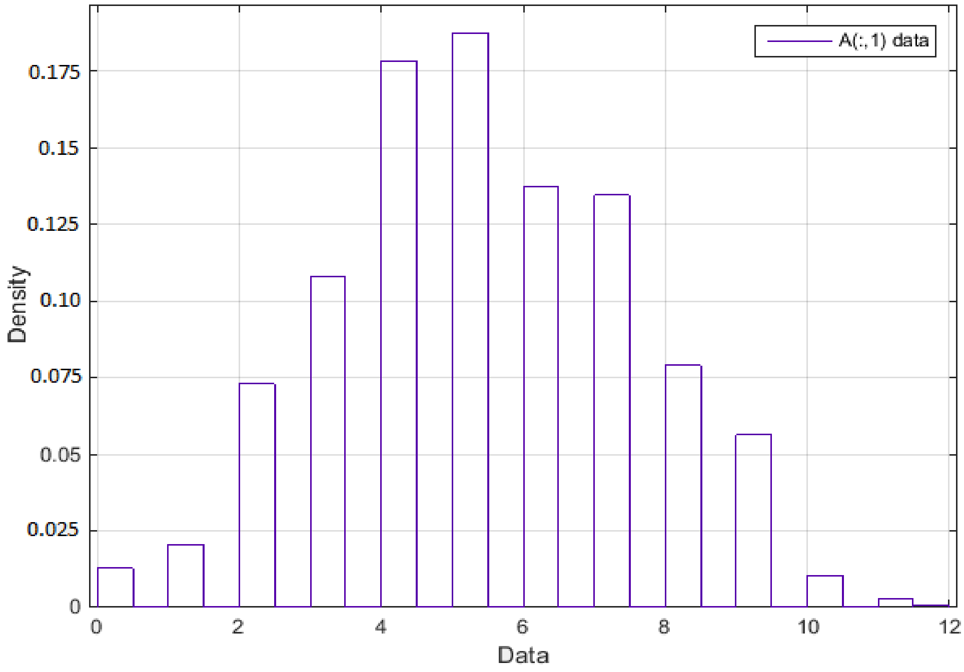


Figure 18 Probability distribution of number of persons successfully rescued

The results in Figure 18 can be fitted using a normal distribution, with a mean value μ =5.18 and standard deviation σ =2.13.

The probability of rescuing at least e.g. six persons is:

$$P(X \geq 6) = \sum_{i=6}^{n} P(X = i) \tag{15}$$

$$P(X \geq 6) = 0.41$$

The monthly rescue distributions show the probability of successfully rescuing people for the specific month. Figure 19 shows the probability functions of the months January, April, July, and October. These months are chosen to represent different seasonal conditions.

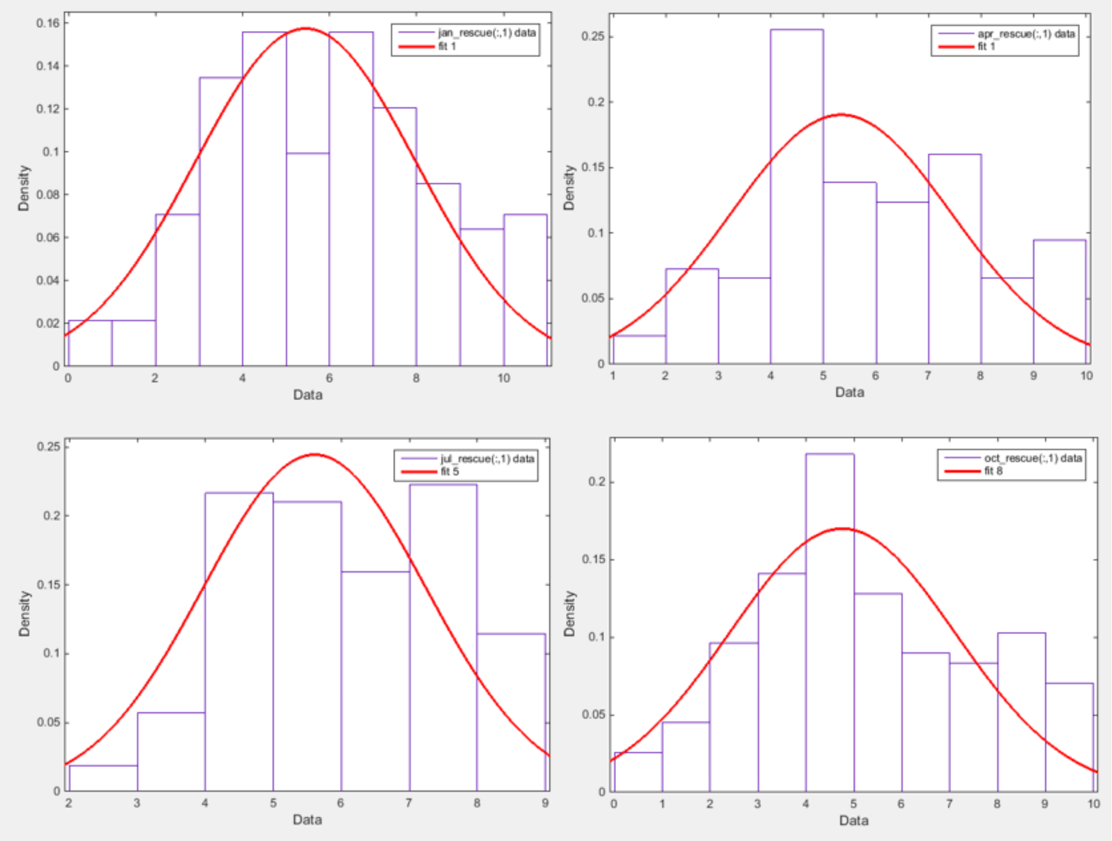


Figure 19 Rescue capacity at Apollo field in January, April, July, and October

Table 2 Mean of number of rescued and the probability of successfully rescuing at least six persons

Month	Mean number of rescued [persons]	Probability of rescuing at least six
January	5.44	0.49
April	5.34	0.44
July	5.6	0.49
October	4.75	0.35

4.2 Deterministic rescue capacity in larger region in the Barents Sea

Figure 20 shows the number of successfully recovered persons at twenty-five different locations in the Barents Sea, ranging from 60 to 375 nautical miles from Hammerfest. The rescue capacity showed in Figure 20 does not consider the weather conditions' effect on the flying time. In other words, it assumes a "wind free" environment. This calculation is performed to give an indication of what can be expected from the simulation model, and the results are used for comparison.

The different numbers on the map determine the number of persons that is successfully rescued within 120 minutes. Distance from the marked points in nautical miles from the Hammerfest base is seen in Figure 16.

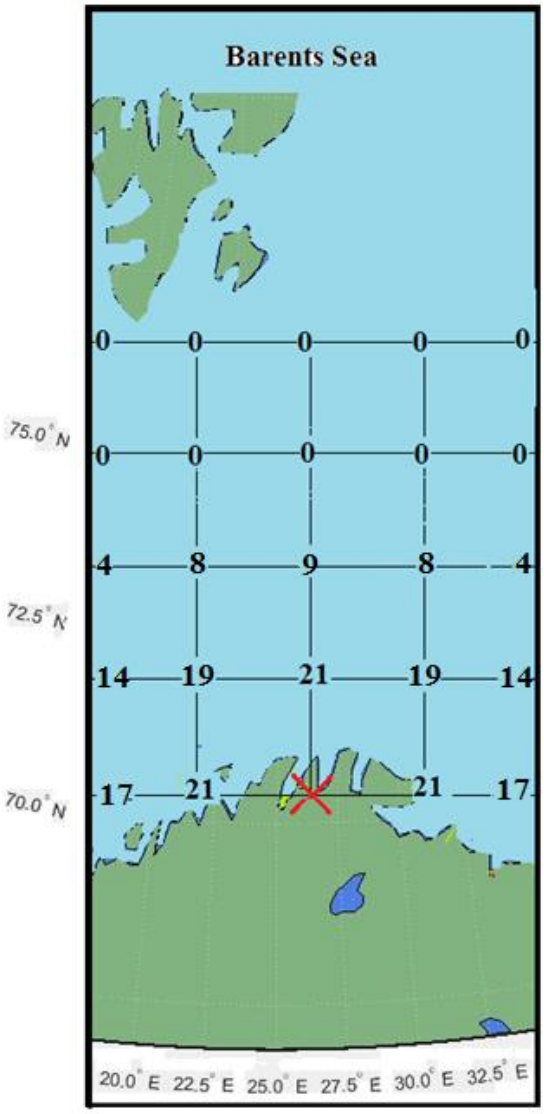


Figure 20 Deterministic rescue capacity in the Barents Sea region, with the connected distances showed in Figure 16

4.3 Results of the rescue capacity in a larger region of the Barents Sea

To evaluate the effect of weather on the helicopter in transit to an accident site, the model implements weather data for multiple locations in the Barents Sea. Weather data is collected from 16 areas, and the effect of the weather along the route is calculated. The model considers the changing wind conditions along the route and calculates the total flying time.

The following sections include the probability of successfully rescuing at least 1, 5, 15, and 21 persons for the Barents Sea region. The reason for presenting the results for exactly 1, 5, 15, and 21 persons is to evaluate the change in results from minimum one passenger to the maximum of 21 passengers.

Tables including the rescue probability from the model and the results of the deterministic calculations are included in the follwing sections. The probabilities found in these tables are the exact result from the simulation model. The results of the deterministic calculations are included for comparison. The tables are included to give additional information about the results shown in Figure 22, Figure 23, Figure 25, and Figure 27. The number of persons found possible to rescue in the deterministic calculations in section 4.2 is included in the tables for comparison.

The results from the simulation model are presented in the following sections and are further discussed in section 5.1.2.

4.3.1 Probability of rescuing at least one person

The probability of successfully rescuing at least one person for the examined area in the Barents Sea is shown in Figure 22, for four different months. Figure 22 shows different probability regions for the area. We can see that the probability of a successful rescue decreases with increasing distance from the base – as expected. The green area in each of the illustrations indicates that rescuing one person within this area is possible for 90-100 % of the simulation runs. For the most northern points there are 0 % probability to manage a rescue of one person within the time limit.

Probabilities of rescuing at least one person are calculated using the simulation model and compared to deterministically calculated values for the same points in the grid, shown in Figure 21. Comparison of simulated and deterministic results is shown in Table 3.

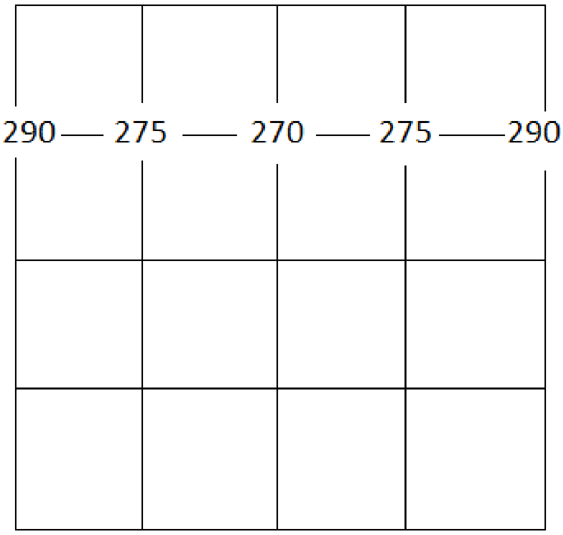
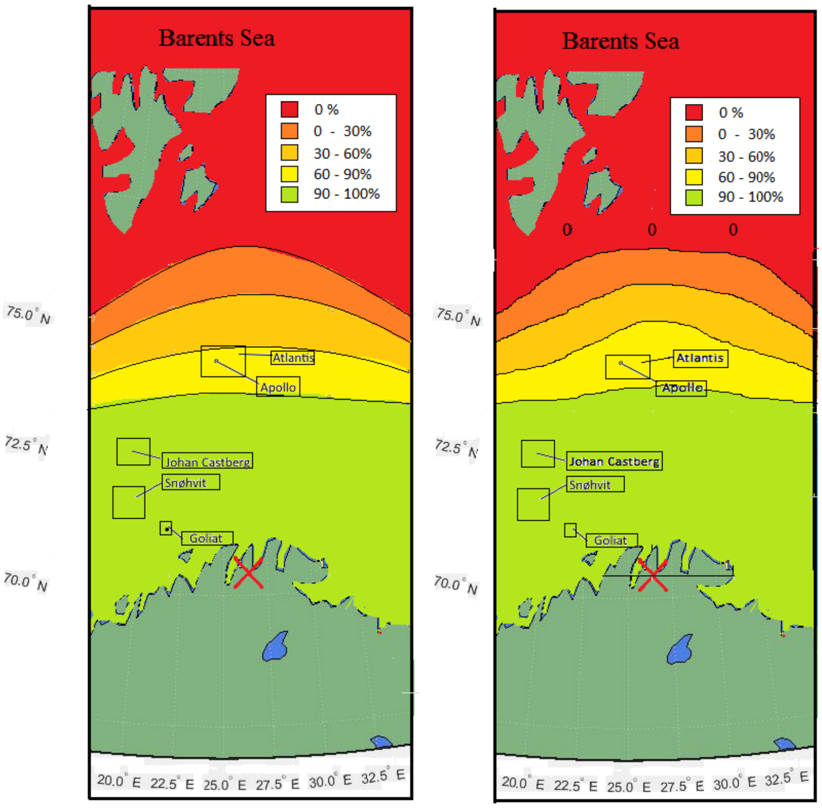


Figure 21 Distance from Hammerfest to points in the grid where the probability is found to be between 0.01 and 0.89.

Table 3 Probability of successfully rescuing one person in different months

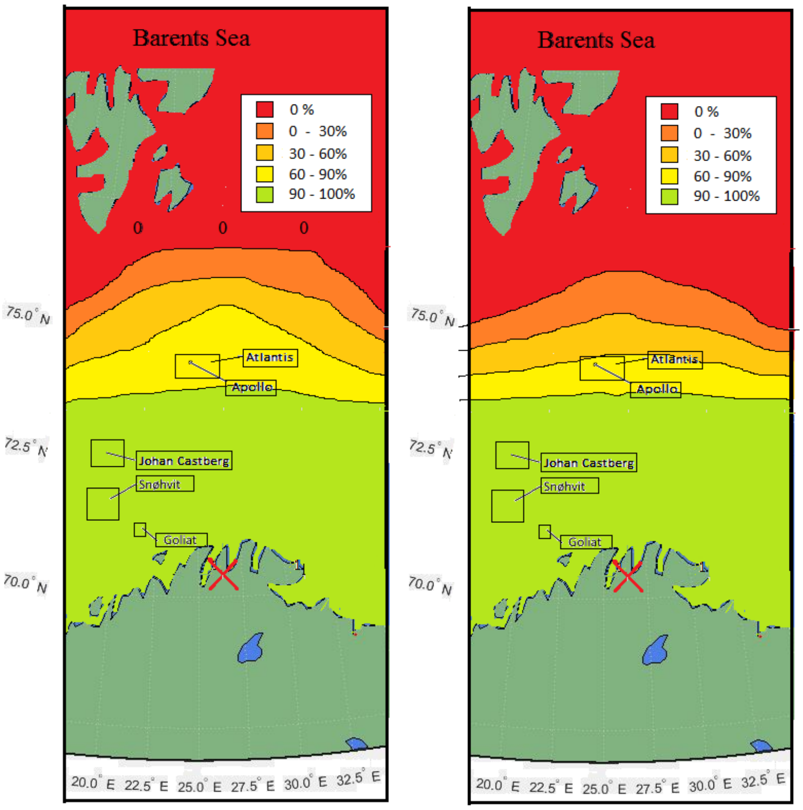
Distance	January	April	July	October	Deterministic
290 nm	0.11	0.08	0.11	0.03	0 persons
275 nm	0.44	0.44	0.52	0.03	0 persons
270 nm	0.51	0.66	0.69	0.43	0 persons
275 nm	0.42	0.48	0.49	0.33	0 persons
290 nm	0.12	0.08	0.08	0.02	0 persons

The results of the deterministic calculations from Section 4.2, Figure 20, established that it is not possible to rescue any persons at this distance, shown in the deterministic column in Table 3. The simulation results show that there is a certain probability to rescue at least one person at each of these points.



Probability of rescuing at least 1 person, January

Probability of rescuing at least 1 person, April



Probability of rescuing at least 1, July

Probability of rescuing at least 1, October

Figure 22 Probability of managing to rescue at least one person within the time requirement of 120 minutes.

4.3.2 Probability of rescuing at least five persons

Probability of successfully rescuing at least five persons for the examined area in the Barents Sea is shown in Figure 23. Due to results being equal for the four seasonal months, only one illustration is shown. The green area in the illustration indicates that rescuing five persons within this area is possible for 90-100 % of the simulation runs. For the most northern points there is a 0 % probability to manage a rescue of five persons within the time limit.

Probabilities of rescuing at least five persons are calculated using the simulation model and compared to deterministically calculated values for the same points in the grid, shown in Figure 21. Comparison of simulated and deterministic results is shown in Table 4.

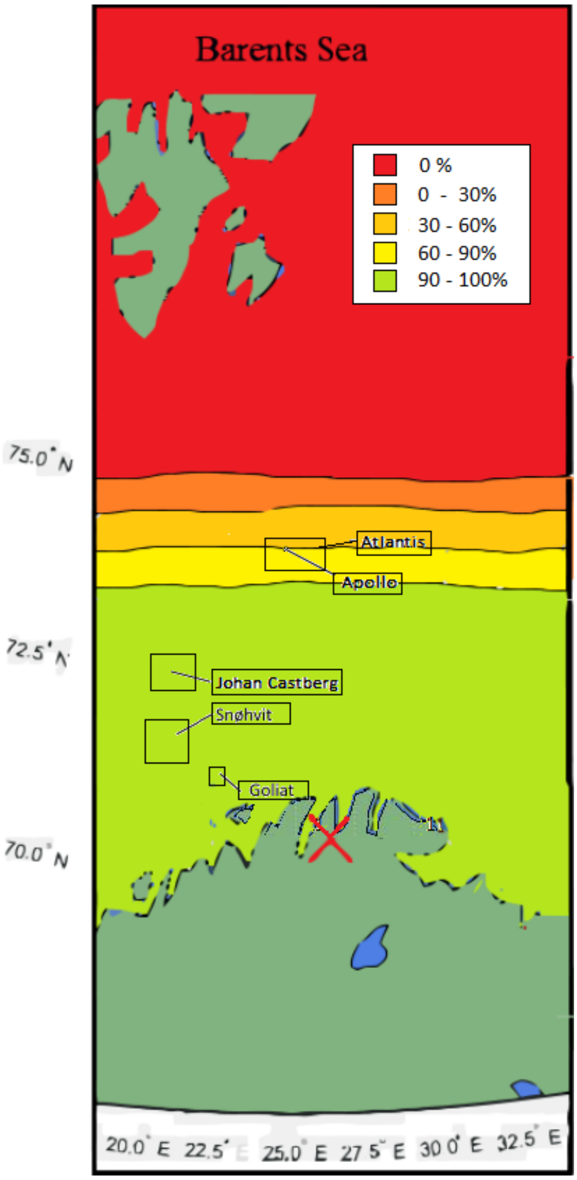


Figure 23 Probability of rescuing at least five persons all year

Table 4 Probability of successfully rescuing at least five persons for different distances

Distance	January	April	July	October	Deterministic
290 nm	0	0	0	0	0 persons
275 nm	0	0	0	0	0 persons
270 nm	0.0026	0.027	0	0	0 persons
275 nm	0	0.027	0	0	0 persons
290 nm	0	0	0	0	0 persons

The results of the deterministic calculations from Section 4.2, Figure 20, established that it is not possible to rescue any persons at this distance, shown in the deterministic column in Table 4. The simulation results show that there is close to zero probability of rescuing minimum five persons at each of these points.

4.3.3 Probability of rescuing at least 15 persons

The probability of successfully rescuing at least 15 persons for the examined area in the Barents Sea is shown in Figure 25, for four different months. The green area in the figures indicates that rescuing 15 persons within this area is possible for 90-100 % of the simulation runs. For the most northern points there are 0 % probability to manage a rescue of 15 persons within the time limit. The red area, indicating 0 % probability of rescuing at least 15, has increased in size compared to Figure 22 and Figure 23.

Probabilities of rescuing at least 15 persons are calculated using the simulation model and compared to deterministically calculated values for the same points in the grid, shown in Figure 24. Comparison of simulated and deterministic results is shown in Table 5.

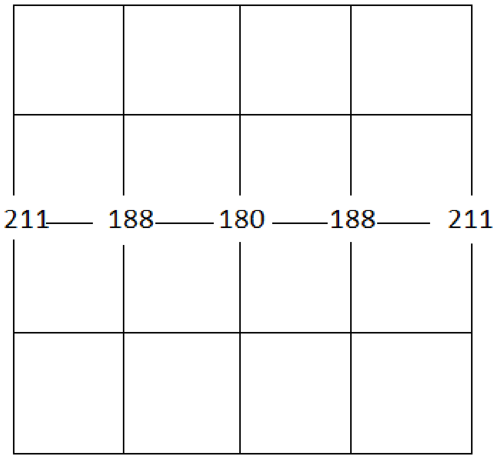
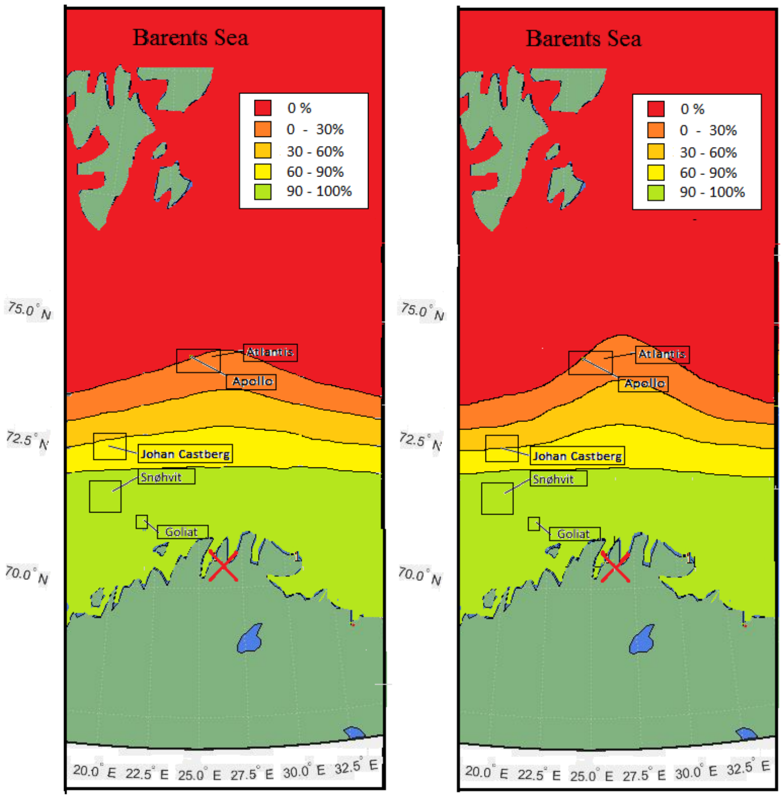


Figure 24 Distance from Hammerfest to points where the probability is found for rescuing at least 15 persons

Table 5 The probability of successfully rescuing 15 persons, including the number calculated deterministically

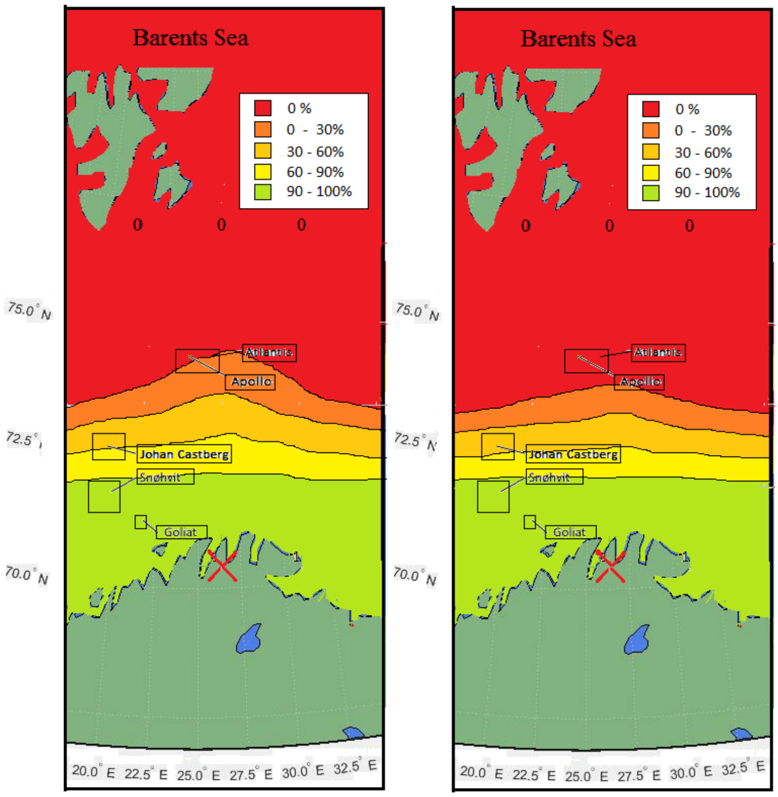
Distance	January	April	July	October	Deterministic
211 nm	0	0.003	0	0	4 persons
188 nm	0.19	0.19	0.21	0.14	8 persons
180 nm	0.34	0.47	0.42	0.27	9 persons
188 nm	0.17	0.21	0.16	0.10	8 persons
211 nm	0	0	0	0	4 persons

The results of the deterministic calculations from Section 4.2, Figure 20, established that it is possible to rescue between four and nine persons at this distance, shown in the deterministic column in Table 5, while simulation results show that there is a certain probability to rescue at least 15 persons at each of these points.



Probability of rescuing at least 15 persons, January

Probability of rescuing at least 15, April



Probability of rescuing at least 15, July

Probability of rescuing at least 15, October

Figure 25 The probability of managing to rescue 15 persons within the time requirement of 120 minutes.

4.3.4 Probability of rescuing at least 21 persons

The probability of successfully rescuing at least 21 persons for the examined area in the Barents Sea is shown in Figure 27, for four different months. The green area in the illustrations indicates that rescuing 21 persons within this area is possible for 90-100 % of the simulation runs. For the most northern points there are 0 % probability to manage a rescue of 21 persons within the time limit. The red area, indicating 0 % probability of rescuing at least 21 persons, has increased in size compared to Figure 25.

Probabilities of rescuing at least 21 person are calculated using the simulation model and compared to deterministically calculated values for the same points in the grid, shown in Figure 26. Comparison of simulated and deterministic results is shown in Table 6.

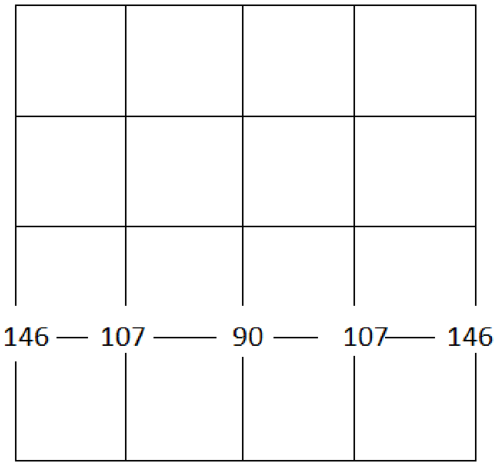
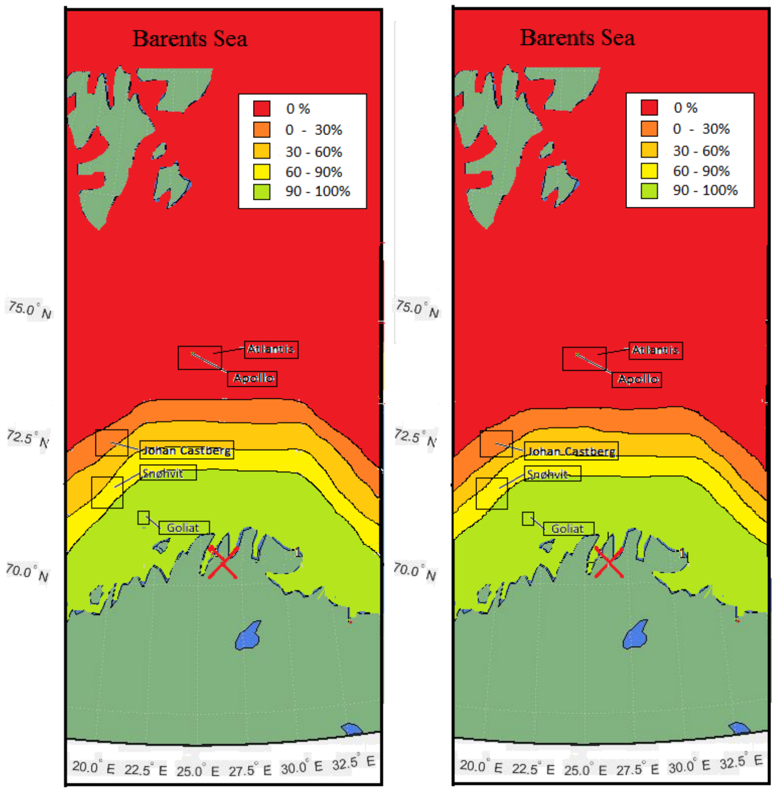


Figure 26 Distance from Hammerfest to points where the probability is found for rescuing at least 21 persons

Table 6 Probability of successfully rescuing 21 persons, including the number calculated deterministically

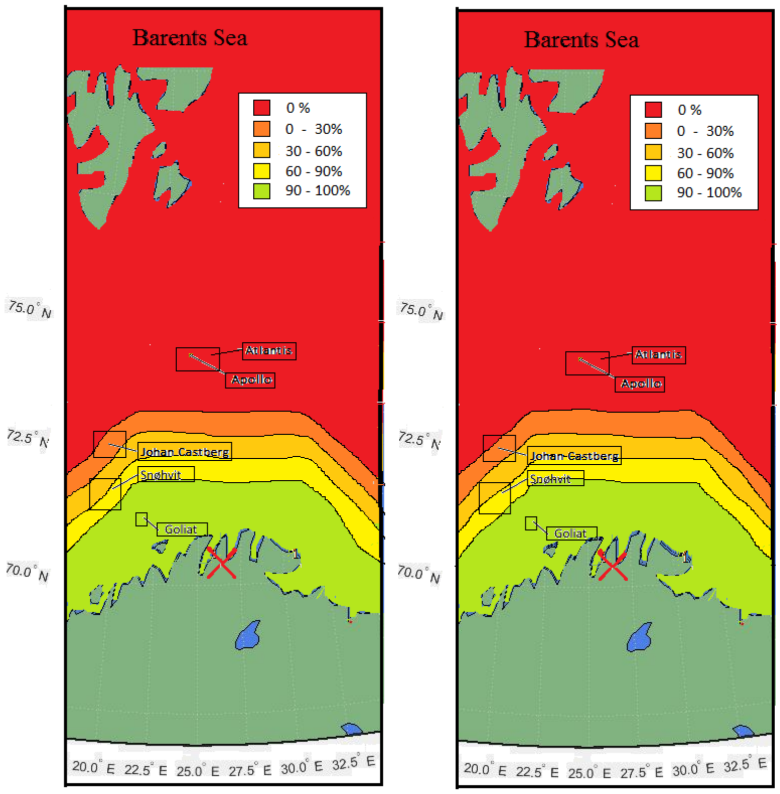
Distance	January	April	July	October	Deterministic
146 nm	0.31	0.18	0.06	0.15	14 persons
107 nm	1	1	1	1	19 persons
90 nm	1	1	1	1	21 persons
107 nm	1	1	1	1	19 persons
146 nm	0.14	0.03	0.008	0.03	14 persons

The results of the deterministic calculations from Section 4.2, Figure 20, established that it is possible to rescue between 14 and 21 persons at this distance, shown in the deterministic column in Table 6 while simulation results show that there is a certain probability to rescue at least 21 persons at each of these points.



Probability of rescuing at least 21, January

Probability of rescuing at least 21, April



Probability of rescuing at least 21, July

Probability of rescuuing at least 21, October

Figure 27 Probability of managing to rescue 21 persons within the time requirement of 120 minutes.

5 Discussion

In this chapter, the main results of the thesis are discussed. In addition, the simulation model is evaluated. The existing regulations are evaluated, and additional recommendations are suggested.

5.1 Evaluation of the results

In the following sections, the results from the simulation model are evaluated and discussed. Figures from the results can be found in Chapter 4.

5.1.1 The results of a single field in the Barents Sea

The previous study, presented in Section 2.5, identified that it was possible to recover six persons from the sea at a location 200 nm from the onshore base in Hammerfest.

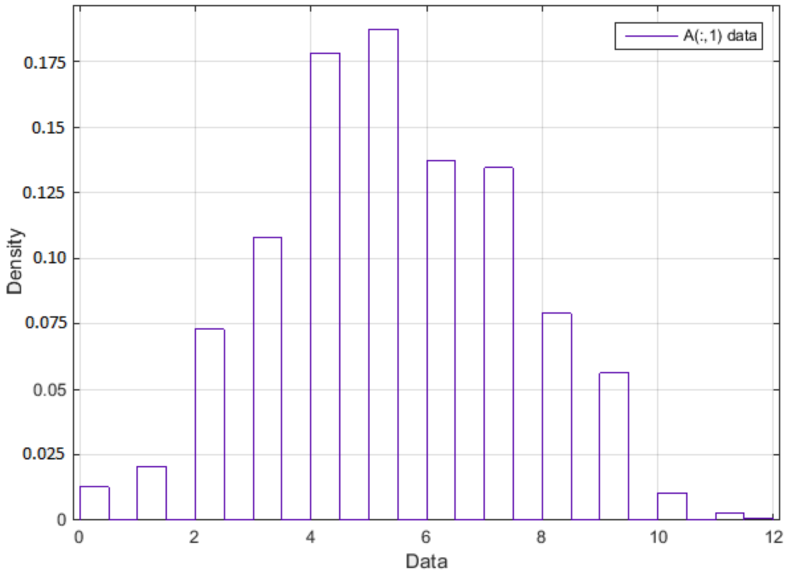


Figure 28 distribution of the number of rescued persons, implementing weather data for all 12 months.

The results, presented in section 4.1, show that the number of rescued people vary from 0 persons, up to 11 persons maximum. Managing to rescue five persons has the highest number of occurrence at 18.7 %. The results from the previous study found that the helicopter could rescue six persons if the weather conditions were disregarded. The results from the simulation show that the number of persons rescued will vary with the wind speed and direction. Seen in Figure 28 is the distribution of the number of persons rescued through a year.

The model calculates the effect of the wind speed and direction on the helicopter operations. The result shows that the mean value is five persons, which occurs 18 % of the simulation runs. In section 4.1, the probability of managing to rescue at least six persons was established at 41 %. This leaves 40.3 % probability that it is possible to rescue four persons or less. This indicates that the probability of rescuing more than five and less than five is equal.

The wind effect will either give additional or decreased flying time based on the wind direction relative to the helicopters course heading. In this case, where the location is fixed, the helicopters course heading will remain the same. The result, therefore, show that there is no trend in the wind direction.

The mobilisation time in the simulation model varies between 15 and 20 minutes, while in the previous study from Section 2.5, the value was fixed at 15 minutes. This could be one reason for the highest occurrence of rescuing five, and not six as calculated deterministically.

Figure 19 shows the probability distribution for the months January, April, July, and October, which accounts for the seasonal variation throughout the year. Table 2 shows the probability of successfully rescuing minimum six persons in the same months. The results indicate little difference between the seasonal wind conditions.

However, since the effect of the weather is a combination of the wind speed and its direction, high wind speed at a high angle relative to the helicopter can have the same effect as lower values with a more head on direction. It will, therefore, be difficult from these results to establish any trend of higher wind speeds during the winter months compared to the summer months. The average wind speed from the simulation model and the connected average number of rescued persons are listed in Table 7. For distributions see Appendix I – Wind data of a single field, from four months.

Table 7 The mean number of rescued at a single field, and the connected mean wind speed.

Month	Mean number of rescued [persons]	Mean wind wpeed [knots]
January	5.44	19.3
April	5.34	15.85
July	5.6	11.49
October	4.75	17.4

The average wind speed is higher during January and October, compared to April and June. However, the average numbers of rescued persons do not vary accordingly. This could indicate that the wind direction during the summer months give more resistance than the wind during winter months.

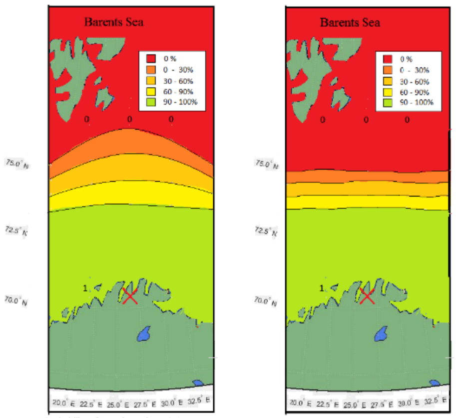
Calculations of the wind effect are obtained from general vector calculations, but how much the waves will affect the operations is more uncertain. The Civil Aviation Authority (Authority, 1995a) evaluated the limitations of surface conditions for retrieval of persons from the water, including the sea-state. It is conducted that SAR helicopters are generally capable of performing rescue operations in any weather conditions, except surface fog.

5.1.2 The results of rescue capacity of a larger region of the Barents Sea

In section 4.3, the probability of successfully rescuing minimum 1, 5, 15, and 21 persons from the sea within 120 minutes is evaluated for different locations in the Barents Sea.

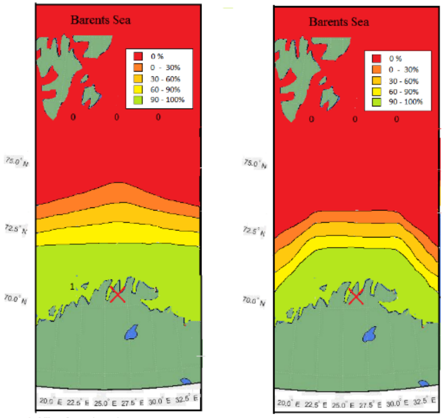
Figure 29 below shows that the distance is the deciding factor for the rescue capacity. It is noticeable that the probability of a complete rescue of at least five persons is less than the probability of managing to rescue at least one. The results show that the locations with the largest distance from Hammerfest have a zero percent probability to manage rescuing minimum one person. This means that it is not manageable to complete a rescue in these locations using the base in Hammerfest. When the number of people requiring rescue increases, the green area with 90-100 % probability decreases towards the shoreline.

The probability of successfully managing to rescue a certain amount of people is evaluated. When a high number of rescue capacity is evaluated, the green zone indicating 90-100 % probability decreases. At the same time, the red area, representing 0 % rescue probability, increases. This indicates that it is only possible to rescue a full helicopter close to shore, and when the distance increases, the number of rescued decreases.



Probability of rescuing at least 1, January

Probability of rescuing at least 5, January



Probability of rescuing at least 15 persons, January

Probability of rescuing at least 21, January

Figure 29 Probability of rescuing 1, 5, 15, and 21 persons within 120 minutes, in January

The iso-lines, representing the different probabilities of successful rescue operations, are established using interpolation. These iso-lines might have been different if the grid had additional points and weather windows. This would give more data points, and would give results that were more exact. The results in Section 4.3 still give a valid indication of the probability of a successful rescue operation throughout the Barents Sea.

The results of the deterministic calculations, which disregards the weather conditions, are slightly more conservative compared to the results from the simulation model, see Figure 20. The figure includes the grid points from where the data points are approximately collected.

Section 4.3 includes Table 3 to Table 6, which present the probability, in decimals, of successfully rescuing 1, 5, 15, and 21 persons. The tables also include the result of the deterministic calculations at the same locations. These tables give the results from the simulation model a context. Table 3 shows that the deterministic calculations found it impossible to rescue anyone at this distance. The results from simulation model, on the other hand, show that the probability of rescuing minimum one person range between 0 and 70 % at the different locations. The results are close to equal for all the evaluated months. Since the deterministic calculations revealed that no one could be rescued at these locations, the results from the simulation model indicate beneficial tailwind.

The probability of successfully rescuing at least five persons is shown in Table 4. The result from the deterministic calculations show that it is not possible to rescue any persons at this location. The result from the simulation indicate very low to no probability of rescuing a minimum of five persons for all the evaluated months. From the results, one does not know how often it is possible to rescue more than one and less than five persons. Based on the results from the deterministic calclations stating that it is not possible to rescue anyone at this location, one can deduce that to manage a rescue at this position tailwind is required.

Table 5 includes the probability of successfully rescuing minimum 15 persons from the sea within 120 minutes. The probability of succeeding ranges from 0 to 47 %. With little variance in the evaluated months. The results of the deterministic calculations range from 4 to 9 persons rescued at the connected distances. Since the results of the deterministic calculations are lower than the number from the model, it demonstrates that the percentages in Table 5 represent the percentage of the time with tailwind.

The probability of rescuing minimum 21 persons at certain distances from Hammerfest is shown in Table 6. The number of persons found possible to rescue in the deterministic calculations ranges from 14 to 21 persons. The two distances furthest away from Hammerfest has a probability ranging between 0 and 30 %. This indicates the same as in Table 3, Table 4, and Table 5, that part of the time tailwind is present and that there is little variance in the monthly results.

However, in Table 6, for some of the distances the simulation model established that 100 % of the time it would be possible to recover 21 persons. The deterministic result found that it was possible to rescue 19 persons at this location. It was expected that the simulated probability of successfully rescuing 21 persons at this location would have been lower. 100 % probability indicates that for all simulation runs, the model found that it was possible to rescue 21 persons. This indicates that there might be an error in the model. However, when checking the model, no reason for this error could be found.

Considering the different months, there is little difference between the probability of a succesful rescue. Indicating that the effect of wind conditions is similar in the evaluated months.

5.2 Evaluation of the simulation model

The results in this thesis are dependent on the development of the simulation model as well as the input values used. This section covers the uncertainties regarding the simulation model and its limitations. This will then give an indication of the reliability of the results.

5.2.1 Model limitations

The simulation model includes several simplifications and assumptions. Some simplifications are made regarding the wind conditions and its effect on the helicopter’s flying time. The wind data used is measured at 10 meters above sea level. This will not be accurate for the wind speed that the helicopter travels through. Still, it is used in this thesis to give an idea of what can be expected if the wind speed at helicopter height is similar to what is measured 10 m above sea level. The weather data for the larger area of the Barents Sea is a limited collection of the three years from 2012 to 2014. This might affect the results.

When the model considers the rescue capacity at the single field, it assumes that the wind conditions along the route are constant and equal to the observed wind at the field. The same yields when considering the 16 different weather “windows”: the model assumes that the wind is constant within each “window”.

As it proved difficult to obtain valid data on the effect of waves on the rescue operation, the model assumes that the recovery time has a normal distribution. It is assumed a mean value of 3 minutes and standard deviation of 1 minute.

When running this simulation, what is of interest is the number of people that is managed rescued within 120 minutes. Having this, the return trip is not considered in the case studies. If one assumes the same weather data for the return leg, the wind will have the opposite effect of what it had getting there.

When calculating the distance of each leg within different weather “windows”, standard sine laws were used. Since the earth is a sphere, and not flat, great circle distance calculations should have been used, but for simplification it was not. Since the legs are shorter distances, the effect of this is neglected.

5.2.2 Generic modelling

The model is meant to be generic, meaning that it can be used to evaluate the response time at any given field of interest, given that the appropriate weather data from that area is implemented. Simulating the response time in random wind conditions gives information of the situation in previously observed weather.

5.3 Evaluation of existing regulations

Most of the existing regulations and guidelines that exist in the oil and gas industry were adopted after major accidents, where gaps in earlier regulations were identified. When exploring fragile areas such as the Arctic and other remote areas, it is desirable to have preventive regulations to minimize the risk of hazardous scenarios. In the case of a helicopter ditching in a remote area, which is studied in this thesis, it would be beneficial that certain emergency response regulations are in place before commencing exploration in these areas. It is suggested that the regulation or guideline should state that the number of passengers on board a transportation helicopter does not exceed the number of what can be successfully recovered at the planned destination. This approach is used by Statoil (Nina Skjegstad, 2015, Pers. Comm., 23. March). However, when the distance increases, the number of people of which one can manage to rescue decreases. Looking at the results of the single field of Apollo, a Statoil operated field, the probability of rescuing at least six persons from the water within the time requirement is approximately 40 %. With today’s standard of helicopters, and the air speed that they can maintain, it would not be possible to transport more than five persons at the time to the field. This will not be very cost efficient, and another reason to consider other options for search and rescue in this area.

The Transport Safety Board of Canada (2010) recommended prohibiting transport helicopter operations over water when the weather conditions would not allow for safe ditching, or successful evacuation and rescue. A report from the United Kingdom HSE Authority (1995b) states the importance of considering the water surface conditions along the route and not just at its ends. The report argues that improved methods should ensure that survivors of a helicopter ditching can have reasonable expectations of being picked up alive. There is generally a clear drive for not performing offshore activity when there are not sufficient evacuation and rescue systems in place. Nor when there is no reasonable expectation of being rescued alive (Jacobsen et al., 2012). Based on the results of the simulation, the distance is the main challenge regarding if it is possible to rescue all 21 persons within the time requirement. A suggestion to ensure that one can rescue all the persons on board the helicopter could be to not commence transportation with a higher number passengers than what is found possible to recover within the time limit.

The Norwegian Oil and Gas Association (2012) have suggested in their requirements for area based preparedness, that 3 minutes per person shall be used as the standard time it takes to recover one person from the water on average. In low visibility, high sea states, and bad weather conditions this retrieval time may vary. There are not many studies performed on pick-up rates in deteriorating weather conditions (Peter Schütz, 2015, Pers. Comm., 29. January). Further investigation into this should be evaluated.

6 Conclusions and further work

The wind will affect the helicopter operations. When simulating for a single field located 200 nautical miles from Hammerfest, the results varied between zero and eleven rescued within 120 minutes. This shows that depending on wind direction, the number of rescued will vary. On the other hand, there is no clear difference in the results from the different months. To conclude, the wind will affect helicopter operations, but it does not matter in which month the rescue is performed.

For the larger area of the Barents Sea, the results show that the weather will affect the rescue operations. The results also show that the distance is the main factor for establishing how many can be rescued from a location. The variation in mobilisation time and recovery time gives small differences in the results. The results also show that there is little variation in the results based on which month the simulation runs in. The probability of a successful rescue is close to equal for the different months.

Based on the results of this thesis, it is suggested that weather observations are used to find the maximum number of personnel to transport in the transportation helicopters. The maximum number being the number of persons that you can rescue within 120 minutes, in the given wind conditions.

To further develop the complexity of the model, the mentioned limitations of the model should be considered and improved. To improve the validation of the wind data, one could use DNV calculations mentioned in “Environmental conditions and environmental loads”. The calculations can assess the appropriate wind speed at actual helicopter height, instead of at 10 meters above sea level. This would give more realistic results of the effect of the wind on operations. It would be interesting to include several stochastic parameters into the model. Visibility and wave data will most likely affect the rescue operations, and it would be of interest to implement these. The results would be then more robust, considering additional factors.

In addition, it would be of interest to consider a grid with finer mesh, with additional weather windows along the route. This could then give a more exact indication of the effect of weather along the route.

With small adjustments and implementation of weather data, the model can be used to assess the helicopter emergency response capacity in other remote areas.

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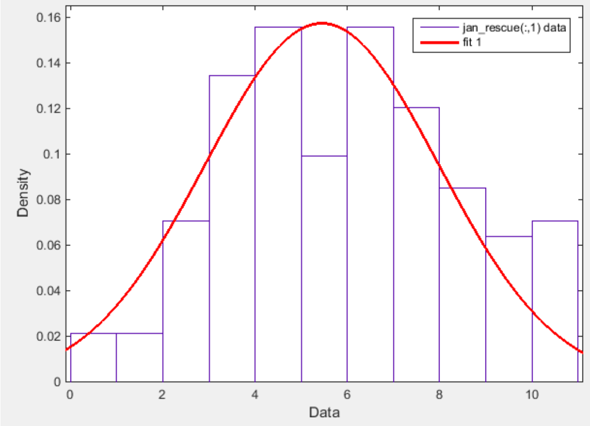
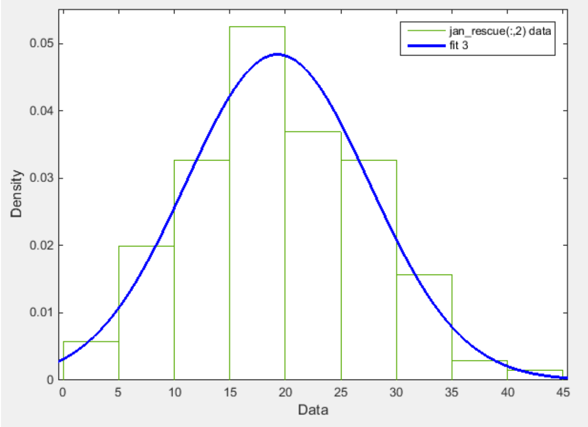
8 Appendices

Appendix I – Wind data of a single field, from four months

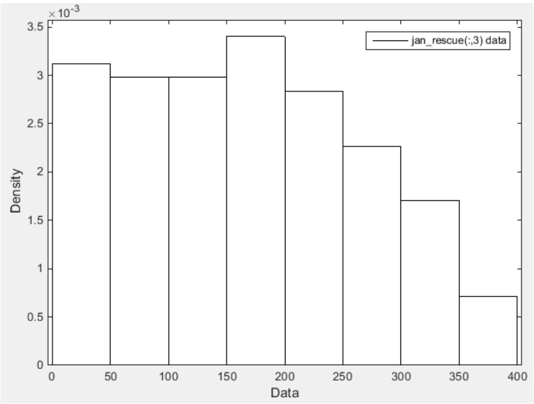
Data from January:



January, simulated number of rescued, mean 5.44

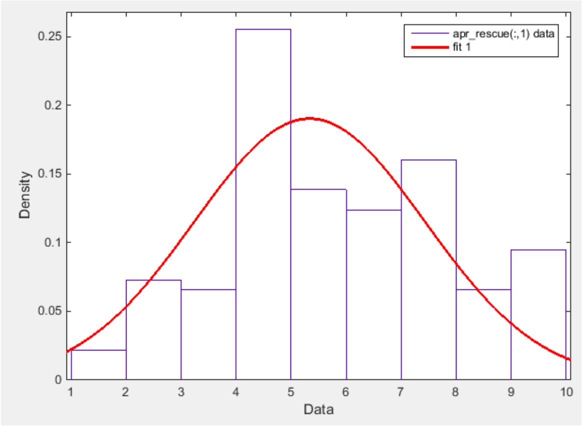


January, wind speed, mean 19.3 knots

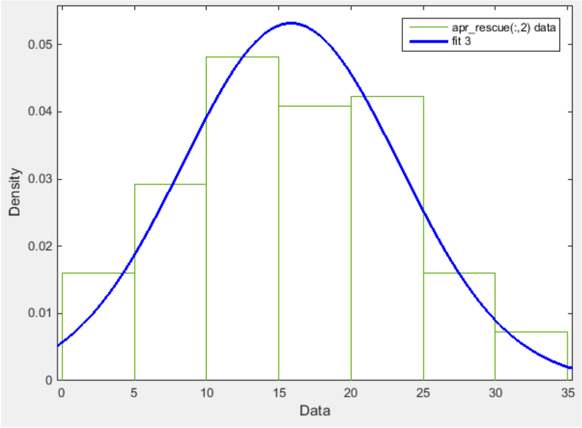


January, wind direction

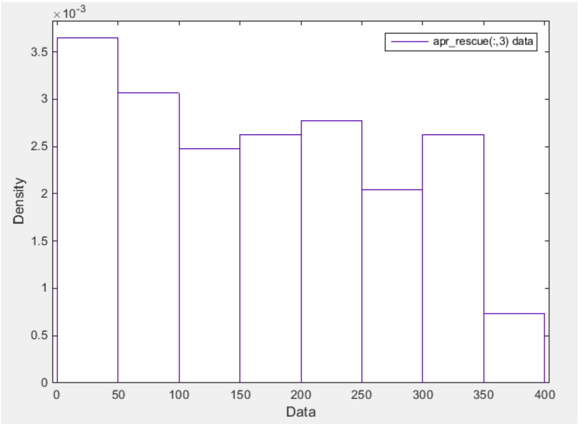
Data from April:



April, simulated number of rescued, mean: 5.34 persons

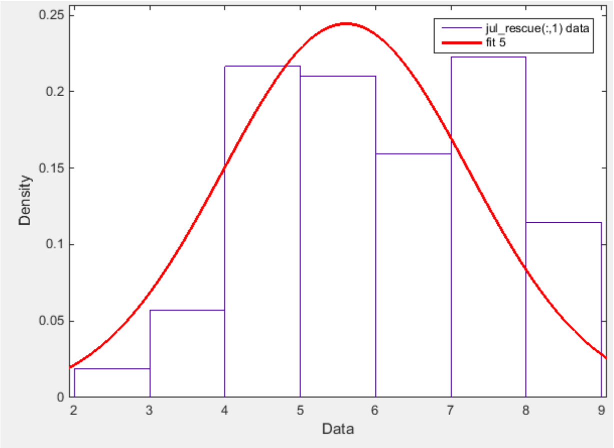


April, wind speed, mean: 15.85knots

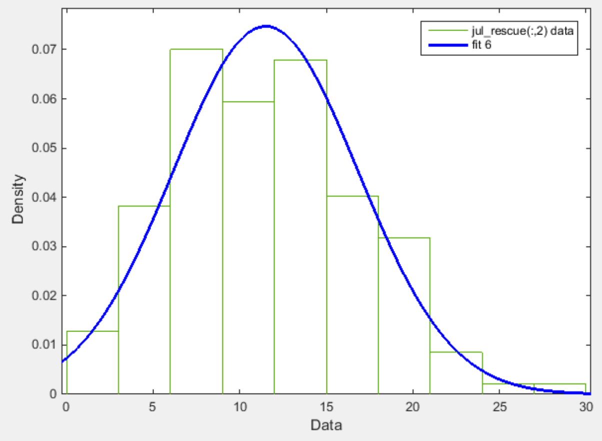


April, wind direction

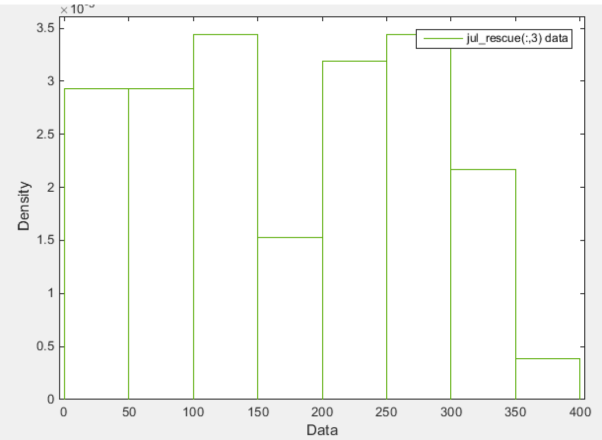
Data from July:



July, simulated number of rescued, mean: 5.6 person

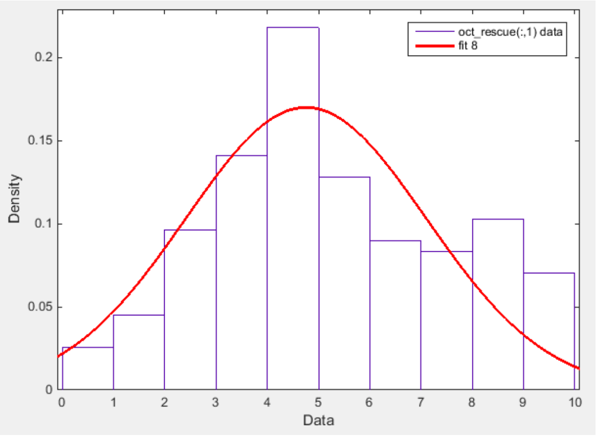


July, wind speed mean: 11.49m/s

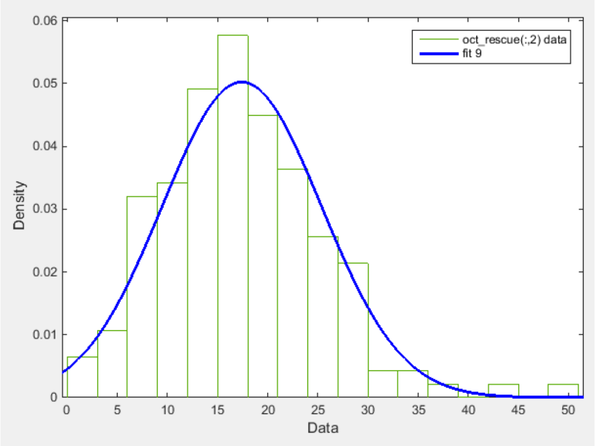


July, wind direction

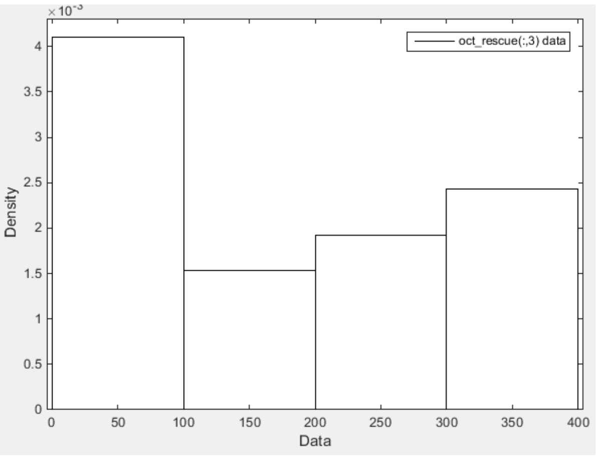
Data from October:



October, simulated number of rescued, mean: 4.75 persons



October, wind speed, mean: 17.4 knots



October, wind direction

Appendix II – MATLAB Code

The model consists of two main MATLAB scripts: one for the single field case and one for the larger area. The same simulation model is used in both cases, see Appendix III - SimEvents simulation model.

- input_positions.m
    - Course.m
    - wave.m
    - wind.m
    - wind_vector.m
    - ground_speed.m
    - transit_time
- reading_weather.m
    - uwind.m
    - angles.m
    - wind_month.m
    - omrade2.m
    - windspeed.m
    - groundspeed.m
    - locations.m
    - list.m

Each of the main scripts have several function scripts which are included in this appendix.

Main script for single field, input_positions.m

```
%Take in inputdata of position
close all
clear all
clc

for s= 1:2000;
%----------------------------------------------------------%
lat1 = 24; %input('Enter latitude of position 1 > ');
lon1 = 74; %input('Enter longitude of position 1 > ');
lat2 = 23.681944; %input('Enter latitude of position 2 > ');
lon2 = 70.663333; %input('Enter longitude of position 2 > ');

%Calculations

[tc1,d] = Course(lat1,lat2,lon1,lon2);
[jan_wave, feb_wave, mar_wave, apr_wave, may_wave, jun_wave,...
    jul_wave, aug_wave, sep_wave, oct_wave, nov_wave, dec_wave] = wave();
[jan,feb,mar,apr,may,jun,jul,aug,sep,oct,nov,dec]=wind();
[wind_speed, wind_direction, month_w, variabel] =
wind_vector(jan,feb,mar,apr,may,jun,jul,aug,sep,oct,nov,dec);
[GS] = ground_speed(wind_speed, wind_direction, tc1);
[flying_time1] = transit_time(d,GS);
```

```
flying_t = strcat(['flying_time1']);
set_param('rescue_cap/subsystem', 'flying_t', flying_t);
simOut = sim('rescue_cap');

antall(s,1) = number(2,1);
antall(s,2) = month_w;
antall(s,3) = flying_time1;
antall(s,4) = wind_speed;
antall(s,5) = wind_direction;


end
```

Course.m

```
function [tc1,d] = Course(lat1, lat2, lon1, lon2);

lat1=lat1*pi/180;
lat2=lat2*pi/180;
lon1=lon1*pi/180;
lon2=lon2*pi/180;

%d calculates the distance between the two points

d=2*asin(sqrt((sin((lat1-lat2)/2))^2 + cos(lat1)*cos(lat2)*(sin((lon1-
lon2)/2))^2));
d=d*180*60/pi;

if sin(lon2-lon1)<0

    tc1=acos((sin(lat2)-sin(lat1)*cos(d))/(sin(d)*cos(lat1)));
else

    tc1=2*pi-acos((sin(lat2)-sin(lat1)*cos(d))/(sin(d)*cos(lat1)));

end
tc1=(tc1*180/pi);
end


%http://williams.best.vwh.net/avform.htm accessed 24.03.15
%((sin(lat2)-sin(lat1)*cos(d))/(sin(d)*cos(lat1)))
```

wave.m

```
function [jan_wave, feb_wave, mar_wave, apr_wave, may_wave, jun_wave,
jul_wave, aug_wave, sep_wave, oct_wave, nov_wave, dec_wave] = wave()

C = csvread('Wave_m_file.csv',0,0);
D=C(:,[1 2 7 8]);
j1=1;k1=1;l1=1;m1=1;,n1=1;,o1=1;,p1=1;,q1=1;,r1=1;,s1=1;,t1=1;,u1=1;
for i1=1:61368   ;
```

```
    if D (i1,2)==1;
        jan_wave(j1,1)=D(i1,3);
      j1=j1+1;
    end
     if D (i1,2)==2;
        feb_wave(k1,1)=D(i1,3);
        k1=k1+1;
    end
        if D (i1,2)==3;
        mar_wave(l1,1)=D(i1,3);
        l1=l1+1;
        end
    if D (i1,2)==4;
        apr_wave(m1,1)=D(i1,3);
        m1=m1+1;
    end
   if D (i1,2)==5;
        may_wave(n1,1)=D(i1,3);
        n1=n1+1;
   end
    if D (i1,2)==6;
        jun_wave(o1,1)=D(i1,3);
        o1=o1+1;
    end
    if D (i1,2)==7;
        jul_wave(p1,1)=D(i1,3);
        p1=p1+1;
    end
    if D (i1,2)==8;
        aug_wave(q1,1)=D(i1,3);
        q1=q1+1;
    end
    if D (i1,2)==9;
        sep_wave(r1,1)=D(i1,3);
        r1=r1+1;
    end
    if D (i1,2)==10;
        oct_wave(s1,1)=D(i1,3);
        s1=s1+1;
    end
    if D (i1,2)==11;
        nov_wave(t1,1)=D(i1,3);
        t1=t1+1;
    end
    if D (i1,2)==12;
        dec_wave(u1,1)=D(i1,3);
        u1=u1+1;
end
end
end
```

wind.m

```
function [jan,feb,mar,apr,may,jun,jul,aug,sep,oct,nov,dec]=wind

A = csvread('Wave_m_file.csv',0,0);
B=A(:,[1 2 5 6]);
j=1;, k=1;, l=1;, m=1;, n=1;, o=1;, p=1;, q=1;, r=1;, s=1;, t=1;, u=1;,
for i=1:61368;
```

```
    if B (i,2)==1;
        jan(j,1)=B(i,3);
        jan(j,2)=B(i,4);
      j=j+1;
    end
     if B (i,2)==2;
        feb(k,1)=B(i,3);
        feb(k,2)=B(i,4);
        k=k+1;
    end
        if B (i,2)==3;
                mar(l,1)=B(i,3);
        mar(l,2)=B(i,4);
        l=l+1;
        end
    if B (i,2)==4;
        apr(m,1)=B(i,3);
        apr(m,2)=B(i,4);
        m=m+1;
    end
   if B (i,2)==5;
        may(n,1)=B(i,3);
        may(n,2)=B(i,4);
        n=n+1;
   end
    if B (i,2)==6;
        jun(o,1)=B(i,3);
        jun(o,2)=B(i,4);
        o=o+1;
    end
    if B (i,2)==7;
                jul(p,1)=B(i,3);
        jul(p,2)=B(i,4);
        p=p+1;
    end
    if B (i,2)==8;
        aug(q,1)=B(i,3);
        aug(q,2)=B(i,4);
        q=q+1;
    end
    if B (i,2)==9;
        sep(r,1)=B(i,3);
        sep(r,2)=B(i,4);
        r=r+1;
    end
    if B (i,2)==10;
        oct(s,1)=B(i,3);
        oct(s,2)=B(i,4);
        s=s+1;
    end
      if B (i,2)==11;
        nov(t,1)=B(i,3);
        nov(t,2)=B(i,4);
        t=t+1;
    end
    if B (i,2)==12;
        dec(u,1)=B(i,3);
        dec(u,2)=B(i,4);
        u=u+1;
end
end
end
```

wind_vector.m

```
%Finds random month and a connected random weather observation
function [wind_speed, month_w, variabel, wind_direction] = wind_vector
(jan,feb,mar,apr,may,jun,jul,aug,sep,oct,nov,dec);
month_w= ceil(rand()*12);

if month_w == 1
    variabel = ceil(rand()*length(jan));
    wind_speed = jan(variabel,1);
    wind_direction = jan(variabel,2);
elseif month_w == 2
    variabel = ceil(rand()*length(feb));
    wind_speed = feb(variabel,1);
    wind_direction = feb(variabel,2);
elseif month_w == 3
    variabel = ceil(rand()*length(mar));
    wind_speed = mar(variabel,1);
    wind_direction = mar(variabel,2);
elseif month_w == 4
    variabel = ceil(rand()*length(apr));
    wind_speed = apr(variabel,1);
    wind_direction = apr(variabel,2);
elseif month_w == 5
   variabel = ceil(rand()*length(may));
    wind_speed = may(variabel,1);
    wind_direction = may(variabel,2);
elseif month_w == 6
    variabel = ceil(rand()*length(jun));
    wind_speed = jun(variabel,1);
    wind_direction = jun(variabel,2);
elseif month_w == 7;
    variabel = ceil(rand()*length(jul));
    wind_speed = jul(variabel,1);
    wind_direction = jul(variabel,2);
elseif month_w == 8;
    variabel = ceil(rand()*length(aug));
    wind_speed = aug(variabel,1);
    wind_direction = aug(variabel,2);
elseif month_w == 9;
    variabel = ceil(rand()*length(sep));
    wind_speed = sep(variabel,1);
    wind_direction = sep(variabel,2);
elseif month_w == 10;
    variabel = ceil(rand()*length(oct));
    wind_speed = oct(variabel,1);
    wind_direction = oct(variabel,2);
elseif month_w == 11;
    variabel = ceil(rand()*length(nov));
    wind_speed = nov(variabel,1);
    wind_direction = nov(variabel,2);
else month_w == 12;
    variabel = ceil(rand()*length(dec));
    wind_speed = dec(variabel,1);
    wind_direction = dec(variabel,2);
end
wind_direction;
wind_speed;
wind_speed = wind_speed *1.944; % altering to knots

end
```

ground_speed.m

```
function [GS] = ground_speed(wind_speed, wind_direction, tc1);
C=tc1;
air_speed = 140; %input('Enter helicopter air speed > ');


Av_deg=(180+C-wind_direction);

if Av_deg>180
    Av_deg = 360-Av_deg;
else Av_deg;
end

Av_rad= Av_deg*(pi/180); % convert to randians %inkluder noen form for if
wind_direction > 180 bla blabla


Aw=asin(sin(Av_rad)*(wind_speed/air_speed));
Aw=Aw*(180/pi);

Ac_deg=180-Av_deg-Aw;
Ac_rad=Ac_deg*(pi/180);

GS= air_speed*((sin(Ac_rad))/(sin(Av_rad)));
end



%%Angle_radians = (pi/180)*angle_degrees
%distance_radians=(pi/(180*60))*distance_nm
```

transit_time

```
function [flying_time1] = transit_time(d,GS);

flying_time1 = (d/GS)*60;


end
```

Main script for larger area, reading_weather.m

```
%------------Information---------------------------------------%
This is the main script, where weather data is implemented, calculations are
performed, and simulation is initiated taking in the calculated information.

The script calculates the effect of the wind on the helicopter operation, and how
the weather effects the flying time when flying through several weather “windows”.
%--------------------------------------------------------------%
clear all
close all
clc


for s=1:500;

% reads in weather data, and stores the information in new lists

weather = ('weather14.nc');
weather1213 = ('weather12_13.nc');


u_wind14 = ncread(weather, 'u10');
v_wind14 = ncread(weather, 'v10');
u_wind1213=ncread(weather1213,'u10');
v_wind1213=ncread(weather1213,'v10');


latitude1213=ncread(weather1213, 'latitude');
longitude1213=ncread(weather1213, 'longitude');
latitude_14=ncread(weather, 'latitude');
longitude_14 =ncread(weather, 'longitude');
time= ncread(weather, 'time');
time1213=ncread(weather1213, 'time');

%Reads in the calculated leg distances through each weather “window”
windows=xlsread('legs.xlsx');

%puts all data for the time measurements into one list time_t

[time_t]=time_list(time, time1213);

%saves wind data from 2012-2014 in one matrix, calculates the length of the
%wind speed vector - the actual wind speed.

[windspeed_vector, u_wind, v_wind]=uwind(u_wind1213, u_wind14, v_wind14,
v_wind1213);

%finds the wind direction
[winddirection]=angles(u_wind,v_wind, windspeed_vector);

%collecting the wind data from the three years into monthly lists, ie.
%jan=jan12&jan13 &jan14..
[jan,feb,mar,apr,may,jun,jul,aug,sep,oct,nov,dec]= ...
     wind_month(windspeed_vector,time_t);
```

```
%Sorts the wind direction into monthly lists
[dir_jan,dir_feb,dir_mar,dir_apr,dir_may,dir_jun,dir_jul,dir_aug,dir_sep,…
dir_oct,dir_nov,dir_dec]= winddirections(winddirection,time_t);


%Establishes the weather data for the 16 different areas between
%2012-2014. dividing where column 1 = jan, 2=feb etc. And the z-axes is
%areas 1-35. ex. (:,3,4) = all wind data from march in area 4.

[wind_area]=omrade2(jan,feb,mar,apr,may,jun,jul,aug,sep,oct,nov,dec);
[area_winddirection]= omrade3(dir_jan, dir_feb, dir_mar, dir_apr, dir_may,
dir_jun, dir_jul, dir_aug, dir_sep, dir_oct, dir_nov, dir_dec, u_wind);

% generating random variables for wind speed for all 16 areas from weather
% data file for a certain month - which is displayed as month_w.
[wind_speed,month_w] = windspeed(wind_area, area_winddirection);

%establishing the connected groundspeeds based on the wind speed and
% direction in each weather window
[GS1] = ground_speed(wind_speed);

%finds the total distances to the intersections in the grid (no scaling)
[dist_list]=grid_dist();

% calculating the connected groundspeeds for the different weather windows
% all 25 helicopter trips, and finding the total flying time for each point
% with the effect of the weather.
[tot_flyingtime] = locations(GS1,windows);


for a=1:25; %runs the simulation 25 times, taking in a list of each flying
time to the 25 locations in the grid
tot_flyingt = tot_flyingtime(a,1);

tot_flying = strcat(['tot_flyingt']);
set_param('rescue_map25/subsystem', 'tot_flying', tot_flying);
simOut = sim('rescue_map25');

antall(a,1) = number(2,1);
antall(a,2) = month_w;

 end
 ab= antall(:,1);
 cd= antall(:,2);
 number_rescued(:,s)=ab;
 month(:,s)= cd;

end
```

```
%Storing a list of the number of rescued for all 25 locations, and the
connected month of the evaluation
 list_nr(:,1)=reshape(number_rescued,[12500,1]);
 list_nr(:,2)=reshape(month,[12500,1]);

[area]=list(list_nr);

%-----------------------------------------------------------------------%
```

uwind.m

```
%saving all u_wind and v_wind vectors in two matrices

function[windspeed_vector, u_wind, v_wind]=uwind(u_wind1213, u_wind14,
v_wind14, v_wind1213);

a=size(u_wind1213,3);
b=size(u_wind1213,3)+1;
c=size(u_wind14,3);
a1=size(v_wind1213,3);
b2=a+1;
c2=size(v_wind14,3);



for i=1:a;
u_wind(:,:,i)= u_wind1213(:,:,i);
end

for j=1:c;

u_wind(:,:,b)= u_wind14(:,:,j);
b=b+1;
end

for i=1:a1;
v_wind(:,:,i)= v_wind1213(:,:,i);
end

for j=1:c2;

v_wind(:,:,b2)= v_wind14(:,:,j);
b2=b2+1;
end
%This calculation combines the u- and v-vector of the windspeed giving the
%total windspeed at the points.
windspeed_vector=sqrt(u_wind.^2 + v_wind.^2);
end
```

angles.m

```
function [winddirection]=angles(u_wind,v_wind, windspeed_vector);

lon= size(u_wind,1); % 25
lat= size(u_wind,2); %10
times = size(u_wind,3); %8770

for b=1:lon;
   for c=1:lat;
       for d=1:8770;



if u_wind(b,c,d) >0 && v_wind(b,c,d)>0;
    angle = asin(u_wind(b,c,d)/windspeed_vector(b,c,d))*(180/pi)+180;

elseif u_wind(b,c,d)<0 && v_wind(b,c,d)>0;
    angle = asin(u_wind(b,c,d)/windspeed_vector(b,c,d))*(180/pi)+180;

elseif u_wind(b,c,d) >0 && v_wind(b,c,d)<0;
    angle = acos(v_wind(b,c,d)/windspeed_vector(b,c,d))*(180/pi)+180;

else u_wind(b,c,d)<0 && v_wind(b,c,d)<0;
    angle = asin(u_wind(b,c,d)/windspeed_vector(b,c,d))*(180/pi)*(-1);
end

  winddirection(b,c,d)=angle;
      end
    end

end
end
```

wind_month.m

```
%--------------information------------------------------------------------%
Sorts the weather data into different months. Time measurements from EMfSFJ
was given in hours from year 1900, therefore to establish which month they
belong to, the list is searched through to identify if the time measurement
is within jan, feb, mar etc. To find this numbers, calculations were performed
by hand.

The same was done for winddirections.m and is not showed in the appendix.
%-----------------------------------------------------------------------------%

function [jan,feb,mar,apr,may,jun,jul,aug,sep,oct,nov,dec]= ...
     wind_month(windspeed_vector,time_t);


j2=1;, k2=1;, l2=1;, m2=1;, n2=1;, o2=1;, p2=1;, q2=1;, r2=1;, s2=1;, t2=1;,
u2=1;,j=1;, k=1;, l=1;, m=1;, n=1;, o=1;, p=1;, q=1;, r=1;, s=1;, t=1;, u=1;,j1=1;,
k1=1;, l1=1;, m1=1;, n1=1;, o1=1;, p1=1;, q1=1;, r1=1;, s1=1;, t1=1;, u1=1;,


for w=1:length(time_t);
   if time_t(w,1)<= 1000056 && 999312 < time_t(w,1);
   jan14(:,:,j2) =windspeed_vector(:,:,w);
    j2=j2+1;
  end
  if time_t(w,1)> 1000056 && time_t(w,1)<=1000728;
     feb14(:,:,k2)=windspeed_vector(:,:,w);
       k2=k2+1;
  end
  if time_t(w,1)<=1001472 && time_t(w,1)> 1000728;
     mar14(:,:,l2)=windspeed_vector(:,:,w);
      l2=l2+1;
  end
     if time_t(w,1)<= 1002192 && time_t(w,1)> 1001472;
     apr14(:,:,m2)=windspeed_vector(:,:,w);
  m2=m2+1;
     end
     if time_t(w,1)<= 1002936 && time_t(w,1)> 1002192;
     may14(:,:,n2)=windspeed_vector(:,:,w);
   n2=n2+1;
     end
      if time_t(w,1)<= 1003656 && time_t(w,1)> 1002936;
      jun14(:,:,o2)=windspeed_vector(:,:,w);
      o2=o2+1;
  end
  if time_t(w,1)<= 1004400 && time_t(w,1)>1003656;
      jul14(:,:,p2)=windspeed_vector(:,:,w);
    p2=p2+1;
  end
  if time_t(w,1)<= 1005144 && time_t(w,1)> 1004400;
      aug14(:,:,q2)=windspeed_vector(:,:,w);
          q2=q2+1;
  end
  if time_t(w,1)<= 1005864 && time_t(w,1)> 1005144;
    sep14(:,:,r2)=windspeed_vector(:,:,w);
      r2=r2+1;
  end
  if time_t(w,1) <= 1006608 && time_t(w,1)> 1005864;
     oct14(:,:,s2)=windspeed_vector(:,:,w);
```

```
         s2=s2+1;
  end
  if time_t(w,1)<= 1007328 && time_t(w,1)>1006608;
    nov14(:,:,t2)=windspeed_vector(:,:,w);
       t2=t2+1;
  end
  if time_t(w,1)<= 1008072 && time_t(w,1)>1007328;
    dec14(:,:,u2)= windspeed_vector(:,:,w);
     u2=u2+1;
  end
```

omrade2.m

```
%----------------------information----------------------------------------------------
--%
The wind data is collected in a three dimensional matrix, where the wind data for
all twelve months for one location. The z-axes represent the different locations.

The same is done for the wind direction, in omrade3.m, the file is not listed in
the appendix, due to it being similar to this one.
%-----------------------------------------------------------------------------------
---%
function
[wind_area]=omrade2(jan,feb,mar,apr,may,jun,jul,aug,sep,oct,nov,dec);

a= size(jan,3);
b= size(feb,3);
c= size(mar,3);
d= size(apr,3);
e= size(may,3);
f= size(jun,3);
g= size(jul,3);
h= size(aug,3);
j= size(sep,3);
k= size(oct,3);
l= size(nov,3);
m= size(dec,3);

lat=[ 3 5 7 9]; % list=length(lat)*length(lon);
lon=[ 9 13 17 21 ]; %where lat=[75 73.5 72 70.5] lon=[ 18 21 24 27 ]

areaCounter = 0;
 for s = 1:length(lat);
     for t = 1:length(lon);          % in a new area
       areaCounter = areaCounter+1;

  a=size(jan,3); %length of months 31days long
  b=size(feb,3); %length of months 28days long
  c=size(apr,3); %length of months 30days long

%takes the wind data matrices, and stores the information for 16 different areas
into one matrix called areas.
%The columns represent all the collected weather data from each month 1-12
%each 2D matrix gives all measured data for that specific area.

  for i=1:b; % uses the shortest number of months to avoid unwanted zero values.
area(i,1)=jan(lon(t),lat(s),i);
```

```
area(i,2)=feb(lon(t),lat(s),i);
area(i,3)=mar(lon(t),lat(s),i);
area(i,4)=apr(lon(t),lat(s),i);
area(i,5)=may(lon(t),lat(s),i);
area(i,6)=jun(lon(t),lat(s),i);
area(i,7)=jul(lon(t),lat(s),i);
area(i,8)=aug(lon(t),lat(s),i);
area(i,9)=sep(lon(t),lat(s),i);
area(i,10)=oct(lon(t),lat(s),i);
area(i,11)=nov(lon(t),lat(s),i);
area(i,12)=dec(lon(t),lat(s),i);

  end
  % saves calculated values from area, and stores it into omr2
  wind_area(:,:,areaCounter) = area;

      end
 end
```

windspeed.m

```
%Randomly pics a month, and assigns wind_speed and wind_direction for the
%same time unit for the 16 different areas.
function [wind_speed, month_w] = windspeed(wind_area, area_winddirection);
month_w= ceil(rand()*12);

for i=1:16;
    list=ceil(rand()*(size(wind_area,1)));
    wind_speed(i,1)=wind_area(list,month_w,i)*1.944; % altering to knots;
wind_speed(i,2)=area_winddirection(list,month_w,i);
    wind_speed(i,3)=month_w;
end
end
```

groundspeed.m

```
%Calculates new speed based on effect of windspeed and direction

%This function considers that certain areas are travelled through more
%often than others. Such as the area close to the origin are far more
%travelled through than the far points. This function Finds the connected
%groundspeed that each helicopter has through that area, taking in the
%course angle of the helicopter, and the wind_direction in that area.
function [GS1] = ground_speed(wind_speed);

air_speed = 140; %input('Enter helicopter air speed > ');
windows=xlsread('legs.xlsx');

for i= 1:size(windows, 1); %16 points in the grid - not including
C(i,1) = windows(i,1);

%takes the course of point C(i,1), and the wind direction in area(i) to
%calculate the helicopter speed in area(i).
Av_deg=(180+C(i,1)-wind_speed(i,2));

if Av_deg>180
    Av_deg = 360-Av_deg;
else Av_deg;
end

Av_rad= Av_deg*(pi/180); % convert to randians

Aw=asin(sin(Av_rad)*(wind_speed(i,1)/air_speed));
Aw=Aw*(180/pi);

Ac_deg=180-Av_deg-Aw;
Ac_rad=Ac_deg*(pi/180);

GS= air_speed*((sin(Ac_rad))/(sin(Av_rad)));
GS1(i,1)=GS;

% Groundspeed for course C(i) to point (i) in area(i)
%ex. so that the groundspeed for a helicopter travelling to point(1,1) is
```

```
%cacluated in area1, and a helicopter travelling to (1,2) we find he
%groundspeed in area(2)
```

locations.m

```
function [tot_flyingtime] = locations(GS1,windows);

omr_1 = GS1(1,:); % list including the groundspeed for all courses flying
through this area
omr_2 = GS1(2,:);
omr_3 = GS1(3,:);
omr_4 = GS1(4,:);
omr_5 = GS1(5,:);
omr_6 = GS1(6,:);
omr_7 = GS1(7,:);
omr_8 = GS1(8,:);
omr_9 = GS1(9,:);
omr_10= GS1(10,:);
omr_11= GS1(11,:);
omr_12= GS1(12,:);
omr_13= GS1(13,:);
omr_14= GS1(14,:);
omr_15= GS1(15,:);
omr_16= GS1(16,:);



%establishing the total time it takes to fly to the different points,
%taking in the weather effect
dist1 =
(windows(1,2)/omr_1(1,1))+(windows(1,2)/omr_5(1,2))+(windows(1,2)/omr_10(1,
3)) + (windows(1,2)/omr_14(1,3));
dist2 =
(windows(2,2)/omr_2(1,1))+(windows(2,2)/omr_6(1,2))+(windows(2,2)/omr_10(1,
4)) + (windows(2,2)/omr_14(1,4));
%finn gjennomsnittlig GS mellom 2-3,6-7,10-11,1415,dist3 = 1/(
%the distances 3,8,13,18 are found using the area to the left of the route.
dist3= (90/omr_2(1,2))+(90/omr_6(1,3))+(90/omr_10(1,6))+(90/omr_14(1,11));
dist4=
(windows(3,2)/omr_3(1,1))+(windows(3,2)/omr_7(1,2))+(windows(3,2)/omr_11(1,
4)) + (windows(3,2)/omr_15(1,4));
dist5=
(windows(4,2)/omr_4(1,1))+(windows(4,2)/omr_8(1,2))+(windows(4,2)/omr_11(1,
3)) + (windows(4,2)/omr_14(1,3));
dist6=
(windows(5,2)/omr_5(1,1))+(windows(9,4)/omr_9(1,2))+(windows(10,10)/omr_10(
1,5)) + (windows(14,10)/omr_14(1,5));
dist7=
(windows(6,2)/omr_6(1,1))+(windows(6,2)/omr_10(1,2))+(windows(14,14)/omr_14
(1,7));
dist8= (90/omr_6(1,3))+(90/omr_10(1,6))+(90/omr_14(1,11));
dist9=
(windows(7,2)/omr_7(1,1))+(windows(7,2)/omr_11(1,2))+(windows(15,14)/omr_15
(1,7));
```

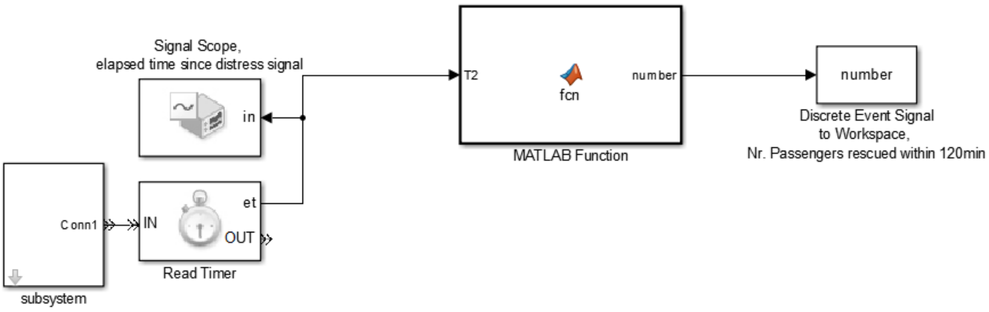
```
dist10=
(windows(8,2)/omr_8(1,1))+(windows(12,4)/omr_12(1,2))+(windows(11,10)/omr_1
1(1,5)) + (windows(15,10)/omr_15(1,5));



dist11= (windows(9,2)/omr_9(1,1))+(windows(14,2)/omr_14(1,1));
dist12= (windows(10,6)/omr_10(1,3))+(windows(14,6)/omr_14(1,3));
dist13=(90/omr_10(1,6))+(90/omr_14(1,11));
dist14= (windows(11,6)/omr_11(1,3))+(windows(15,6)/omr_15(1,3));
dist15= (windows(12,2)/omr_12(1,1))+(windows(15,2)/omr_15(1,1));
dist16= (windows(13,2)/omr_13(1,1))+(windows(14,18)/omr_14(1,9));
dist17= (windows(14,2)/omr_14(1,1));
dist18= (90/omr_14(1,11));
dist19= (windows(14,2)/omr_14(1,1));
dist20= (windows(16,2)/omr_16(1,1))+(windows(15,18)/omr_15(1,9));
dist21= (90/omr_13(1,2))+(90/omr_14(1,10));
dist22= (90/omr_14(1,10));
dist23=0;
dist24= (90/omr_15(1,10));
dist25= (90/omr_16(1,2))+(90/omr_15(1,10));

tot_flyingtime(1,1)=dist1*60;
tot_flyingtime(2,1)=dist2*60;
tot_flyingtime(3,1)=dist3*60;
tot_flyingtime(4,1)=dist4*60;
tot_flyingtime(5,1)=dist5*60;
tot_flyingtime(6,1)=dist6*60;
tot_flyingtime(7,1)=dist7*60;
tot_flyingtime(8,1)=dist8*60;
tot_flyingtime(9,1)=dist9*60;
tot_flyingtime(10,1)=dist10*60;
tot_flyingtime(11,1)=dist11*60;
tot_flyingtime(12,1)=dist12*60;
tot_flyingtime(13,1)=dist13*60;
tot_flyingtime(14,1)=dist14*60;
tot_flyingtime(15,1)=dist15*60;
tot_flyingtime(16,1)=dist16*60;
tot_flyingtime(17,1)=dist17*60;
tot_flyingtime(18,1)=dist18*60;
tot_flyingtime(19,1)=dist19*60;
tot_flyingtime(20,1)=dist20*60;
tot_flyingtime(21,1)=dist21*60;
tot_flyingtime(22,1)=dist22*60;
tot_flyingtime(24,1)=dist24*60;
tot_flyingtime(25,1)=dist25*60;
end
```

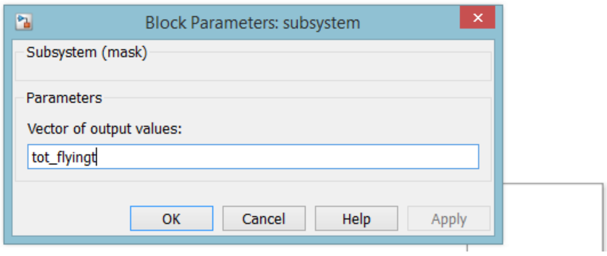
list.m

```
%-------------------information---------------------------------------%
This function converts the information and stores the results into a
3-dimentional matrix area.
%---------------------------------------------------------------------%
function [area]=list(list_nr);
j=1;, k=1;, l=1;, m=1;, n=1;, o=1;, p=1;, q=1;, r=1;, s=1;, t=1;, u=1;,
for i=1:12500;

    if list_nr(i,2)==1;
    January(j,1)=list_nr(i,1);
    j=j+1;
    elseif list_nr(i,2)==2;
        February(k,1)=list_nr(i,1);
        k=k+1;
    elseif list_nr(i,2)==3
        March(l,1)= list_nr(i,1);
        l=l+1;
    elseif list_nr(i,2)==4;
        April(m,1)=list_nr(i,1);
        m=m+1;
    elseif list_nr(i,2)==5
        May(n,1)= list_nr(i,1);
        n=n+1;
    elseif list_nr(i,2)==6;
        June(o,1)= list_nr(i,1);
        o=o+1;
    elseif list_nr(i,2)==7;
        July(p,1)=list_nr(i,1);
        p=p+1;
    elseif list_nr(i,2)==8;
         August(q,1)=list_nr(i,1);
         q=q+1;
    elseif list_nr(i,2)==9;
        September(r,1)=list_nr(i,1);
        r=r+1;
    elseif list_nr(i,2)==10;
        October(s,1)=list_nr(i,1);
        s=s+1;
    elseif list_nr(i,2)==11;
        November(t,1)=list_nr(i,1);
        t=t+1;
    else list_nr(i,2)==12;
        December(u,1)=list_nr(i,1);
        u=u+1;
    end
end

%Finds the numbers of observations each month
a= (length(January))/25;
b=(length(February))/25;
c= (length(March))/25;
```

```
d= (length(April))/25;
e= (length(May))/25;
f= (length(June))/25;
a1= (length(July))/25;
b1= (length(August))/25;
c1= (length(September))/25;
d1= (length(October))/25;
e1= (length(November))/25;
f1= (length(December))/25;

%Reshapes the months so that row = area, column = nr rescued in that month

jan1 = reshape(January, [25,a]);
feb2= reshape(February, [25,b]);
mar3=reshape(March, [25,c]);
apr4=reshape(April, [25,d]);
may5=reshape(May, [25,e]);
jun6=reshape(June, [25,f]);
jul7=reshape(July, [25,a1]);
aug8=reshape(August, [25,b1]);
sep9=reshape(September, [25,c1]);
oct10=reshape(October, [25,d1]);
nov11=reshape(November, [25, e1]);
dec12=reshape(December, [25,f1]);

%Makes one matrix where (month, rescued, area)
for i=1:25

area1(1,1:a)=jan1(i,1:a);
area1(2,1:b)=feb2(i,1:b);
area1(3,1:c)=mar3(i,1:c);
area1(4,1:d)=apr4(i,1:d);
area1(5,1:e)=may5(i,1:e);
area1(6,1:f)=jun6(i,1:f);
area1(7,1:a1)=jul7(i,1:a1);
area1(8,1:b1)=aug8(i,1:b1);
area1(9,1:c1)=sep9(i,1:c1);
area1(10,1:d1)=oct10(i,1:d1);
area1(11,1:e1)=nov11(i,1:e1);
area1(12,1:f1)=dec12(i,1:f1);

area(:,:,i) = area1;
end
 end
```

Appendix III - SimEvents simulation model





Subsystem (mask)

Parameters

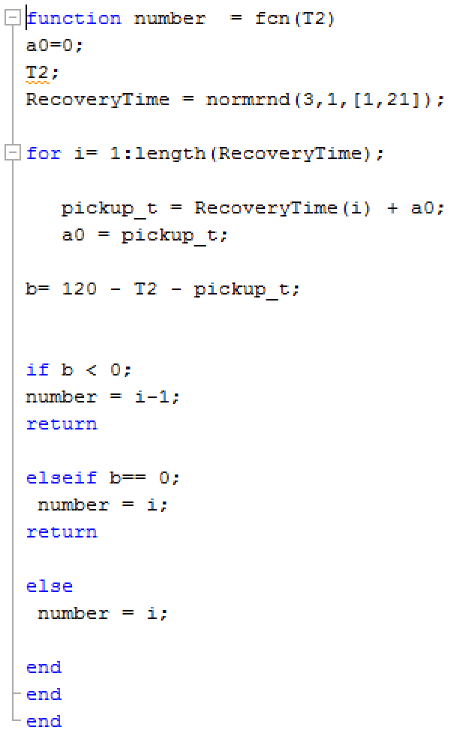
Vector of output values:

tot_flyingt

Matlab function block:

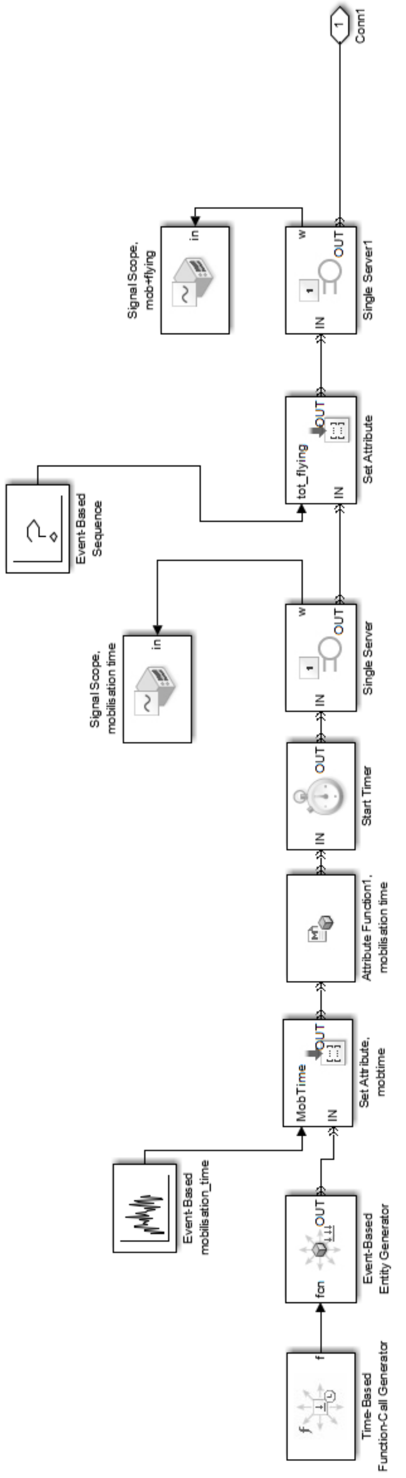
%---------------------------information---------------------------%
measures total time to arrive at accident site, and picks up persons with a normal distribution until time requirement of 120 min is met.

%--%



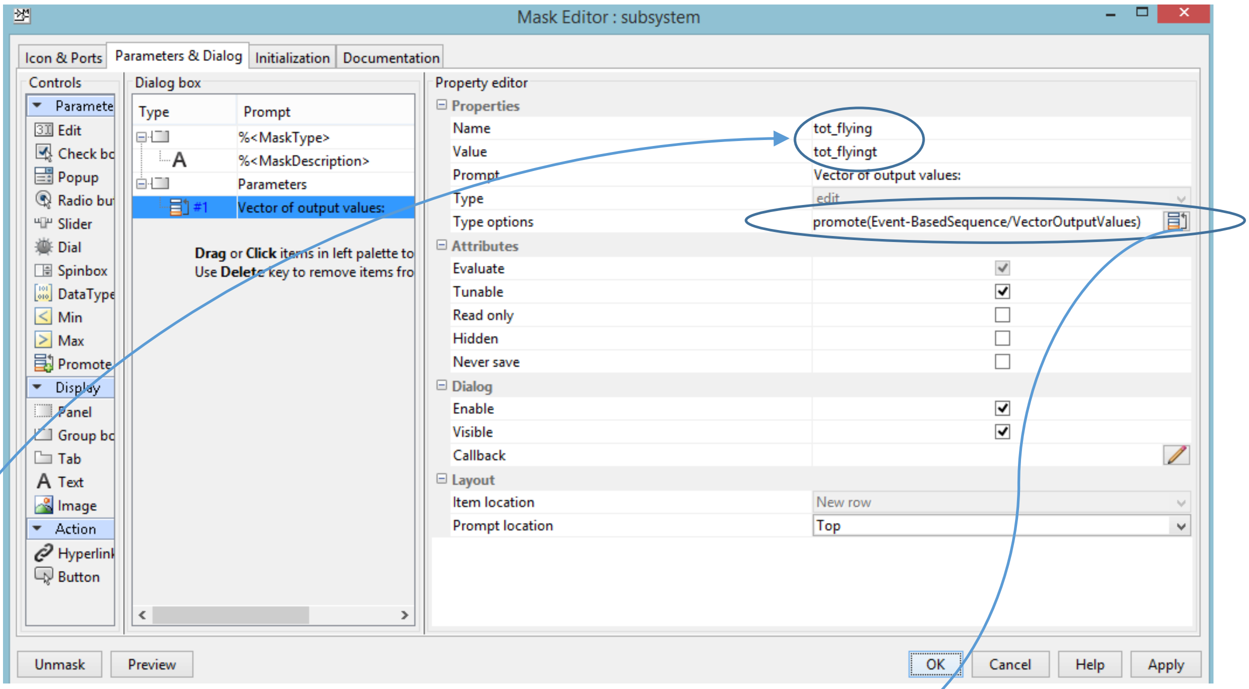
```
function number   = fcn(T2)
a0=0;
T2;
RecoveryTime = normrnd(3,1,[1,21]);

for i= 1:length(RecoveryTime);

   pickup_t = RecoveryTime(i)  + a0;
   a0 = pickup_t;

b= 120 - T2 - pickup_t;


if b < 0;
number = i-1;
return

elseif b== 0;
 number = i;
return

else
 number = i;

end
end
end
```

Submodel assigning mobilisation time and flyingtime



Mask editor of the subsystem

To ensure that the parameter is assigned values from the Matlab script, the “type options” box should be set at “VectorOutputValues”



Mask Editor : subsystem

Icon & Ports | Parameters & Dialog | Initialization | Documentation

Dialog box

Type	Prompt
	%<MaskType>
A	%<MaskDescription>
	Parameters
#1	Vector of output values:

Drag or **Click** items in left palette to
Use **Delete** key to remove items fro

Property editor

Properties

Name	tot_flying
Value	tot_flyingt
Prompt	Vector of output values:
Type	edit
Type options	promote(Event-BasedSequence/VectorOutputValues)

Attributes

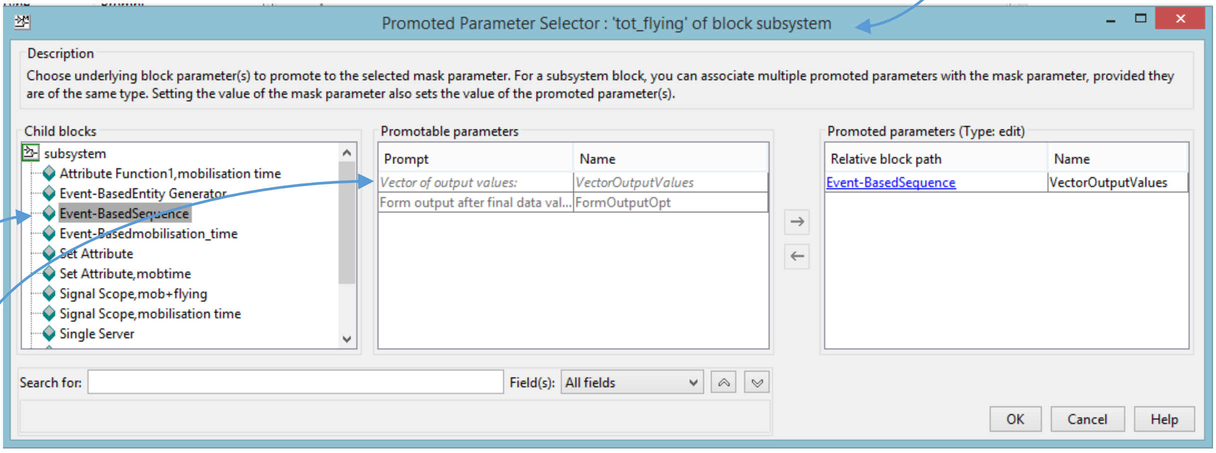
Evaluate	☑
Tunable	☑
Read only	☐
Hidden	☐
Never save	☐

Dialog

Enable	☑
Visible	☑
Callback	

Layout

Item location	New row
Prompt location	Top



Promoted Parameter Selector : 'tot_flying' of block subsystem

Description

Choose underlying block parameter(s) to promote to the selected mask parameter. For a subsystem block, you can associate multiple promoted parameters with the mask parameter, provided they are of the same type. Setting the value of the mask parameter also sets the value of the promoted parameter(s).

Child blocks

- subsystem
  - Attribute Function1,mobilisation time
  - Event-BasedEntity Generator
  - Event-BasedSequence
  - Event-Basedmobilisation_time
  - Set Attribute
  - Set Attribute,mobtime
  - Signal Scope,mob+flying
  - Signal Scope,mobilisation time
  - Single Server

Promotable parameters

Prompt	Name
Vector of output values:	*VectorOutputValues*
Form output after final data val...	FormOutputOpt

Promoted parameters (Type: edit)

Relative block path	Name
Event-BasedSequence	VectorOutputValues

Search for: Field(s): All fields

Here one chooses the block that one wants to assign values to.

Choose the “VectorOutputValues”.

Finally, ensure that the name and values match with the name and value from the script.

Appendix IV – Interpolation of probability, example January month