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Evacuation and Rescue in the Barents Sea

Critical issues for safe petroleum activity

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STAVANGER **…………..**S.R.Jacobsen**……………………**

17. juli 2012

1 PREFACE

1.1 *The objective of the report*

Exploration for petroleum resources is increasing in the Barents Sea. Optimism is rising due to recent hydrocarbon discoveries on Skrugard, Havis and Norvarg and the agreement with Russia regarding the border at sea. There will potentially be all year activity in the Norwegian sector of the Barents Sea.

Norwegian petroleum regulations require that personnel on a facility can be evacuated quickly and efficiently to a safe area at all times, Activity Regulation § 77 d) [11], and in all weather conditions, Facilities Regulation § 44 [12]. The objective of this thesis is to examine limitations and critical issues for emergency preparedness in the Barents Sea.

The following hypothesis will be investigated: All year petroleum activity is not possible in the Barents Sea with regard to emergency preparedness unless sufficient attention is given to critical factors influencing evacuation and rescue.

1.2 *Major contents of the report*

The report considers the Barents Sea area from the Norwegian coast to Bjørnøya in the north and the border with Russia in the east. Background information on the climate conditions in the Norwegian sector of the Barents Sea and special features of the area are presented. Use of helicopters, emergency response vessels, fast recovery daughter craft, man overboard boats, lifeboats and survival suits for evacuation and rescue purposes are discussed in order to identify critical issues with regard to successful and sound operations.

1.3 *Disclaimer*

Although being an employee of the Norwegian Petroleum Safety Authority, views expressed in this thesis are not to be regarded as the view of the authorities. All views and interpretations of regulations expressed in this thesis are those of the author.

Notes:

1. The use of [#] in this report indicates a document listed in the reference list in section 8.
2. The use of *italics* indicates that the text is quoted from the referenced document.

2 ACKNOWLEDGEMENTS

2.1 Thanks to others who have assisted and contributed

This thesis would not have been possible to write without support and assistance from many persons, colleagues and organisations who have willingly and enthusiastically engaged in discussion to provide experience and details related to operations in the Barents Sea.

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Erik Hamremoen, Statoil, for information related to helicopter operations in general and in the Barents Sea in particular.

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Representatives of Transocean, Noreco and SAFE who provided interviews and experience with operations in the Barents Sea.

Representatives of Simon Møkster Shipping who provided useful critique of the rescue scheme for long haul flights in the Barents Sea.

I must also thank my wife, Eli, for support, commenting this document to help make it comprehensible and keeping our home operating for the last 6 months. From the autumn it is my turn to do the same for her as she embarks on her master's degree.

2.2 Thanks to supervisor

Professor Ove Tobias Gudmestad, University of Stavanger, who has shown a keen interest in this work and provided excellent guidance and encouragement.

2.3 Thanks to sponsors

The Norwegian Petroleum Safety Authority who, together with the University in Stavanger, has developed this course and sponsored my participation leading to a master's degree.

3 ABSTRACT

3.1 A briefing on the objective of the work

All year petroleum activity is not possible in the Barents Sea with regard to emergency preparedness unless sufficient attention is given to critical factors influencing evacuation and rescue.

The objective of this thesis is to examine conditions relevant to evacuation and rescue of personnel from facilities operating in the Barents Sea. We are concerned with the boundary between situations that we can manage within emergency preparedness, procedures, technology and the situations where we may not be able to expect success. Certain situations may not be covered by emergency preparedness procedures due to conscious decisions that are made in the process of risk and emergency preparedness analysis, the selection of acceptance criteria and situations of hazard and accident. Limiting factors can be identified within the areas of human, technology, operational or organisational perspectives. Experts are normally aware of the limitations that are "designed into the system". Limitations should be dealt with openly and honestly within a risk management regime.

3.2 Information about the limitations of the report

The report considers the Norwegian sector of the Barents Sea north of the Norwegian mainland, south of Bjørnøya and extending eastwards towards the Norwegian/Russian border that came into effect in 2011. This corresponds roughly to the area that is open for exploration and exploitation of petroleum resources in the Norwegian sector of the Barents Sea.

3.3 A briefing of the methods that are used

Emergency preparedness for the petroleum activity in the Barents Sea is examined based on:

- Risk management theory: Risk Analysis, ALARP, Emergency Preparedness Analysis and Defined Situations of Hazard and Accident (DSHA).
- Examination of literature pertaining to emergency preparedness and survival in cold climates and remote areas.
- Performing analysis of barriers using event trees, bow ties and networks to identify critical issues related to successful emergency preparedness.
- Examination of information gathered from relevant accident investigation reports related to maritime and aviation accidents.

- Performing interviews to gather experience from operations in the Barents Sea and to triangulate the results of analysis and calculations.
- Performing example calculations relevant to evacuation and rescue.

3.4 The most important results

Every effort should be made to prevent the need for emergency preparedness resources and if required, evacuation, survival and rescue equipment should perform satisfactorily in order to eliminate or reduce injury and loss of life. Weather conditions in the Barents Sea are such that certain critical technical solutions may not be appropriate in some circumstances. Immersions suits are critical to survival of persons in the sea and should be used with caution outside of the design envelope. Helicopters are equipped with floatation systems that may be insufficient in sea states that are currently accepted for transport flights. It can be difficult to rescue persons from lifeboats in harsh weather and this may pose an extra threat to survival if ice accretion threatens the stability of the vessels. The useful operational window of equipment and a person's ability to use the equipment should be known and activities should be planned within this envelope.

3.5 Major findings and conclusions

The lack of infrastructure and long distances combined with the climatic conditions of the Barents Sea lead to challenges that require special consideration and management. Performance requirements related to medical evacuation of ill or injured persons will be challenged as activity moves further north and away from mainland Norway. Compensating measures will need to be implemented to ensure that the need for emergency preparedness resources is reduced at the same time as improving access to these resources as the need cannot be eliminated.

As work has progressed on this thesis, it has become increasingly clear that it is insufficient to only consider the traditional regimes of emergency preparedness within the area of evacuation and rescue. In the case of an accident involving many injured persons, there is a challenge with regard to the capacity of the public health services in Northern Norway. This is further aggravated by large distances and limited resources for transportation. In order to prevent the loss of life, the availability of emergency health services onshore must be considered when evaluating the total acceptability of petroleum operations in the Barents Sea.

Increased awareness of the physical and psychological limitations of a person and the limitations of evacuation, survival and rescue equipment is required combined with improved planning of activities based on this knowledge.

Departure criteria for helicopter transport should be developed to ensure a reasonable prospect of rescue under the prevailing conditions during the flight.

Ice accretion remains an issue that requires attention particularly for emergency response vessels, lifeboats, fast recovery daughter craft and man overboard boats.

Emergency response vessels should be designed to retrieve lifeboats from the sea in a broad range of sea conditions and as far as reasonably practicable be able to perform this operation close to the limit of the conditions that can be anticipated.

Improved access to medical assistance onboard the facility is required due to distance and unpredictable weather conditions. Improved health requirements and screening of personnel who will work on facilities in the Barents Sea is recommended.

All year activity everywhere in the Barents Sea is only possible if comprehensive risk analysis is performed, the ALARP process applied and necessary measures are put in place to compensate for the specific challenges of the area.

3.6 Recommendations for further work

Research helicopter ditching and accidents in the sea to identify critical issues related to escape and survival in order to improve helicopter underwater escape training.

Research voluntary safety training involving developing tolerance to cold water and dealing with a stressful environment during escape from a helicopter and subsequent survival in the sea. Evaluate the benefits compared to current helicopter underwater escape training.

Develop a decision support tool based on a comprehensive set of departure criteria for helicopter flights.

Develop a civilian helicopter in flight refuelling system (HIFR) suited for use in the Arctic.

Develop suitable methods for evacuation in cold climates where sea conditions can vary from calm to violent storm or even hurricane in open water conditions to many varieties of ice types and cover.

4 INTRODUCTION

There is an assumption that a large part of the world's undiscovered petroleum resources are located in the Arctic. This has caused increasing interest in the High North. The Barents Sea in particular is one of the areas where it is expected to find large petroleum resources [27 p12], and petroleum related activity is increasing in the Barents Sea. Optimism is rising due to recent hydrocarbon discoveries on Skrugard, Havis and Norvarg, the agreement reached for the border with Russia, the planned start of production on Goliat 2013 and the announcement of the 22nd concession round in Norway. There will potentially be all year activities (year round exploration activity & permanent production installations: subsea, floating or fixed) in the Norwegian sector of the Barents Sea.

4.1 Problem

Hypothesis: All year petroleum activity is not possible everywhere in the Barents Sea with regard to emergency preparedness unless sufficient attention is given to critical factors influencing evacuation and rescue.

What critical factors influence emergency preparedness, rescue operations and survival in the Barents Sea? Can these critical factors be managed effectively? The critical factors and limitations are evaluated in a human, technology, operational and organisational perspective.

Humans: A person can limit successful emergency preparedness operations because they are not able to use the equipment properly (lack of competence). There may be reasons (individual, mental and physical strength) that make them unable to use the equipment or act correctly under prevailing conditions in an emergency situation. Human limitation is of particular concern in the case of cold weather and winter darkness.

Technology: Emergency equipment has inherent technical limitations. Safe and successful use of the equipment cannot be guaranteed if used outside the design envelope.

Operations: Operational measures and procedures are often defined in order to increase safety. If these are violated or the assumptions are neglected, they may no longer provide the intended protection.

Organisation: The organisation sets the framework within which humans (H) operate (O) equipment (T). The decisions made within an organisation have a direct impact on the performance and safety level of the organisation. For example, the organisation, during risk management processes, may choose not to have emergency preparedness for rare events. This is a conscious decision that defines a limiting condition for performance in given situations.

4.2 Reasons for choice of problem

The objective of this thesis is to examine conditions relevant to evacuation and rescue of personnel from facilities operating in the Barents Sea. The boundary between situations that can be managed within emergency preparedness procedures and technology and the situations where failure may be expected are of interest when making decisions to perform an operation. Certain situations are not covered by emergency preparedness procedures due to conscious decisions that are made in the process of risk and emergency preparedness analysis and the selection of acceptance criteria and situations of hazard and accident. Other limiting factors can be identified within the areas of human, technology, operational or organisational perspectives. Experts are normally aware of the limitations that are "designed into the system". These limitations are not necessarily well communicated to society but may be exposed in the case of an accident. This may lead to a media crisis and public outrage if an accident should occur and emergency preparedness appears insufficient compared to society's expectations. Limitations should be dealt with openly and honestly in a risk management regime.

4.3 A brief description of the methods

Emergency preparedness for petroleum activity in the Barents Sea is analysed with regard to issues that may be critical to success during all year operations.

A study of search and rescue (SAR) in the United Kingdom using a Bayesian Belief Network has been used as a basis when starting to identify critical issues. This has been compared with literature regarding emergency preparedness, survival in cold climates and remote areas and information gathered from relevant accident investigation reports related to maritime and aviation accidents.

The results of risk analysis and emergency preparedness analysis have been used to identify situations that occur and need to be planned for in order to avoid the loss of life. Incidents or "defined situations of hazard and accident" (DSHA) that have occurred and unfortunately, occur with a significant frequency are investigated. Accident investigation reports are reviewed to gather information that is critical to evacuation, rescue and ultimately survival. The findings from these activities have been used in analysis of barriers using bow ties and event trees to identify critical issues related to successful emergency preparedness in the Barents Sea.

Calculations have been performed to investigate issues affecting the availability and capacity of rescue resources for incidents that may occur far from shore.

Interviews have been used to gather experience from persons who are familiar with operations and conditions in the Barents Sea. The interviews have been used to triangulate and test the results of analysis and calculations.

Finally some recommendations are offered to improve the overall probability of survival and success in emergency preparedness operations in a remote area and a cold climate.

4.4 The limitations of the report

This report concentrates on the phases of evacuation and rescue. Escape within or on a facility to the location of the means of evacuation is considered being outside of the scope of work. The area considered is limited to the Norwegian sector of the Barents Sea south of Bjørnøya and extending eastwards towards the Norwegian/Russian border. This area is enclosed by the red and blue lines as shown on the map in figure 1.

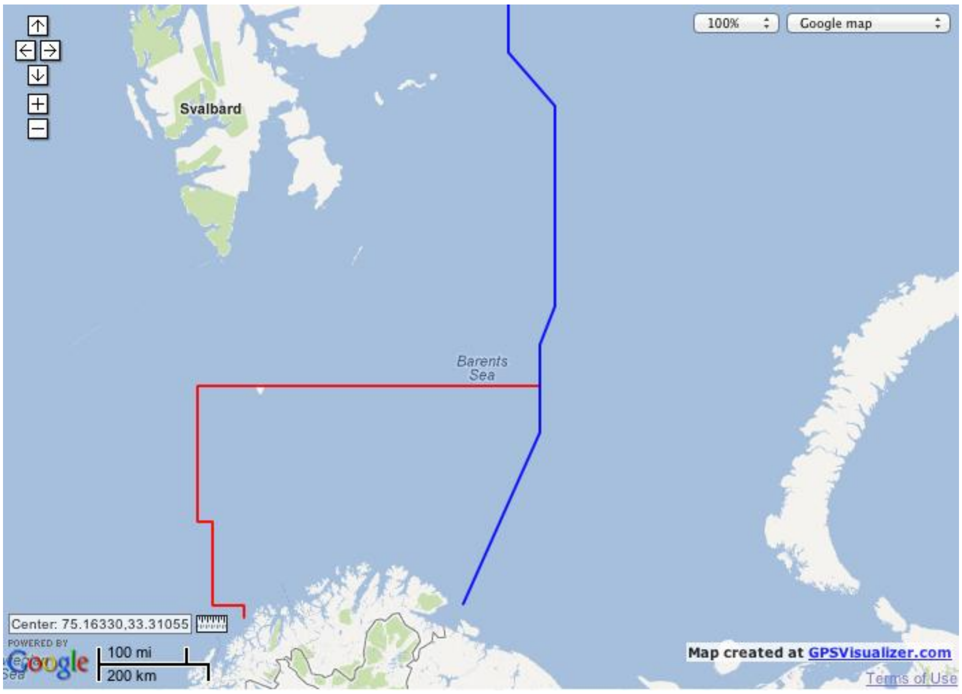

Figure 1, Map of the area and the Norwegian/Russian border in the Barents Sea [78 & 87]

The border between the Norwegian Sea and the Barents Sea is defined by the International Hydrographic Organization as *a line joining the southernmost point of West Spitzbergen to North Cape of Bear Island, through this island to Cape Bull and thence on to North Cape in*

Norway at 27°45'E [98]. In this report, the Norwegian sector of the Barents Sea is defined as the area from 15°E to the Norwegian/Russian border at 37°E and from 70°N to the latitude of Bjørnøya at 74,5°N. This corresponds roughly to the area of the south western Barents Sea that is or will soon be opened for petroleum activities [87]. The Norwegian/Russian border from the coast through the Barents Sea to the North Pole has been disputed for approximately 40 years. In September 2010 the border dispute between Norway and Russia was resolved and an agreement was signed [78]. The border is shown as the blue line in figure 1.

Methods for anti-icing, protecting vessels and structures against ice accretion, and for the removal of ice, de-icing, are not discussed in detail this thesis. Information on this subject is available in the following documents:

- Assessment of Superstructure ice protection as Applied to Offshore Oil Operations Safety, Charles Ryerson, April 2009 [55]
- Secure launch of lifeboats in cold climate, looking into requirements for winterisation, S. Torheim and O.T. Gudmestad, 2011, [43]

4.5 Government premises for the area

The Norwegian government has stated its visions, ambitions and strategies for the High North and the petroleum industry in a white paper to Parliament in 2012 [28]. In addition to the regulations, important documents, for example white papers to Parliament, have been published which define frame conditions [27-33]. It is important to bear this in mind when evaluating evacuation and rescue in the Barents Sea.

The petroleum sector is one of the most important industries in Norway. The petroleum industry is characterised by high risk potential for harm to persons, the environment and material assets. After the Alexander Kielland accident in 1980, there has been consensus in government and the petroleum industry that the activity must be performed with the lowest possible reasonable risk of injury and accidents. The Norwegian government's Soria Moria declaration of 2005 stated that the petroleum industry in Norway should be world leaders in the area of Health, Safety and Environment. This vision reflects and reinforces long and systematic work to strengthen HSE in the sector [27].

Management

There is a regulatory requirement that the activities shall be carried out in a prudent manner based both on an individual and an overall assessment of all factors of relevance for planning and implementation with regard to health, safety and the environment. A high level for health, safety and the environment shall be established, maintained and further developed, cf. Frame Regulation § 10 [9]. The key requirement to further develop and continuously improve the level of health, safety and environment is well known and an established principle for the petroleum industry [27 p280].

The Norwegian Ministry of Labour underpins that the principles of holistic management and continuous improvement are two particularly important preconditions for achieving improvements in the safety level [27 p280].

Visions for the High North

The high north is Norway's most important strategic priority for foreign policy. The key foreign policy objectives in the high north are to safeguard peace, stability and predictability and to ensure a comprehensive ecosystem based management protecting biodiversity and thereby providing a basis for sustainable exploitation of resources [28 p19].

It is Norway's ambition to be a leader in key areas of wealth creation in the north and the best steward of the environment and resource exploitation in the north. This requires close interaction between national, regional and local authorities, businesses and relevant research institutions [28 p20]. The Government will facilitate the development of petroleum activities in the Barents Sea and ensure that the activities will have positive implications for local and regional wealth creation. It is important that there is a good basis for sound resource management and sustainable development in this region. This demands high standards of health, safety and environment, that Norway is a leader in research and development and use of technological solutions offshore, and that Norway has robust oil spill response and search and rescue capacity [28 p110&111].

Evacuation

The regulations stipulate that it should be possible to evacuate personnel from the facilities to a safe area quickly and effectively under all weather conditions. The Ministry of Labour emphasizes that it is important that all personnel on board facilities are to be evacuated quickly in a dangerous situation, regardless of weather, and will ensure that the PSA follows up the issue [27 p301].

Emergency preparedness in the High North

The Arctic is a region characterized by long distances, difficult climate and relatively few rescue resources. Three factors are therefore essential. First the prevention of accidents is important because the consequences for personnel and the environment may be greater with accidents in the North. Secondly, cooperation between countries is essential for the effective utilization of available rescue resources and to execute rescue as quickly as possible. Finally, it is important to note that time factors, distances and the climate will render certain actions impossible, no matter how large resources are provided for emergency services.

It is therefore important that participating companies and their sector organizations work systematically to reduce the risk of accidents and in the event of an incident are able to handle deal with a crisis with their own resources to a greater extent than is necessary in other sea areas. The Government wants to promote transparency concerning the challenges, development of knowledge and experience transfer [28 p101].

Summary of visions, ambitions, goals and strategies

- The Barents Sea (High North) is a prioritised area of strategic importance to Norway.
- Norwegian petroleum industry shall be world leaders in HSE.
- It is Norway's ambition to be a leader in key areas of wealth creation in the north and the best steward of the environment and resource exploitation in the north.
- The industry shall further develop and continuously improve the level of health, safety and environment.
- All personnel on board facilities are to be evacuated quickly in a dangerous situation, regardless of weather.
- The Government wants to promote transparency concerning the challenges, development of knowledge and experience transfer.
- The industry shall work systematically to reduce the risk of accidents and be able to handle (resolve/deal with) a crisis with their own resources.

4.6 Regulatory requirements

Unless specifically stated, reference to regulations in this thesis means the common Norwegian HSE regulations issued jointly by the Norwegian Petroleum Safety Authority (PSA), the Norwegian Climate and Pollution Agency (CPA) and Norwegian Board of Health Supervision (BHS). The combined regulations are comprised of the Framework Regulation [9], the Management Regulation [10], the Activities Regulation [11] and the Facilities Regulation [12].

The overruling requirement is that all activities shall be performed in a prudent manner as stipulated in the Frame Regulation §10 [9]

The activities shall be prudent, based both on an individual and an overall assessment of all factors of relevance for planning and implementation of the activities as regards health, safety and the environment. Consideration shall also be given to the specific nature of the activities, local conditions and operational assumptions.

A high level for health, safety and the environment shall be established, maintained and further developed.

The Norwegian regulations are built around the requirement of functionality. The regulations refer to industry standards and norms where the authorities have found that the safety level required by the regulation can be met by using the referenced standard. This is a principle laid down in the Frame Regulation § 24 [9].

4.7 Requirements set by industry bodies

When the responsible party uses a standard referenced in the guidelines to the regulations, it can normally be assumed that the regulatory requirements have been met [9]. It is in the industries' own interest to develop standards that the authorities can refer to in the guidelines to the regulations. Some of the most commonly referenced standards and norms are the international standards developed by ISO and the Norwegian standards developed by the Petroleum industry and known as Norsok standards.

In addition, the industry has developed guidelines through the Norwegian Oil Industry Association (OLF). These guidelines are normally not referred to in the regulations but are an important contribution to a common set of requirements for the industry. The OLF guidelines for emergency preparedness and for helicopter operations are referred to in this thesis.

4.8 History of petroleum activities in the Barents Sea

The information in this section is the result of an analysis of Barents Sea exploration well data gathered from the Norwegian Petroleum Directorate's fact pages on Internet [92]. Background information for this section is provided in appendix A.4.

Exploration in the Norwegian sector of the Barents began on 1st June 1980 with Treasure Seeker drilling well 7120/12-1 for Norsk Hydro. The well was permanently abandoned as dry with weak hydrocarbon shows on 12th October 1980

Exploration in the Barents Sea was a summer activity from the first exploration wells in 1980 until 1986. During this period there were normally two or more rigs drilling in the region. This period has been the most active exploration period so far. Ross Rig and Polar Pioneer were the first rigs with a full winter drilling program starting in the winter of 1987/1988. From 1987 until 1994 exploration became an all year activity but predominantly a winter activity. Normally there was one rig active, occasionally two in this period.

After a period of low or no exploration from 1994 to 2004, exploration is increasing. In the period from 2000 to 2011, exploration has been an all year activity. Predominantly there has only been one rig active at a time, drilling being performed mainly in autumn and winter.

There is all year production on the subsea Snøhvit field, started in 2007. The first manned production installation will be the Goliat FPSO planned to be installed in 2013. New field developments can be expected in the near future for the Skrugard and Havis fields.

As a curiosity it can be mentioned that the exploration well drilled furthest from mainland Norway in the Barents Sea was operated by Norsk Hydro using Polar Pioneer in 1992 on block 7316/5-1. The well location was 73.51997°N, 16.43325°E, ca 217 NM or 402 km from Hammerfest.

4.9 The 22nd concession round

On the 2nd November 2011, qualified companies were invited to nominate blocks of interest for the 22nd concession round. The Norwegian oil and energy minister, Ola Borten Moe, announced at the Arctic Frontiers conference in Tromsø in January 2012 that interest was particularly high for the Barents Sea. A total of 181 blocks were nominated in this area, the highest number ever [79].

"In this nomination, there has been particular interest in our northern seas, which confirms the Barents Sea as an exciting and internationally attractive petroleum province. This represents a great opportunity for the entire region. Exploration of all opened areas is also very important to achieve further activity, employment and spin-offs in all of Norway," said the oil and energy minister, Ola Borten Moe [79].

A total of 37 companies have nominated blocks on the Norwegian continental shelf and the Barents Sea. The Norwegian Oil and Energy department (OED) has reduced the number of blocks from the nominated 181 to 72 open for application. OED has mainly concentrated on blocks that are of interest to more than one operator. A number of the blocks are at or beyond 200 NM from Hammerfest. Maps are included in appendix A.6. The invitation to apply for participation in blocks in the 22nd round was announced on 26th June 2012 and the granting of new licenses is scheduled for the spring of 2013 [80].

In connection with the announcement of opening the 22nd concession round for application, the oil and energy minister, Ola Borten Moe said, *"We are now experiencing record levels of interest in the Barents Sea. With 72 of a total of 86 open blocks the Barents Sea stands out as the sea of opportunity in the 22nd round. We have had very encouraging exploration results, and I will now give the industry access to new areas related to these discoveries"* [80].

5 METHODS *(incl. theory)* AND MATERIALS *(background/facts)*

5.1 Introduction to methods employed for analysis

Emergency preparedness for petroleum activities in the Barents Sea is examined based on:

- Risk management theory: Risk Analysis, ALARP, Emergency Preparedness Analysis and Defined Situations of Hazard and Accident (DSHA).
- Examination of literature pertaining to emergency preparedness and survival in cold climates and remote areas.
- Performing analysis of barriers using event trees, bow ties and networks to identify critical issues related to successful emergency preparedness.
- Examination of information gathered from relevant accident investigation reports related to maritime and aviation accidents.
- Performing interviews to gather experience from operations in the Barents Sea. This information is used to triangulate results of analysis and calculations.
- Performing example calculations relevant to evacuation from facilities far from shore.

5.1.1 Research design

Qualitative scenario analysis is used as the main research method in this thesis. Bow tie analysis, supported by event trees and influence networks have been used to examine the effects of findings in literature and interviews when applied to specific scenarios.

5.1.2 Review of the strength and weaknesses of the selected methods

The main analysis in this thesis is performed using event trees and bow ties to identify critical issues. The analysis has been performed with a basis in literature and interviews with personnel who have experience from the Barents Sea. A qualitative approach has been used rather than quantitative. This approach has been chosen because the goal has been to screen the information to identify critical issues that should be given consideration when planning petroleum activity in the Barents Sea. A more detailed qualitative and quantitative approach should be employed by those venturing into the Barents Sea to identify issues and optimise the choice of solutions through risk analysis and ALARP process.

The quality of the work done in this thesis may have been improved if it had concentrated on one detailed analysis rather than on three situations and a proposal for rescue on long haul routes. The work in this thesis is potentially too broad to give an in depth insight into specific issues. However, the author considers that attention drawn to specific issues is documented, justified and does provide a basis for increased awareness of challenges to evacuation and rescue in petroleum activity in the Barents Sea.

5.1.3 Reliability and validity of data

When performing interviews with persons involved in the petroleum industry, trade unions and search and rescue organisations, it has been made clear that a student is enquiring about relevant issues and that information provided is for the student's thesis and not to an employee of the Norwegian Petroleum Safety Authority (PSA). Even though an attempt has been made to keep the two different roles of the author separate, it cannot be ruled out that the response to the questions has been influenced by the fact that the student is an employee of the Norwegian authorities. There is, however, no reason to believe that information has been withheld or that incorrect information has been provided.

When considering information found in investigation reports from previous accidents, it is important to be aware of the relevance of the information in today's operations. There have been many improvements made to equipment, personnel competence and the way in which operations are performed today. The information gathered from investigation reports has been of a generic nature related to the challenges posed during evacuation and rescue. The aim has been to evaluate issues related to methods and operations that are relevant independently of a specific make of equipment.

Another issue that needs to be addressed is the experience that the author has gained from working with these issues in the capacity of an employee of the PSA. It cannot be ruled out that the author has been influenced in discussions with colleagues at the PSA and his supervisor at the University of Stavanger. It is difficult to separate oneself from the experience one has and the knowledge base that has been developed. There is a danger that the author is biased and interprets findings in light of prior knowledge rather than taking a broad and open look at the collected data.

A final comment needs to be made concerning the authors background as an engineer rather than a social scientist. This may lead to a bias towards placing greater emphasis on technical aspects rather than the role of social issues like the role people, operations and organisations play in robust evacuation and rescue systems.

5.1.4 Use of interviews

Interviews have been conducted with personnel working at the Joint Rescue Co-ordination Centre in Bodø, members of the crew on the Sea King rescue helicopter stationed at Banak and Sola, personnel responsible for helicopter operations a petroleum company, personnel responsible for HSE in a trade union, personnel in a drilling entrepreneur company, an operating company and personnel with experience in operation of emergency response vessels. These persons have a considerable combined experience of issues that are important to both emergency preparedness and helicopter operations in the Barents Sea. They have provided valuable insights into the specifics of the problems examined in this thesis.

5.1.5 Use of literature

There is extensive literature available covering specific issues related to operation in cold climates, the Barents Sea and issues related to survival at sea after marine or aviation accidents. As far as possible, it has been an objective to confirm information found in literature sources through interviews with persons familiar with operation in the Barents Sea. The documents that are used as a source of information in this thesis are listed in the reference section. Some of the most important documents that have been used in order to triangulate and verify critical issues regarding survival and rescue of persons at sea and in cold climates are listed below:

- Frank Golden, Michael Tipton, 2002, Essentials of Sea Survival, Human Kinetics [7]
- Lisa Norrington, John Quigley, Ashley Russell, Robert Van der Meer, 2008, Modelling the reliability of search and rescue operations with Bayesian Belief Networks, Reliability Engineering and System Safety no. 93 p949-949 [44]
- CAP 641 Report of the Review of Helicopter Offshore Safety and Survival, Civil Aviation Authority, First published February 1995 [63]
- Cold challenges, Health and working environment on facilities in northern areas, 2010, Thelma/PSA [45]

Work by Golden and Tipton [7] is referenced in the Thelma [45] and NATO [26] documents reducing independence between sources to some extent. The following documents are not used directly as references in this thesis, however they provide useful background information supporting the issues discussed.

- International Maritime Organisation (IMO), May 2006, Guide for cold water survival, MSC.1/Circ.1185, Ref: T2/6.01 [25]

- NATO Research and Technology Organisation, February 2008, Survival at Sea for Mariners, Aviators and Search and Rescue Personnel, RTO-AG-HFM-152 [26]

5.1.6 Bow Tie analysis

The Bow Tie method and its associated diagrams will be used to analyse barriers in place to ensure that threats, hazards and consequences are managed. The bow tie method has been developed by combining fault tree analysis, event tree analysis and the concept of barriers.

5.1.7 Networks

Lisa Norrington, John Quigley, Ashley Russel and Robert van der Meer have published a paper "Modelling the reliability of search and rescue operations with Bayesian Belief Networks". It considers the effectiveness of Search and Rescue operations coordinated by the UK Maritime and Coastguard Agency [44].

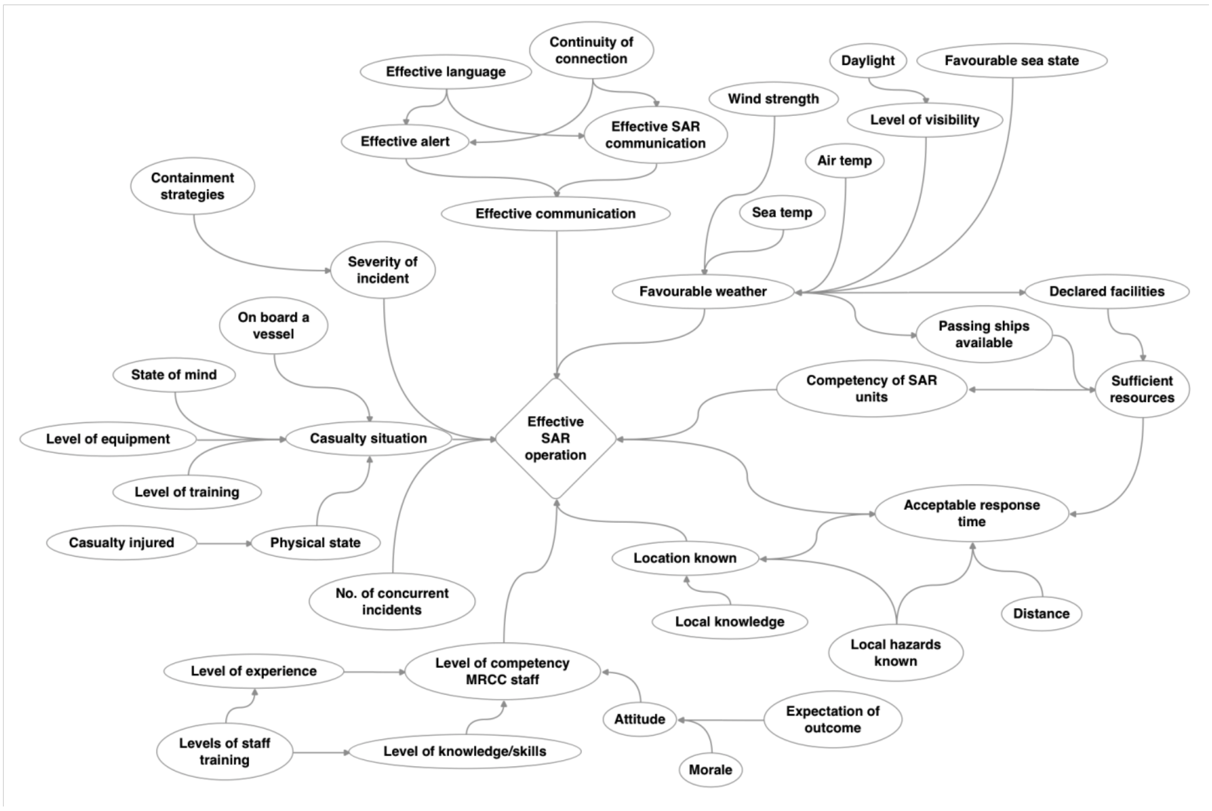

Figure 2, Bayesian Belief Network used in analysis of UK marine rescue centres [44]

They have used the method to evaluate the probability of success of a search and rescue operation in light of a reorganisation of the Main Rescue Coordination Centres (MRCC) in the UK. The probability of success of a search and rescue operation has, however not been calculated in this thesis. The Bayesian Belief Network (BBN) in figure 2 above has been used as a starting point to identify and evaluate critical issues that have an effect on the outcome of evacuation and rescue operations in the Barents Sea. The network provides a basis to explore relevant issues influencing the processes of evacuation and rescue. These issues are explored in section 6 using event trees and bow tie diagrams to identify barriers to protect against negative development of situations of hazard.

5.1.8 Use of calculations

Great circle routes providing the shortest distance between to points are used. In the cases where distances have been analysed, the Haversine formula [93] is used to calculate the distance and the heading. The calculations have been verified by using an Internet program [94] based on the Vincenty method of great circle calculation [56]. The effect of wind on the helicopter trajectory has also been considered and calculation of the ground speed based on air speed and wind speed has been performed. The position of airports is taken from Airport-Data.com on Internet [96]

5.2 Risk management

5.2.1 Risk analysis

In this thesis, emphasis is placed on some processes within risk management without covering all aspects of the concept. The focus is on risk analysis, acceptance criteria, defined situations of hazard and accident (DSHA) and the concept of ALARP (as low as reasonably practicable).

Risk is a natural part of society and is controlled through risk management processes. We cannot choose to live without risk and therefore, we define an acceptable level for the residual risk that we cannot remove. Risk analysts may approach risk with a scientific rationality, while ordinary persons, those who must live with decisions based on the mechanical and mathematical results of risk analysis, have a perception of the risk. A person's perception is often complicated and based on a variety of issues that are difficult to define with numbers. Risk perception has to do with how individuals understand, experience and deal with risk. Risk has to do with all aspects of a person's perception of danger and hazards, the consequences the hazards may lead to and what they consider to be acceptable risk levels [1 p40].

Risk acceptance criteria (RAC) are defined in advance of a risk analysis process. RAC set the upper limit of risk that will be accepted. They are also used as a decision basis when evaluating choice of solutions and risk mitigation measures. Acceptance criteria are usually defined for risk of loss or damage to persons, environmental and economic values [1 p153]. It is normal to define a lower limit of risk. If the results of the risk analysis calculations in a quantitative risk analysis (QRA) fall below the lower limit, the risk level is considered as negligible. The area between the upper and lower risk acceptance level define the ALARP area. Risks that fall within this range should be dealt with employing risk-reducing measures. Risk reducing measures should be identified and implemented to reduce the risk level in the ALARP area unless there is a disproportionately large negative relationship between the benefits (risk reduction) and disadvantages (cost or practical) to achieve reduction [4 p118].

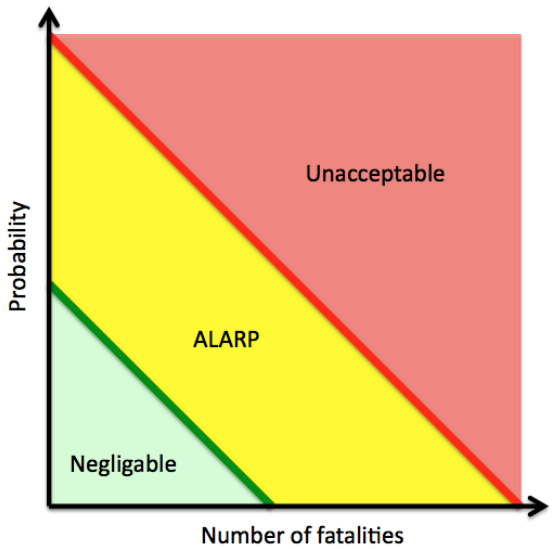

Figure 3 Risk acceptance criteria and the ALARP principle

Most persons have a relationship to risk and risk acceptance criteria. In the simplest form, we have an opinion about the "chances" that we are willing to take. It can be anything from buying a lottery ticket to investing large sums of money on the share market (economic risk), or cycling to work or participating in an extreme sport like skydiving (risk of personal injury or even death).

Risk analysis is based on generic statistical information of events at similar facilities or activities that are to be analysed. Based on this information and taking into account plant-specific factors (e.g. safety systems) a prediction of the probability of events occurring at the facility being analysed is calculated. This is not an exact science because one cannot predict the future of the plant by analyzing possible scenarios and potential outcomes. The results of a risk analysis are an estimate of the future, the plant's history cannot be written in advance. According to Aven et.al., "*It is important to distinguish between the statistical analysis of historical data, and assessments of what the world will look like in the future"* [1 p42].

Based on the risk that one has chosen to accept, an assessment of potential situations of hazard and accident is performed. These situations are called defined situations of hazard and accident (DSHA) and govern the design of emergency response measures that are established. If the probability of an event occurring is above a predefined level, emergency response measures need to be established in order to take care of the consequences. In this process the "worst case" events often have such a low probability that the emergency response plans are not designed to cover these rare events. Contingency plans for a worst-case event, may well be developed but the requirements set for performance of emergency response will not necessarily be met if the event occurs. An example of this would be a disaster with 1000 critically injured persons. The selection of DSHAs and associated performance requirements for emergency response measures, set significant limits on how contingency measures are dimensioned. At this stage a latent future crisis may be designed into the system if "probability" turns out not to be on our side and the "improbable" event occurs. If an accident outside of the design criteria occurs at some stage in the lifetime of the system, attention may be drawn to an apparent lack of emergency response if the limitations have not been communicated. This may occur even though the situation is handled properly within the plan, acceptance criteria and performance requirements.

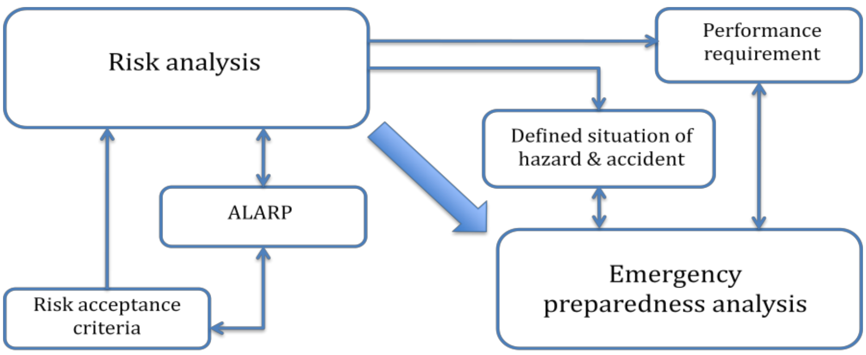

Figure 4 Simplified model for risk and emergency preparedness analysis

The process of risk analysis and emergency preparedness analysis is a requirement in the regulations, cf. Management Regulation § 17 [9] and is normally performed according to the methods described in Norsok Z-13 [17].

It is important that the data used in risk analysis is relevant and qualified for the activity. Recognised sources for generic data for use in risk analysis are listed in Norsok Z-013 Annex D. This generic data may not be relevant for the Barents Sea without further qualification. Norsok Z-013 recommends the use of data from the Gulf of Mexico and the UK for helicopter transport [17 p83]. Data from the Gulf of Mexico will need to be evaluated carefully for relevance. The UK document deals with some issues that are relevant to the Barents Sea and is a reference document in this thesis [63].

5.2.2 Emergency preparedness

An emergency is defined as *a hazardous event that cannot be handled by normal measures and requires immediate action to limit its extent, duration or consequences* [15].

Emergency preparedness includes all technical, operational and organisational measures to prevent a hazardous situation developing into an accident, or that prevents or reduces the harmful effects of an accident. In the petroleum industry it is common to limit emergency preparedness to the measures that are implemented under the leadership of the emergency response organisation [1 p121].

The process of risk and emergency preparedness analysis leads to defined situations of hazard and accident (DSHA). The DSHAs are the hazardous and accidental events that will be used for dimensioning of emergency preparedness and the basis for the emergency preparedness plan [17]. According to the Activity Regulation § 73, the responsible party, i.e. the operator, shall establish emergency preparedness measures for the DSHA's [11]. A list of typical DSHA's for operations on the Norwegian continental shelf is shown below [41].

- Acute pollution to sea
- HC leak in process area, process fire or explosion, riser leak followed by fire/explosion
- Loss of well control, blowout followed by fire/explosion
- Fire in living quarters, electrical rooms, auxiliary equipment
- Falling object
- Personal injury/illness (Medevac)
- Man overboard when working over the sea
- Loss of control of radioactive source
- Ship on collision course, collision with platform supply vessel
- Personnel in the sea in connection with emergency evacuation
- Helicopter accident in the sea, helicopter accident on facility
- Accident with radioactive source
- Terror or act of sabotage
- Epidemic
- Extreme weather (forecast)

There are four regions on the Norwegian continental shelf where operators have chosen to cooperate and share resources, typically helicopters and vessels. These four areas are the Southern Fields, Troll-Oseberg, Tampen and Halten. There are 7 DSHAs defined within the regime of area emergency preparedness and specific performance requirements are associated with each of these [41].

- Man overboard when working over the sea
- Personnel in the sea following a helicopter accident
- Personnel in the sea following an emergency evacuation
- Danger of ship collision
- Acute release of oil
- Fire with the need for external assistance
- Acute medical situation (injury, illness) with need for external assistance

In 2008 the PSA engaged Preventor to examine the status of emergency preparedness in the Norwegian petroleum industry. It was found that one of the most common situations requiring emergency preparedness resources is the need for ambulance transport or medical evacuation (medevac) of a patient from an offshore facility to a place where medical services can be provided onshore [41 p78]. As illustrated in figure 5 below, on the right it can be seen that for the period from 2003 to 2007, there was a fairly constant annual total of approximately 230 ambulance flights per year. In the same figure 5, on the right it can be seen that the number of flights per 1000 persons within each area varies greatly form ca 6 to 30 per 1000. The reason for the large difference between the Southern Fields and Halten is given as being the fact there are more scheduled transport flights to the densely populated Southern Field area compared to a relatively sparsely populated area on Halten. In the southern area it is possible to send less urgent cases onshore using a scheduled transport flight rather than deploying a SAR helicopter [41 p44].

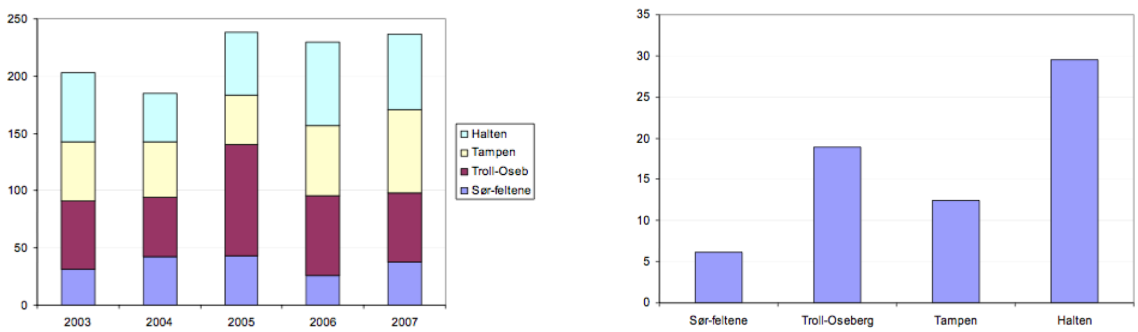

Figure 5, Left: Total number of ambulance flights for all SAR helicopters on the Norwegian shelf for the period of 2003 to 2007, Right: Number of ambulance flights per 1000 employees for all SAR helicopters on the Norwegian shelf [41 p44]

In the Barents Sea it is common that there is only one scheduled flight to the rig per day, 5 to 7 days per week. The need for ambulance flights in the Barents Sea is presumed similar to Halten due to few transport flights in the area at present.

Examples of performance requirements for capacity and response times for rescue of personnel are given in OLF guideline 064 Establishing Area Emergency Preparedness [21]. The requirements shown in table 1 are relevant for this thesis. This is a guideline developed by responsible parties in the petroleum industry and is adopted as a standard by most operators. It is normal that operators do their utmost to meet these requirements for their emergency response.

Table 1: Performance requirements

DSHA	Rescue means	Capacity	Performance requirement
Injury or illness of personnel requiring external medical assistance	SAR helicopter Transport helicopter 330 SAR helicopter	1-2 persons	Personnel shall be at hospital within 3 hours
Personnel in the sea due to a helicopter accident	SAR helicopter MOB boat	21 persons	All personnel retrieved from the sea within 120 minutes

5.2.3 Risk communication

Laymen generally have little confidence in experts and one can observe that the confidence of the public is important for success in achieving effective risk communication. It is necessary to take into account the lack of confidence among the public and create good processes with a genuine dialogue between the public and experts. Aven et.al. emphasize that through dialogue, it is important to capture the knowledge and insight of others in addition to the experts, "*Considerations of the politicians, laymen or interest groups, are important for the risk perception that prevails in society. Their reviews are often based on important knowledge and insights that experts do not capture in their considerations*" [1 p41]. A crisis of confidence may be alleviated by ensuring processes where interest groups, public and affected parties are given the opportunity for real participation and influence [1 p42].

Trust plays a central role in risk communication and Renn suggests seven components of trust that must be considered for successful risk communication [3 p223],

- *Perceived competence; Degree of technical expertise in meeting an institutional mandate*
- *Objectivity; Lack of bias in information and performance as perceived by others*
- *Fairness; Acknowledgement and adequate representation of all relevant viewpoints*
- *Consistency; Predictability of arguments and behaviour based on past experience and previous communication efforts*
- *Sincerity; Honesty and openness*
- *Faith; Perception of goodwill in performance and communication*

- *Empathy; Degree of understanding and solidarity with potential risk victims*

Risk communication is a balance between many factors. One does not wish to frighten persons by giving them information that may be difficult to relate to and that can make persons afraid or unduly worried [2 p62]. At the same time it is a goal to convey sufficient information so that persons are aware of the dangers that exist and why one does not take into account the extremely rare events. Trust can be built between the parties by admitting that unlikely events can occur and that emergency preparedness may not be designed to handle such situations.

When risk is communicated, the process can be described in a transmitter/receiver relationship in which the message is affected and can be transferred neutrally, enhanced or weakened. Feedback from receiver to transmitter is exposed to similar influences. Distortion or disturbance by the media occurs in a similar way as in analogue electronic communications. The phenomenon is often referred to as “social amplification of risk” and is described in detail by Renn [3]. Everything that leads to a non-neutral transfer of the message from source to receiver can be described as noise. This may be the media, individuals, groups, organisations or agencies that distort the message. The sketch below is an interpretation of the communication process and is a simplification of the basic elements of Renn's model of communication and the social amplification of risk.

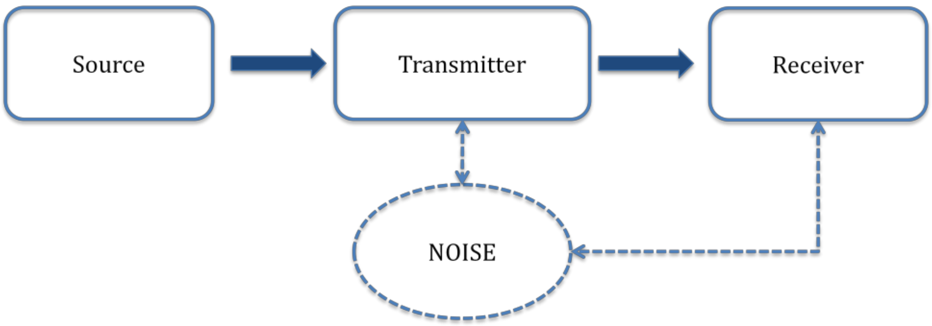

Figure 6 Simplified communication model

5.2.4 Process – risk analysis, risk communication, risk perception

Based on the theory of social amplification of risk and the simplified communication model in figure 6, the process of risk analysis, risk communication and the public’s perception of risk is illustrated in the upper half of the diagram in figure 7. The lower half of the diagram illustrates a similar process for communication and perception in the case of an accident. Similar communication, perception and feedback mechanisms operate in both cases. These two processes are drawn in parallel to illustrate that decisions made in the risk process can be decisive for the perception of the accident.

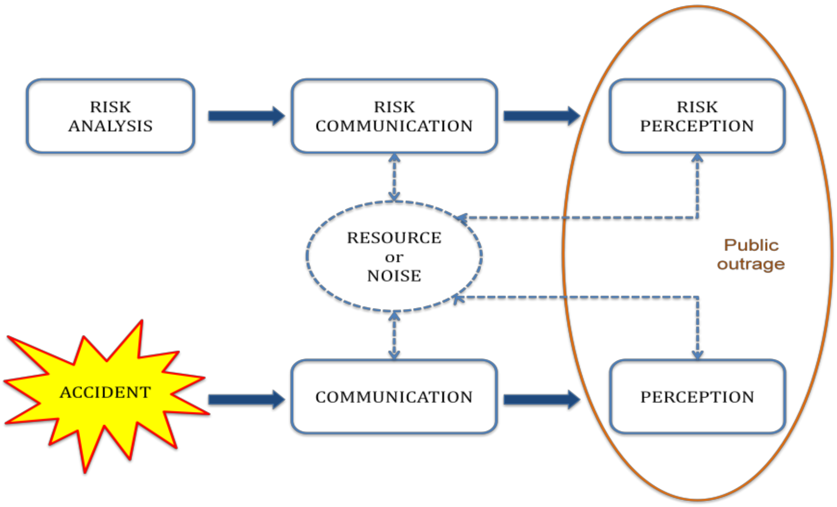

Figure 7, The path to public outrage

Individuals, groups and organizations that can easily be perceived as noise, can make an important contribution to the process. If the process does not take sufficient account of the "noise" it can result in public outrage. With the appropriate involvement of individuals, groups and organizations one may utilise these resources and achieve a positive contribution to the process thereby reducing the probability of “noise and public outrage”. It may be prudent to prepare one’s organization with regard to the mechanisms of interaction with third parties regarding involvement, trust, communication and perception.

5.3 Barriers

The Management Regulation § 5 requires that barriers shall be established to reduce the probability of failures, hazards and accident situations developing and thereby limit possible harm and disadvantage. Where multiple barriers are required for protection there shall be sufficient independence between the barriers. Personnel shall be aware of the barriers that have been established and which function they are intended to fulfil. Furthermore, personnel shall be aware of barriers that are impaired or not functioning and measures shall be implemented to compensate for and reinstate failed or impaired barriers. Performance requirements shall be defined for the technical, operational and organisational elements that make up a barrier function. Performance of barriers can include capacity, reliability, accessibility, efficiency, integrity, robustness and ability to withstand loads [9].

The PSA has provided the following definition of a barrier: *A barrier is a technical, operational or organisational element that when functioning alone or together shall reduce the possibility that a fault, hazard or accident occurs or will limit or prevent damage* [61].

Norsok Z-013 defines a safety barrier as a *physical or non-physical means planned to prevent, control, or mitigate undesired events or accidents*. *Barrier elements are the physical, technical or operational components in a barrier system*. A barrier system is *designed and implemented to perform one or more barrier functions*. The barrier function is intended *to prevent, control or mitigate undesired or accidental events* [17].

The concept of technical barriers is fairly easy to grasp as it employs technical measures like instrumentation, valves, fire extinguishing systems etc. to provide the barrier element. The distinction between the concepts of operational and organisational barriers is perhaps more difficult to define. It has not been possible to find adequate definitions of these terms. It is more common to list and exemplify the types of barriers that are defined as operational or organisational.

The following is an attempt to define the terms:

Technical barriers: Physical barriers in the form of a technical means or measure, typically a physical device, structure or piece of equipment.

Operational barriers: Non-physical barriers that are dependent upon actions of a person, often controlled by procedures and supported by training and experience.

Organisational barriers: Non-physical barriers in the form of strategies, plans or methods developed as a framework for activity by and within an organisation.

In an attempt to illustrate the concept of the function of barriers the following definition is derived from many sources and illustrated in figure 8 below; a barrier is a technical, operational or organisational element that, when functioning alone or together with other barrier elements will break a chain of events and stop or limit the negative development of the situation.

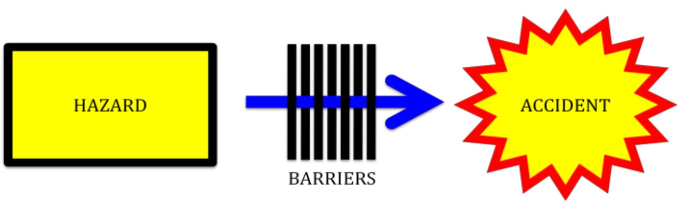

Figure 8, Concept of hazards, barriers and accidents

In 1961 Gibson introduced an energy model, a concept of separating a source of energy or a hazard from a victim or a vulnerable situation by placing a barrier between them. William Haddon popularised this perspective in 1970 by introducing the concept that accidents occur when harmful energy in the absence of barriers is allowed to have an effect on an object or victim [60 p15]. This basic concept is still valid and is the basis of engineering practice when endeavouring to eliminate or prevent accidents [60 p17]. The concept has been developed to encompass physical and non-physical elements referred to as technical, operational and organisational barriers. James Reason's Swiss cheese model is a common illustration of how multiple barriers can be impaired, illustrated as holes, and lead to the failure of the defences resulting in an accident [60 p18].

The Bow Tie method and its associated diagrams will be used to examine barriers in place to ensure that threats, hazards and consequences are managed. The bow tie method has been developed by combining fault tree analysis (on the left in the bow tie), event tree analysis (on the right in the bow tie) and the concept of barriers. These elements are defined in accordance with the Bow Tie method and the training material developed by CGE Risk Management Solutions. Text in cursive indicates definitions taken from the course material [70].

Hazard: *Anything that is a source of potential loss or damage*

Top event: *A point in time that describes the release or loss of control over a Hazard*

Threat: *A possible direct cause that will potentially release a Hazard by producing a Top Event*

Threat barriers: *A barrier that prevents the release of a Hazard by acting against a Threat or Top Event*

Threat control: *A function that prevents or influences a real chain of events in an intended direction*. Threat controls have a proactive function between the threat and the release of the hazard that may lead to the top event if unchecked. They are effective on the left hand side of the bow tie.

- Threat control (elimination): *A proactive function that removes or avoids the threat by designing the problem out of the fault chain on the left side of the bow tie*.
- Threat control (prevention): *A proactive function that does not remove the threat but is a preventive measure that can stop or obstruct the fault chain on the left side of the bow tie*.

Recovery measure: *A barrier that acts on the likelihood or severity of a potential consequence*. Recovery measures have a reactive function between the top event and the consequence and reduce or limit the effect of the top event. They are effective on the right hand side of the bow tie.

- Recovery measure (reduction): *A reactive control that decreases or lessens the effect of the top event thereby limiting the consequence*.
- Recovery measure (mitigation): *A reactive control that lessens the significance of the consequence*. *Takes effect after the consequences have become apparent and works to minimise further consequences*.

Consequence: *A potential event resulting from the release of a Hazard, which directly results in loss or damage*

Escalation factor: *A condition that leads to increased risk by defeating or reducing the effectiveness of barriers (barrier decay mechanism, defeating factors)*

Escalation factor control: *A barrier that manages the conditions that reduce the effectiveness of other barriers*

An evaluation version of BowTie XP software has been used to generate the bow tie diagrams. They have subsequently been modified with a licensed version of the software [71].

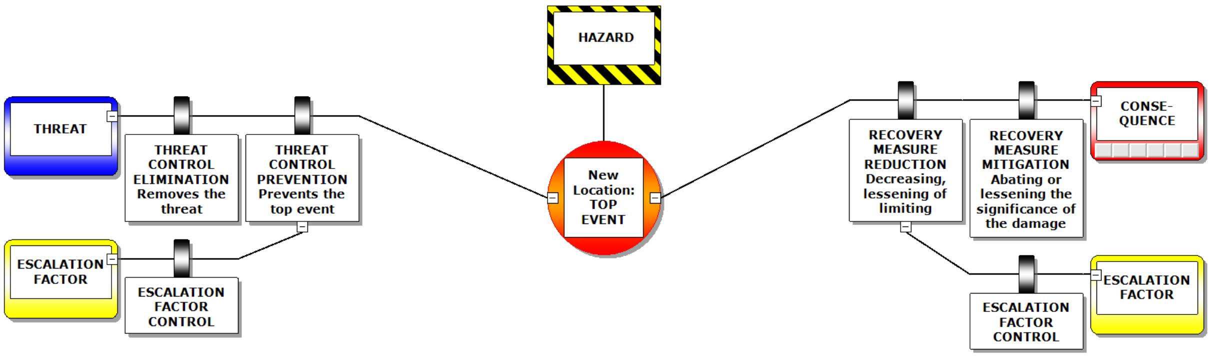

Figure 9, Elements of a bow tie analysis [70]

The diagram in figure 9 above illustrates the building blocks of a bow tie analysis. In order to analyse a complex sequence of events it may be necessary to use a tiered or multi level bow tie analysis as illustrated in figure 10 below. In a tiered analysis a consequence becomes a new top event in the next bow tie and is analysed for threats, threat control, recovery measures and consequences. The process can be repeated until the required level of sophistication is achieved in the analysis.

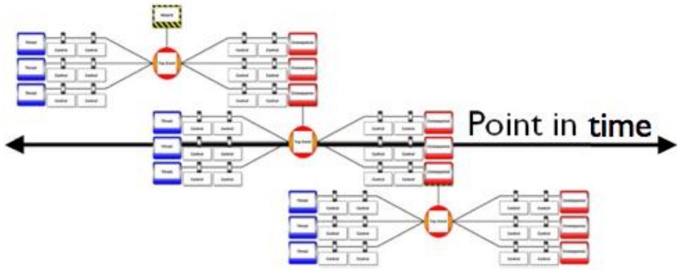

Figure 10, Tiered or multi layered bow tie analysis [70]

A barrier analysis should address the following issues:

- What is the barrier? (System and elements)
- What shall the barrier eliminate or prevent (left hand side)?
- What shall the barrier reduce or mitigate (right hand side)?
- How can the barrier be weakened or defeated? (Escalation factor)
- How can weakening or defeating the barrier be eliminated or prevented? (Escalation factor control)
- What is the performance requirement of the barrier?
- How can the barrier and performance requirements be tested?
- Are there dependencies between the various barriers in the protection system?

5.4 Escape, Evacuation and Rescue

The terms escape, evacuation and rescue are defined in ISO 15544:2010 [15] and the goals of these activities are given in ISO 19906:2010 [14]

Escape

Escape is defined as the *act of personnel moving away from a hazardous event to a place where its effects are reduced or removed* [15]. *The goal of escape is to ensure that, in an emergency, personnel move to a place of relative safety on the installation, consistent with the specified performance standards* [14]

Evacuation

Evacuation is defined as a *planned method for leaving the installation in an emergency* [15]. *The goal of evacuation is to ensure that personnel leave the installation to a place of relative safety outside the hazard zone consistent with the developed performance standards* [14].

Rescue

Rescue is defined as *the process by which those who have entered the sea directly or in survival craft/life rafts are retrieved to a place where medical assistance is available* [15]. *The goal of rescue is to retrieve evacuees to a place of safety* [14].

5.4.1 Evacuation

There are basically two types of evacuation, precautionary and emergency. Precautionary evacuation is carried out when a situation is seen to be developing and personnel onboard the facility that are not essential to the emergency operation are evacuated. Emergency evacuation is performed when a situation has deteriorated beyond control or appears to be developing so quickly that it is deemed safest to evacuate all personnel from the facility.

Table 2, Definition of means of evacuation as given in ISO 15544:2000 and ISO 19906:2010

	ISO 15544 [15]	ISO 19906 [14]	Example
Primary means of evacuation	*Preferred method of leaving the installation in an emergency which can be carried out in a fully controlled manner under the direction of the person in charge*	*Method of evacuation that can be carried out in a controlled manner and under the direction of the person in charge and the preferred means*	Helicopter
Secondary means of evacuation	*Method of leaving the installation in an emergency which can be carried out in a fully controlled manner under the direction of the person in charge, independent of external support*	*Controlled means of removing personnel from the installation, which can be carried out independently of external support*	Bridge, lifeboat
Tertiary means of evacuation	*Method which relies considerably on the individual's own actions*	*Method of leaving the installation that relies heavily on an individual's own actions, is used when the primary and secondary methods are not available, and has an inherently higher risk*	Life raft, ladder, escape chute
Preferred means of evacuation		*Method of choice for evacuating personnel based on the lowest risk and on the familiarity, frequency of use, availability and suitability for prevailing conditions* *Note Normally, this is the method used to transfer personnel to and from the offshore location*	Bridge Helicopter

The various choices of evacuation method have been defined in the ISO standards 15544 and 19906. The definitions are provided and compared in table 2 above. The preferred means of evacuation is normally helicopter, which is almost always the method used for precautionary evacuation. Emergency evacuation will most often be conducted with the facilities own evacuation means, e.g. lifeboats. This may be necessary if there is not time to wait for the arrival of helicopters or if it is not possible to land helicopters due to the nature of the incident, e.g. a gas leak. External resources may be called upon to assist in the evacuation of injured or seriously ill persons.

Norsok S-001 defines and prioritises preferred means of evacuation for facilities that are not connected by a bridge as:

1. Helicopter
2. Free-fall lifeboats
3. Escape chute with life rafts

For installations connected by bridge to other facilities the bridge is considered as the primary means of evacuation [18].

Helicopter evacuation

Helicopter evacuation is considered the preferred method of dry evacuation from a facility. The performance or availability of helicopters is governed mainly by visibility. Under normal operations, a minimum cloud base of 200 to 300 meters is necessary and a horizontal visibility of 0,5 nautical mile. Helicopters do not normally operate on a helicopter deck in winds over 55 to 60 knots, Beaufort 10. Normal transport flights to installations may be performed at wind speeds with gusts up to 60 knots [22].

In an emergency situation the operational limits can be exceeded at the discretion of the pilot [22]. The success of an operation in adverse weather conditions will be dependent on wind speed, visibility, fog or snow and the pilot’s ability to operate under the prevailing conditions. The transport helicopters are the main resource for evacuating personnel in an emergency situation. The Norwegian rescue service, 330 squadron, has an excellent record in rescue operations under adverse conditions. The capacity of the rescue service is limited relative to the large number of persons who can be onboard a facility operating in the Barents Sea.

Marine evacuation – lifeboats and life rafts

In 1998 the Norwegian Petroleum Directorate (NPD) engaged Det Norske Veritas (DNV) to prepare a technical report on evacuation and rescue means. The report is titled Evacuation and Rescue Means, Strength Weaknesses and Operational Constraints, YA-795, Norwegian Petroleum Directorate, 1998 December [40].

According to the report, evacuation by freefall lifeboat is considered the most reliable. The report was made prior to the discovery of weaknesses related to free lifeboats in 2005 and subsequent years. The Norwegian Oil Industry Association (OLF) has performed extensive work related to issues with freefall lifeboats. The OLF work has resulted in many improvements and the new DNV-OS-E406 for freefall lifeboats. The Norwegian Shipowners' Association (NR) has performed studies of the issues related to davit launch lifeboats. The NR work has resulted in recommendations for improved competence, training and maintenance [76].

For operation in the Barents Sea, keeping the lifeboats and release mechanisms free of snow and ice in order to ensure launching is of particular concern [43 & J08]. Ice accretion on lifeboats in the sea is also of concern [65]. These issues are discussed later in this report.

Escape chutes and life rafts have a limited operational window [40]. They generally cannot be used in conditions over Beaufort 8. The prevailing conditions in the winter and a polar low would probably disqualify the use of escape chutes and life rafts in the Barents Sea for considerable periods of the year. The issue of protection from the cold will need to be looked into specifically for persons in a life raft.

The performance of these evacuations is summarised in table 3 below.

Table 3, Performance of evacuation means defined by Beaufort scale [40]

Type of evacuation means	Documented performance	Uncertain performance
Davit launched life rafts	In Beaufort 6	In Beaufort 8
Escape chute	In Beaufort 6	In Beaufort 8
Davit launched lifeboats	In Beaufort 7	In Beaufort 10
Free fall lifeboats	In Beaufort 12	In Beaufort 12

Immersion suits

Personal survival suits are required for all persons working on a facility, cf. Facility Regulation § 45, Survival suits and life jackets [12]. A new immersion suit, Hansen

Protection SeaAir suit, was developed and taken in use in 2007/2008 for helicopter transport and offshore survival.

Entry into the water during winter should be avoided as far as possible especially in temperature conditions where the air temperature is below 0°C and the sea temperature is low. In the Barents Sea high priority should be given to dry escape. The main functions of an immersion suit are to protect against initial cold shock, provide a breathing system for escape from a helicopter in the sea, keep the person afloat, warm and dry, protect from hypothermia and drowning and ensure that the person retains mobility and dexterity, the use of limbs, hands and fingers so that they can take care of themselves [58].

The Norwegian petroleum industry represented by Eni Norge, Total, Nexen and Dong ran a project with SINTEF in 2010/2011 to evaluate the suitability of the SeaAir suit for use in the Barents Sea [84]. The project identified areas that need improvement i.e., better protection of hands and feet and improved functionality of the spray hood and the buddy line [59]. Eni has later initiated a new project to develop an improved survival suit for the Barents Sea based on recommendations and findings in the 2010 project [85]. SINTEF has granted permission to disclose the following information from the reports that are referenced in this thesis [86].

Survival suits are normally tested according to ISO 15027-3:2002 Immersion suits, Part 3: Test methods [16]. This standard requires a water temperature below 2°C and an air temperature below 10 °C. There is no requirement for wind, waves or overflowing of water during the test. The tests performed by SINTEF in 2010 involved wind, waves, overflowing of water, lower air and water temperature [59]. The water temperature was ca. -0,1°C and the air temperature ca. -11°C. Ice accretion on the spray hood, difficulty using the buddy line and cooling of fingers and toes were experienced during the tests. One person completed the full three hour duration time for the test while 4 persons did not. Mean core temperature did not fall more than 0,5°C indicating that no one became hypothermic during the test. The cooling of hands, fingers and feet are not critical for hypothermia but may impair the person's ability to take care of them self and assist in their own rescue. The project made the following recommendations [59]:

- An extra layer of woollen underclothing should be worn or improve suit insulation,
- Improve protection of hands and feet,
- Improve functionality at low temperatures for the spray hood and the buddy line.

Medical evacuation – MEDEVAC

Medical evacuation of sick or injured personnel is termed "medevac" and is a special case of evacuation usually involving a small number of persons, most often only one. This is normally an unplanned activity, and the need can arise at any time of day or night. Decisions, based on the nature of the case, are made by a duty doctor regarding the urgency and need for a medevac operation. The safety related to flying conditions and the urgency of performing the operation may need to be balanced against the consequences of postponing or cancelling a medevac flight.

Ambulance and SAR missions in the Barents Sea are challenging due to long distances, severe weather conditions, and periods of arctic winter darkness. Missions with the Sea King SAR helicopter stationed at Banak have been performed with high regularity and in most cases the missions were rational when considering medical gain and operative risk [57].

For medical evacuation of injured of sick persons it is normal to set minimum requirements for capacity and response time for the means of evacuation, i.e. helicopter [20].

5.4.2 Rescue

Once lifeboats or life rafts have been launched and are outside of the hazard zone, the issue of rescuing survivors is paramount. Personnel onboard intact lifeboats or life rafts are considered to be in a safe situation. Studies show, however, that a person may become apathetic or willing to take large risks in order to get away from the survival craft. Injured persons can be rescued by helicopter provided the operation can be performed without injury to personnel. Transfer of uninjured personnel to an emergency response vessel (ERV) should not be attempted before the sea is sufficiently calm [40 p113].

Table 4, Mean and maximum duration of wind conditions [40]

Beaufort	Mean duration (hours)	Maximum duration (hours)
6	20 to 25	
7	15	60
8	12	30
9, 10, 11	8 to 10	

In connection with an evacuation and rescue operation it is of interest to consider how long a harsh weather condition may last. An indication is presented in table 4 above. The data are based on information from the North Sea and the Norwegian Sea. We can deduce from the data that the duration decreases as the intensity of the weather increases. It is necessary that the lifeboat be equipped to sustain life for the duration of the harsh weather period at the location of an evacuation [40 p113].

If a helicopter or rescue vessel is unable to operate under the prevailing conditions, the survivors will have to ride out the weather and wait for an operational window that allows rescue. The time required to ride out a particular condition will depend on how severe the weather is and how long it is since it started. It is therefore relevant to study the effects of icing on a lifeboat during this time span. The performance of various rescue means is given in table 5 below. The information regarding the rapid response rescue vessel is new information that is added to the table.

Table 5, Performance of rescue means defined by Beaufort scale [40]

Type of rescue means	Documented performance	Uncertain performance
Rescue basket	In Beaufort 5	In Beaufort 7
Rescue zone with net	In Beaufort 6	In Beaufort 8
Dacon scoop	In Beaufort 6	In Beaufort 8
MOB boat	In Beaufort 6	In Beaufort 8
Sealift	In Beaufort 7	In Beaufort 11
Fast recovery craft	In Beaufort 8	In Beaufort 11
Rapid response rescue vessels	In Beaufort 9	
Helicopter	In Beaufort 10	In Beaufort 12

Helicopter rescue

The preferred and most common means of rescue of persons is performed by helicopter. The petroleum industry operates a number of search and rescue (SAR) helicopters that are generally manned by ex servicemen from military operated SAR services. Many of the crew had been trained and served in the Royal Norwegian Air Force 330 squadron [J07].

Rescue crews on SAR helicopters report that night vision goggles (NVG) combined with infrared light from a source on the helicopter is currently the best method for finding a person in the sea when it is dark. The combination of NVG and IR light is reported to be more effective than forward-looking infrared cameras/radar (FLIR) [J02].

Emergency response vessel

Custom designed third generation rapid response rescue vessels or emergency response vessels (ERV) are now available [103 & 104]. They are specially designed to launch and recover a fast recovery daughter craft (FRDC) or man overboard (MOB) boat from a slipway in the stern. The slipway can also be used to recover a lifeboat from the sea. An operator of these vessels has experience in the use of the slipway in sea conditions up to 11 to 12 m waves [J03].

Rescue to conventional standby vessels requires the use of lifting equipment or the transfer of persons from the lifeboat to the standby vessel by a MOB boat, potentially limited to Beaufort 6, or FRDC limited to operate in conditions up to Beaufort 9 [40]. Due to these limitations, there is therefore a good reason to consider the possibility of survivors in a lifeboat having to ride off weather conditions.

In case of ice accretion on an ERV, the captain must know when the vessel is no longer safe. Lifeboats may be expected to ride out a storm with icing conditions and the ERV must be able to do the same [65].

FRDCs are designed to travel at high speed, typically 35 knots, and have a rescue capacity of 21 persons [105]. They are normally between 10 and 13 meters and are equipped with an enclosed wheelhouse. Some production facilities and ERVs are equipped with FRDCs. MOB boats are smaller than an FRDC and do not have an enclosed wheelhouse. MOB boats are also designed to travel at high speed and typically have a rescue capacity of 7 to 10 persons [105 & 107]. Most facilities and all ERVs are equipped with a MOB boat.

5.5 Barents Sea concerns as identified by others

Barents 2020 Work Group 4, Escape, Evacuation and Rescue (EER)

The Barents 2020 project has considered the entire Barents Sea and identified a wide range of issues pertinent to emergency preparedness. A wide range of conditions have been considered and it is recommended that evacuation and rescue systems must be capable of operation in ice or open water situations as well as being prepared for many other environmental and logistical factors. The major risks and concerns that were identified by the work group include the following [47 p140]:

- *Traditional EER methods may not be appropriate at certain times of the year*
- *Ice conditions, icebergs and sea ice, cold weather, wind and other weather conditions*
- *Lack of logistics systems and emergency response vessels to support evacuation*
- *Long distances from the potential emergency site to the support bases and other facilities*
- *Shortage of appropriately equipped vessels that may be called on for assistance*
- *Accumulation of ice on external surfaces and its effect on the operation of equipment*
- *Limited amount of time available to react to a particular emergency situation*

- *Effect of cold on human physiology and psychology, equipment, and materials*
- *Lack of experienced personnel and training facilities for evacuation systems which have been proposed for the Barents Sea*
- *Effect of the polar night and extended periods of darkness on personnel*
- *Communication difficulties due to magnetic conditions, lack of satellite coverage and language differences*
- *Possible lack of qualified medical help*

The importance of these risks for any particular facility will depend on the type of facility, function, location and distance from the rescue bases and rescue resources. The risks will be an integral part of the overall risk assessment and emergency preparedness plan for the installation.

Technology and Operational Challenges for the High North

The Petroleum Safety Authority (PSA) commissioned the University in Stavanger (UIS) and International Research Institute of Stavanger (IRIS) with a project to gain an overview of the technology and operational challenges for the High North as seen from the viewpoint of the Petroleum industry. The final report was published in 2011. Important issues influencing emergency preparedness and rescue and are listed below [42]:

- A new regime for emergency preparedness and rescue is required defining the additional requirements for remote EER capability taking into account such factors as distance from permanent services and existing infrastructure, time to mobilise, challenging weather conditions and appropriate evacuation and rescue methods.
- Ice accretion due to precipitation or sea spray may cause problems on facilities by increasing weight, making critical equipment inaccessible or unworkable and damage caused by falling ice. The prediction of icing and methods for preventing or limiting arctic icing need to be addressed.
- Remote locations and activity far from land may be outside the reach of helicopters leading to challenges for logistics, emergency preparedness and rescue.
- Lifeboats for the safe evacuation of personnel from facilities operating in areas where there is a possibility for occurrence of sea ice.
- Weather conditions in the Barents Sea represent a potential risk impact to safe operation. The development of knowledge and technology targeting these issues is necessary to

reduce uncertainty and facilitate adaptation to the environment and leading to safer operations.

5.6 Barents Sea Climate

There are numerous sources of information regarding the climate of the Arctic. The main sources used in this report are ISO 19906:2010(E) [14], and Norsok N-003 Edition 2, September 2007 [19]. In addition, course material (Gudmestad, O.T. 2009) is taken into account and used as background information. The area of the Barents Sea opened for Norwegian petroleum activity corresponds to the southern half of area 1, Western Region in ISO 19906 [14]. This area is described as having a winter climate all year. The following climatic issues have been identified as pertinent to operations in the Barents Sea.

5.6.1 Air temperature

The maximum average air temperature is +4,4 °C with the annual range between +2,0 to +7,0. The maximum air temperature that can be expected in the southwest, near Goliat and Snøhvit, is in the range of 20°C to 25°C. Towards the north and east, the maximum temperature decreases to the range of 15°C to 20°C.

The minimum average air temperature is -7,7 °C with an annual range between -6,0 to -9,0. The minimum air temperatures that can be expected in the southwest are in the range of -15°C to -20°C. Towards the north and east, the temperatures decrease to the range of -20°C to -30°C [14 & 19]. The minimum air temperatures are shown in figure 11 [19].

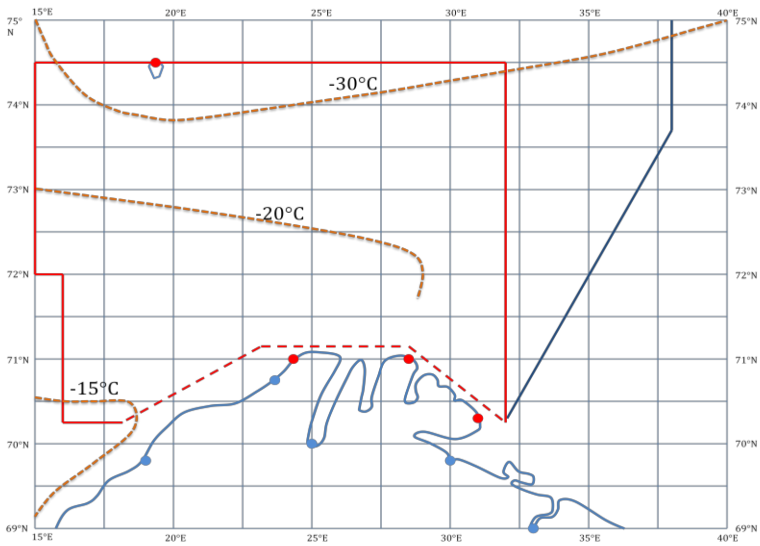

Figure 11, Lowest air temperature with an annual probability greater than 10^{-2} [19]

5.6.2 Sea temperature

The maximum average sea temperature is +7,0 °C with the annual range between +5,0 to +9,0. The maximum sea temperatures that can be expected in the southwest are in the range of 10°C to 12,5°C. Moving towards the north and east, the maximum temperatures decrease to the range of 5°C to 10°C. The minimum sea temperature that can be expected in the southwest is in the range of +2°C to +4°C. Towards the north and east, minimum temperatures decrease to the range of +2°C to -2°C [14 & 19]. Minimum sea temperatures are shown in figure 12.

At Bjørnøya the yearly average sea water temperature is 0,84°C. The average for the winter months, January, February and March is -1,46 °C. The average for the summer months, July, August and September, is 3,43°C [51].

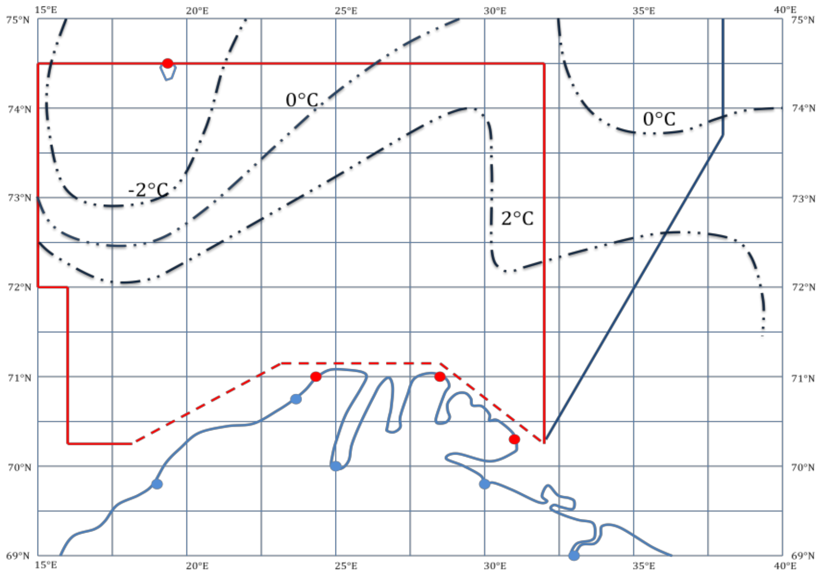

Figure 12, Lowest sea surface temperature with an annual probability greater than 10^{-2} [19]

5.6.3 Visibility

Visibility can be impaired by fog, rain and snowfall. Statistically this can occur for a large number of days during the year. Typically there are 64 days per year with visibility below 2km due to snow and 76 days per year with visibility below 1km due to fog [14]. Measures have been taken to establish internationally agreed fixed shipping lanes lying 30 NM off the coast from the Russian border to Røst, thereby reducing the probability of collision with passing ships. Fog and snowfall that impairs visibility will be an operational issue reducing the availability of helicopter transport and potentially disturbing operation of supply vessels in close proximity to the facility. Severe fog conditions can hinder helicopters performing medical evacuation, precautionary evacuation or rescue operations [68].

At Fruholmen, the horizontal visibility is less than 1000m for 1,51% of the year and less than 10000m for 6,76% of the year. At Bjørnøya the horizontal visibility is less than 1000m 8,58% of the year and less than 10000m 31,76% of the year. These statistics reflect the relative high occurrence of fog in the vicinity of Bjørnøya [51].

5.6.4 Sea conditions

The maximum significant wave height that can be expected in the southwest is 15 m decreasing to 14 m when moving to the north and the east as shown in figure 13 below. Storms can create violent sea and wave conditions disrupting activities and hinder evacuation or survival on the sea [19]. The Norwegian Meteorological Institute's data for the Barents sea indicates that significant wave height Hs is greater than 5 meters in 4,6% of the year in the east (72.58°N, 33.10°E) and 6,61% of the year in the south west (71.58°N, 19.53°E), predominantly in the period October to March [51].

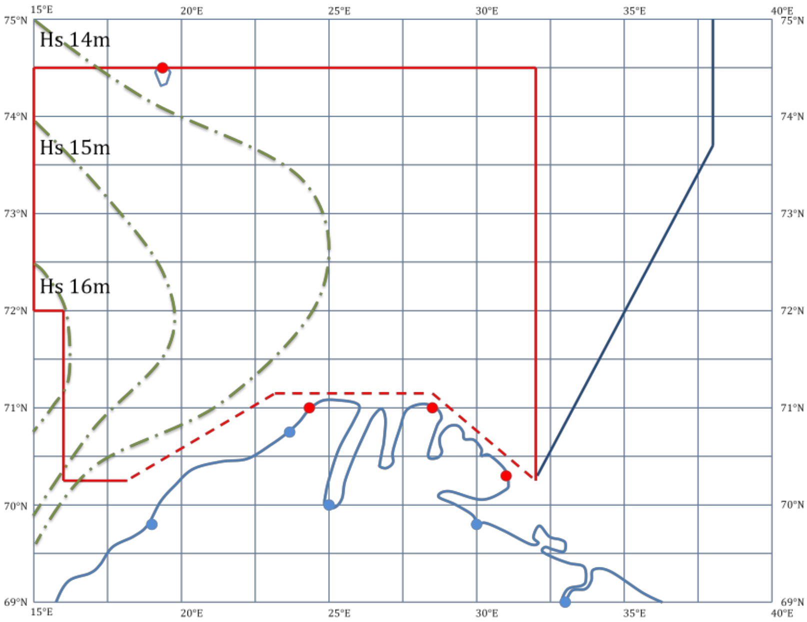

Figure 13, Significant wave height Hs with annual probability greater than 10-2 for sea-states of 3 hour duration [19]

5.6.5 Wind

The 10 minutes average maximum wind speed at 10 m above sea level is 26,6 m/s with the annual range of 25 m/s to 28 m/s. The dominant wind direction during the summer is from the west. The dominant wind direction during the winter is from the northeast. Extreme wind speeds can occur during polar low and polar front conditions [14].

At Fruholmen Fyr, a lighthouse north of Hammerfest, The yearly average wind speed is 13,79 m/s at 10 m above ground level. The average for the winter months is ca 2 m/s higher, the average for the summer months is ca 2 m/s lower [51].

At Bjørnøya, the yearly average wind speed is 12,19 m/s at 10 m above ground level. The average for the winter months is ca 2 m/s higher, the average for the summer months is ca 2 m/s lower [51].

5.6.6 Polar Lows

Polar lows are weather phenomena that are well known from the Norwegian and Barents Sea. The storm or polar low occurs in the season from autumn to winter with a frequency of 2 to 4 per month. Polar lows are a potential threat to all activity in the Barents Sea due to their nature and suddenness with which they develop [66 & 69].

Polar lows develop in a short space of time and have a short lifespan. Typically, polar lows have durations of 6 to 48 hours. They develop swiftly when cold wind blows from the ice covered regions in the north over areas with relatively warm sea. The storm dies or dissipates when it moves over land because the driving force, the warm sea, no longer provides the energy to sustain the wind system. A polar low has a typical diameter of ca. 100 to 500 km making it a relatively small weather system. Typically, a polar low can travel at ca. 15 to 25 knots with the highest observed speed of 52 knots. Winds speeds are typically up to Beaufort force 10 or storm with wind speeds up to 28,4 m/s. Hurricane wind speeds have been observed but are more seldom [69].

The wind is strongest to the west of the centre. The wind decreases in speed to the east of the centre. It is not uncommon that the polar low is accompanied by heavy snowfall. The strong and variable winds can create chaotic conditions on the sea even though there is not enough fetch to build up very large waves. The combination of wind, snow and sea spray can increase the danger of icing on vessels and structures [69].

Polar lows are difficult to forecast due to their rapid movement from the ice edge and the fact that there are few meteorological observation stations in the Barents Sea. Satellite surveillance is necessary to provide reliable forecasts. The coverage provided by satellites is currently not on a full 24 hours basis because the polar orbit only brings the satellite over the area for a limited period each day.

The International Polar Year (IPY) Thorpex research project has led to an increased understanding of the conditions that must be in place for a polar low to develop. There are improved forecasts available for where and when the basic conditions are in place thereby warning of a possible occurrence of a polar low. However, it is still not possible to predict exactly where or when a polar low will develop, only the probability of occurrence in an area. This may improve if there were more meteorological observations points available for the Barents Sea.

For helicopter operations, polar lows are avoided as far as their whereabouts are known or they are detected. Polar lows and weather cells can be detected by weather radar. A route will be chosen around the polar low rather than flying through it. The Sea King pilots have, however, experience of flying through polar lows. Polar lows are not large in extent but have significant air pressure drops, e.g. 20 mbar may be observed. The duration of a flight through a polar low can be from 30 to 45 minutes during which time a wind shift of 180 degrees can be expected. A route around will be selected dependent on the nature of the mission, status of the casualty and fuel availability [J02].

Noer and Lien have made a report on the polar lows that have been observed from 2000 to 2010 [52]. The report covers the area from the east coast of Greenland to Novaya Zemlja and from 65°N to the Arctic ice edge and has registered 139 polar lows in the 11 winter seasons. The map in figure 14 only shows the area of interest in this thesis. There are 44 occurrences during the 11 years suggesting an average frequency of ca. 4 per year for the area being evaluated.

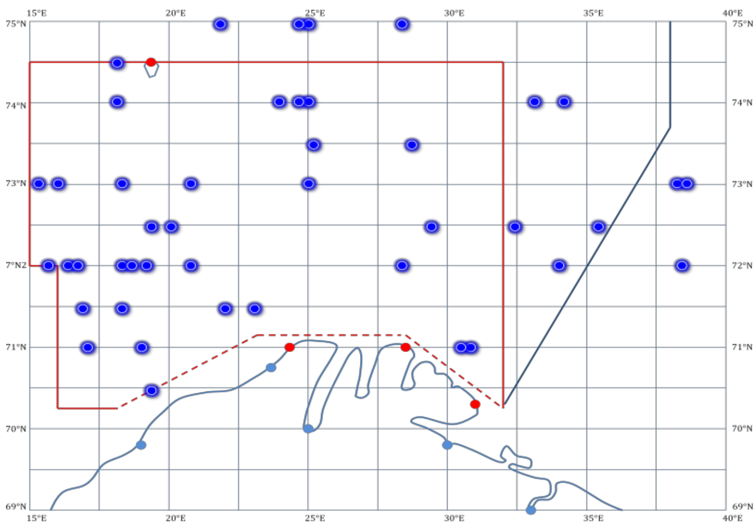

Figure 14, Polar lows registered in the Barents Sea from 2000 to 2010 [52]

An occurrence of a polar low using observed weather data is illustrated in figure 15 below. The actual observations are taken from eklima [90]. The red circles indicate 50 km and 250 km distances from the centre, respectively. There is no information available on the size of the polar low in question. From the observations plotted on the map it appears as though the accompanying winds have reached the coast of Norway and demonstrate a typical wind pattern shown with the red arrows. The observations confirm stronger winds to the west of the centre and an anti clockwise rotation of the storm. The numbers next to the observation points indicate the wind direction, the wind speed and gust in m/s. The observed wind speeds are within the limits for helicopter traffic and evacuation or rescue could be performed during this storm.

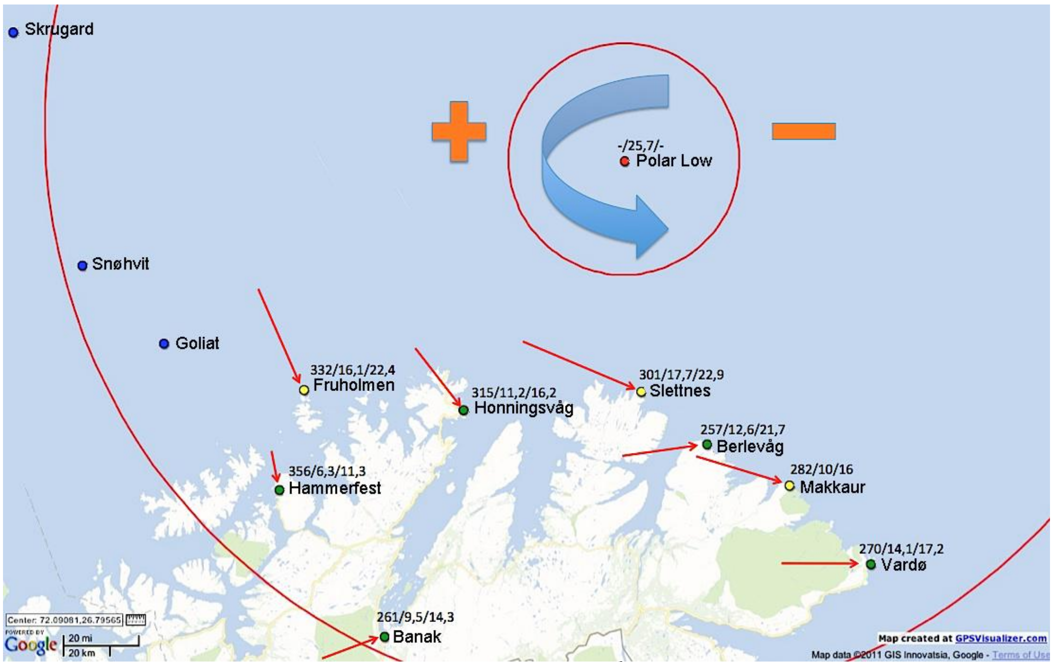

Figure 15, Observation of a polar low 7th January 2009 [52 & 90]

5.6.7 Sea ice and icebergs

The seawater in the Barents Sea will freeze when the water has a temperature between -1,7°C to -1,9°C dependent on the salinity of the water. Sea ice with a return frequency of 100 years normally only occurs north of 73°N and to the east of 31°E. The return frequency for sea ice increases to ca. 10 years at 74°N and ~33°E. It is interesting to note that the area now acquired for exploration due to resolving the border issue with Russia, has a greater probability for sea ice than the areas that are currently opened for activity [14 & 19]. Several large icebergs have been observed south of 74°N and on the coast of northern Norway during 1881 and 1929 [46, 49 & 50].

The map in figure 16 below contains information from 3 sources. The solid lines to the left/west indicate the annual probability of sea ice (light blue) and icebergs (black) as given in Norsok N-003 [19]. The solid lines to the right/east indicate the probability of sea ice (blue) and are based on work by Zubakin et.al. [48 p8]. The blue dashed lines at the top/north indicate the probability of sea ice as given in the Barents 2020 Phase 1 report [46 p14]. Although the Norwegian area currently opened for exploration is considered an ice-free area, developments will need to consider actions of sea ice and icebergs for design loads in order to meet the acceptance criteria of 10^{-4} [77]. Similarly it is of importance to consider sea ice and icebergs when developing operation strategies for structures, vessels and evacuations means that will be employed in the area north of 72,5°N or east of 30°E. This could mean that production units should be considered designed for disconnection in the event of icebergs [64].

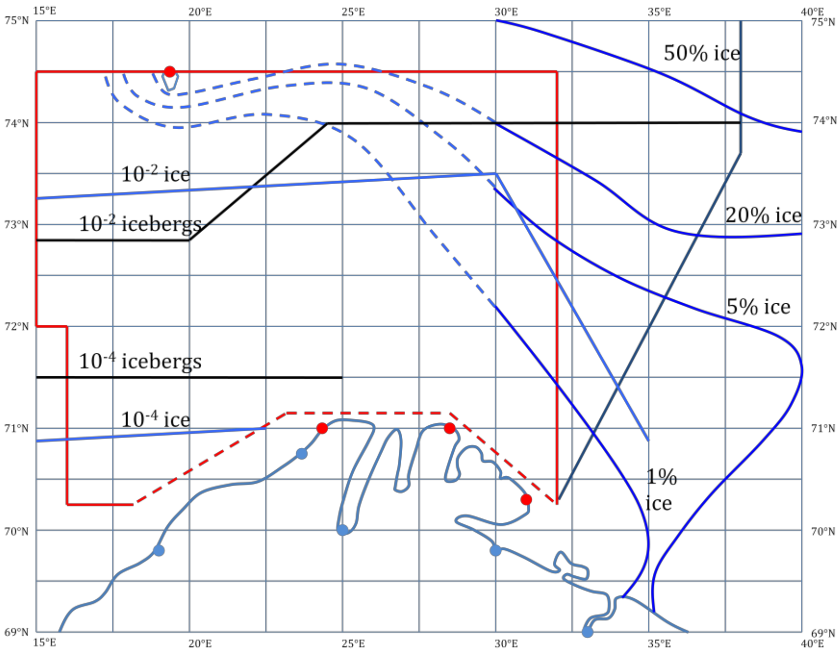

Figure 16, Probability of sea ice and icebergs, annual probability [19, 46 & 48]
The legend is described in the text below.

5.6.8 Summary of main meteorological features

A summary of the main meteorological characteristics of the Barents Sea is shown on the map in figure 17 below. In general it can be said that the wind and waves decrease when moving east while air and sea temperatures and the probability of sea ice increase when moving towards the north east.

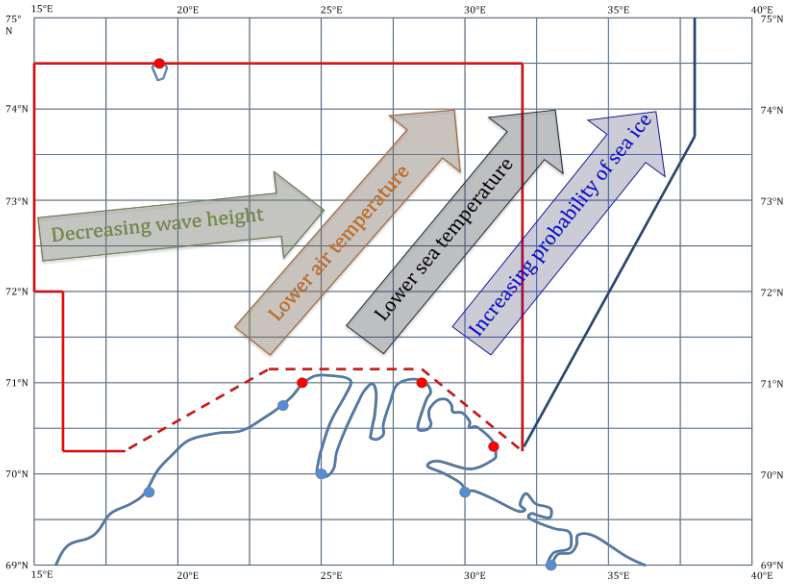

Figure 17, Summary of the main meteorological features of the Barents Sea

5.6.9 Barents Sea Climate – The Future

Successful evacuation and rescue are dependent on the weather conditions at the time of the incident. It is therefore relevant to study the effects of climate change for conditions in the Barents Sea. What changes can be expected? Is there a danger in being "optimistic" about the reduction of ice coverage in the Arctic? Installations can typically have a life span of 10 to 40 years or longer depending on the size of the reservoir. From a discovery is made until a field is in production, there is typically a time span of 5 to 10 years. For fields that are found and not yet developed, or that may be found within the coming years, decisions need to be made about climatic conditions that directly affect both operational and design parameters for a period stretching from today and maybe 50 years into the future. Reliable predictions of meteorological conditions, prudence, caution and possibly conservatism, are of the utmost importance in order to avoid premature decommissioning of facilities.

The Norwegian Polar Institute has published a report that has studied meteorological conditions for the period from 1900 to 2100. Based on historic data and climate models a forecast has been created for the years ahead of us. There is a degree of discrepancy between the results given by the models and it is important to be conscious of the uncertainty this leads to in predictions for the future of the climate [54]. The following is an interpretation of the results presented in the report for the Barents Sea area:

- Temperature for the area is expected to rise between ~2 to 4 °C in the autumn and winter, with a greater increase over land than the sea.

- The frequency of strong wind is expected to increase while the occurrence of polar lows is expected to decrease.
- Precipitation is expected to increase but the season with snow is expected to become shorter.
- The intensity of waves is not expected to change significantly for areas that are already ice free. An increase in significant wave height H_s is predicted from ~2 - 4% with an extreme wave height $H_{extreme}$ increasing by ~2%. The changes can be higher in areas where sea ice recedes.

5.7 Other specific features of the Barents Sea

5.7.1 Icing on vessels

Ice accretion on vessels may threaten the stability of the vessel and in the worst case lead to capsizing [65]. Weather conditions leading to icing on equipment may jeopardise functionality e.g. launching equipment for lifeboats [43] or the function of radar equipment. Climate conditions in the Barents Sea are such that icing on vessels and equipment can normally occur from October to May.

There are two types of icing that need to be taken into consideration for the Barents Sea, atmospheric and sea spray icing. Atmospheric icing occurs in conjunction with low air temperature and precipitation. This form of icing normally leads to smaller amounts of ice developing on structures than sea spray ice accretion. Atmospheric ice has normally a higher density than sea spray ice [5 p191]. Ice accretion caused by sea spray is discussed in this section, as this is the dominant source of ice on structures and vessels.

Sea spray icing is dependent mainly on the following parameters [5 p192]:

- Air temperature: as the air temperature decreases below the freezing point of seawater, ice will be deposited if sea spray occurs.
- Wind speed: increasing wind speed leads to more sea spray and more water in the air to freeze onto the vessel. Beaufort force 6, equivalent to 10,8 m/s, is normally considered as the minimum wind speed for ice accretion to start.
- Sea surface temperature: as the sea surface temperature decreases towards the freezing point, icing will increase as there is less energy that needs to be removed from the sea spray. Seawater normally freezes at -1,9°C in the Barents Sea. The freezing point is

determined by the salinity of the water and less salt in the water leads to a higher freezing point.

- Sea state: as the sea state gets more severe, the wind increases and drives waves that can release sea spray either when breaking or when a vessel sails into the waves. Beaufort force 6 corresponds to waves of Hs=~3m with maximum waves of ~4m.
- Size and type of structure or vessel: ice accretion due to sea spray does not normally occur over 25m above sea level. Sea spray is generally not carried higher than 25m.
- Course relative to the waves and speed: the amount of sea spray developed is a direct result of the speed of the vessel and the angle that the vessels heads into the waves. Decreasing speed and optimising the vessel heading into the waves can reduce icing.

A formula has been developed to predict the rate of ice accretion due to sea spray [5 p197]. The formula takes into account the wind speed (U_a), the freezing point of seawater (T_f), the sea surface temperature (T_w) and the air temperature (T_a). The National Oceanic and Atmospheric Administration (NOAA) have developed the ice accretion predictor (PR).

$$PR = U_a(T_f\text{-}T_a)/(1+0{,}4(T_w\text{-}T_f))$$

Table 6 below illustrates the relationship between the icing predictor (PR) and the rate at which ice can be expected to grow given in cm per hour.

Table 6, Relationship between icing predictor and rate of ice growth [5 p197]

	Light	Moderate	Heavy	Extreme
Icing rate cm/hr	< 0.7	0.7 to 2.0	> 2.0	> 5.0
Predictor	< 20.6	20.6 to 45.2	> 45.2	> 70

Figure 18 below illustrates the relationship between two parameters that are used in the ice accretion predictor. The wind speed in the chart corresponds to the lower limit for Beaufort force 6 to 12, i.e. fresh breeze to hurricane. A fixed air temperature of -10ºC is used to illustrate the effect of decreasing air temperatures. It can be seen that the predictor increases dramatically as the seawater temperature approaches the freezing point. The value of the yellow, orange and red horizontal lines in figure 18 is used to denote an ice growth rate of 0,7cm/h, 2cm/h and 5cm/h respectively.

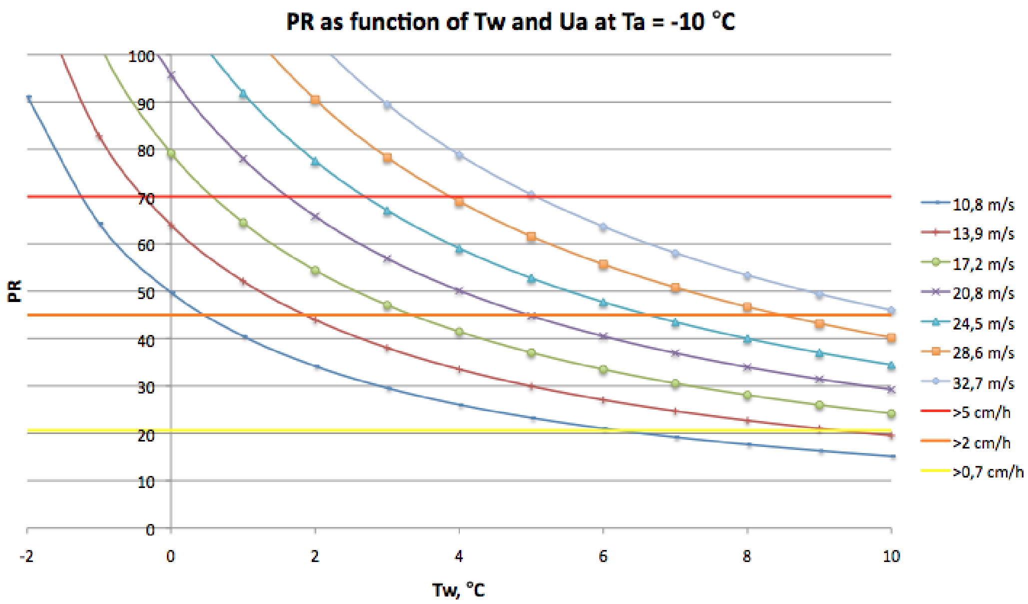

Figure 18, Icing index as a function of seawater temperature (Tw) and the wind speed (Ua) at a fixed air temperature of -10 °C.

5.7.2 Icing on aircraft

The Norwegian Meteorological Institute (DNMI) has made a study concerning the statistical probability of ice accretion on aircraft on routes between northern Norway and Svalbard [53]. The results of the report indicate that there is approximately a 50% probability for icing conditions on aircraft from November to May. This is shown in a table in appendix A.5.

Clouds containing water droplets may lead to ice accretion on aircraft if the air temperature is 0°C or less. The amount of droplets and their size is greatest at temperatures just below 0°C and it is in these conditions that most severe ice accretion is likely to occur. Two cloud structures are considered. Stratiform cloud structures are clouds that are flat but have a large horizontal extent. Cumuliform cloud structures have a larger vertical extent and are more common with severe weather. There are generally large droplets in cumuliform clouds that can lead to rapid ice accretion. Stratiform clouds normally contain smaller droplets but can also lead to rapid ice accretion as the extent of these clouds expose the aircraft to icing conditions for a longer period [53].

Rain at temperatures below 0°C can also lead to ice accretion on aircraft. Freezing rain occurs when the water droplets pass through a layer of air below 0°C. Temperatures normally increase with decreasing altitude. Snow does not normally lead to ice accretion on aircraft because the water is already frozen. However, if the snow contains water, ice accretion may occur [53].

5.7.3 Darkness

The sun is below the horizon all day for a given period during the winter. This results in total darkness, called Polar Night, in the middle of the winter. There are limited periods of twilight during the day until the sun returns. The length of the daylight period decreases rapidly from the autumn equinox until the sun goes below the horizon. Similarly the daylight period increases rapidly from the return of the sun until the spring equinox [91].

Table 7, Dates for the sun below the horizon [91]

Location	Sun leaves	Sun returns
Vardø	23. November	19. January
Hammerfest (Fruholmen)	22. November	20. January
Nordkapp	20. November	22. January
Bjørnøya	07. November	04. February
Longyearbyen	26. October	16. February
North Pole	25. September	18. March

5.7.4 Weather forecasting

Reliable weather forecasting is paramount for safe operations and activities at sea. Meteorological observations are made at locations on the coast of Northern Norway, Bjørnøya, Hopen and Svalbard. Due to the low number of fixed observation stations in and around the Barents Sea, reliable weather forecasts are challenging, especially with regard to forecasting polar lows. As petroleum resources are developed in this area, valuable information will be gained through new observation stations on the offshore facilities [67]. Currently, forecasting accuracy is being improved by comparing the meteorological observations on rigs operating in the Barents Sea with the given forecast for the period [J08].

5.7.5 Radio communication at high latitudes

Challenges regarding radio communications at high latitudes are often mentioned in connection with the Barents Sea. Satellite communication systems using geostationary satellites at the equator do not guarantee coverage north of ca 70°N. The systems may provide communication with good antennas up to 76°N but not beyond 80°N [101]. Geomagnetic storms can have an adverse effect on certain types of radio communication, potentially leading to a total loss of communication at times. In interviews with persons who are familiar with operations in the Barents Sea, these issues are not considered as a threat to effective radio communication as they have a variety of systems. Radio communication is generally better in summer during periods of high air pressure than is experienced in winter during low air pressure [J01, J02 & J04].

5.8 Infrastructure, Facilities and Resources

Petroleum facilities

There are currently no fixed or floating installations in the Norwegian sector of the Barents Sea. The Snøhvit field was developed in 2002 with subsea installations connected by pipeline to an onshore LNG plant at Melkøya near Hammerfest [33 p63]. The Goliat FPSO is planned installed in 2013 [33 p7]. Skrugard will be developed and a facility installed in 2018 [77]. There are occasionally drilling facilities in the area dependent on exploration and production drilling activity.

Supply bases

Activity is currently supported from the supply base at Hammerfest [33]. Kirkenes municipality has an ambition to become an important base for petroleum related activities both in the Norwegian and Russian sector of the Barents Sea [81].

Maritime resources

There is a presence of a variety of vessels due to fisheries, naval activity, maritime tanker and bulk transport, cruise tourism, marine bio prospecting and research activity related to gathering of seismic data [33 p7&8].

Search and rescue resources

The main search and rescue resources in northern Norway covering the Barents Sea are helicopters, Coast Guard vessels and vessels operated by Norwegian Sea Rescue (NSSR). The Norwegian navy's coast guard vessels may have helicopters onboard [J01]. There is a Sea King helicopter (SAR) stationed at Banak in Finnmark operated by the Royal Norwegian Air Force [J02]. When there is exploration, development or well maintenance activity in the Barents Sea, the petroleum industry operates a transport helicopter and an all weather search and rescue (AWSAR) helicopter from Hammerfest [74].

Resources to assist in accidents at sea and rescue operations in Northern Norway and the Barents Sea are limited. Persons, who are familiar with the capacity and availability of the resources, have expressed concern regarding the issue [J01, J02 & 102]. There are large distances and transport of survivors and injured persons may be time consuming. There may be serious challenges rescuing, transporting and providing medical treatment for 80 to 140 survivors of an accident on an offshore petroleum facility in the Barents Sea. This insight raises an additional concern regarding the rescue of potentially thousands of passengers and crew on cruise ships operating in the Barents Sea between Northern Norway and Svalbard. The accident off the west coast of Svalbard with the Russian cruise ship, Maxim Gorkij on the 17th September 1989 involving 575 passengers and 378 crew, could have ended very differently. All persons were rescued due to fortunate coincidences regarding the proximity of a Norwegian Coat Guard vessel and access to rescue helicopters [101].

Medical resources, hospitals

There are hospitals in Hammerfest and Kirkenes providing health services to the inhabitants of the county of Finnmark. The University Hospital of Tromsø is the largest hospital in the region and is located in the county of Troms. Remote medical diagnostics, telemedicine, is provided from the University Hospital of Tromsø. There is a national centre for this type of medical care and support in Tromsø, the Norwegian Centre for Integrated Care and Telemedicine. An extensive air ambulance service is operated from Tromsø. If it should become necessary to treat a large number of injured persons the combined resources of Hammerfest, Kirkenes and Tromsø hospitals could be used with Tromsø dealing with the more serious injuries. It has not been possible to find quantified information regarding the trauma capacity, number of persons who can be treated in connection with a serious accident, for these medical facilities [82]. Traditionally it has been seen that in the case of serious accidents involving many injured persons, the rescue and medical services stretch themselves beyond what could be expected as their normal duty and provide the assistance that is required to save many lives. An example is the bus accident in Lavangsdalen in 2011 [99].

Airports

There are numerous airports in the county of Finnmark, most of these are located on the coast and are shown in figure 19 below. Helicopter flights to facilities in the Barents Sea are currently operated from Hammerfest. The red circle indicates 1 hours flying time, 140 NM, from Hammerfest. The 330 squadron Sea King SAR helicopter is stationed at Banak. Tromsø in the neighbouring county is also indicated on the map, as this is where the largest hospital is situated. Bjørnøya is not an airport for regular traffic but helicopter traffic can be served.

Some of the airports along the coast may be of interest as alternative or emergency airports for petroleum related activities. They are all close to the coast and for some areas of the Barents Sea provide a shorter flight than can be achieved from Hammerfest. The airports at Hammerfest, Honningsvåg (HVG), Mehamn (MEH), Berlevåg (BVG), Båtsfjord (BJF) and Vardø (VAW) have fuel and 24/7 callout for fire fighting services allowing hot refuelling of the helicopter with the rotor running. There are also fuel depots at Bjørnøya and Hopen (beyond the top of the map), however, it can be challenging to land there due to fog. Bjørnøya is at present used as an intermediate base during rescue operations in that area [57 & J02].

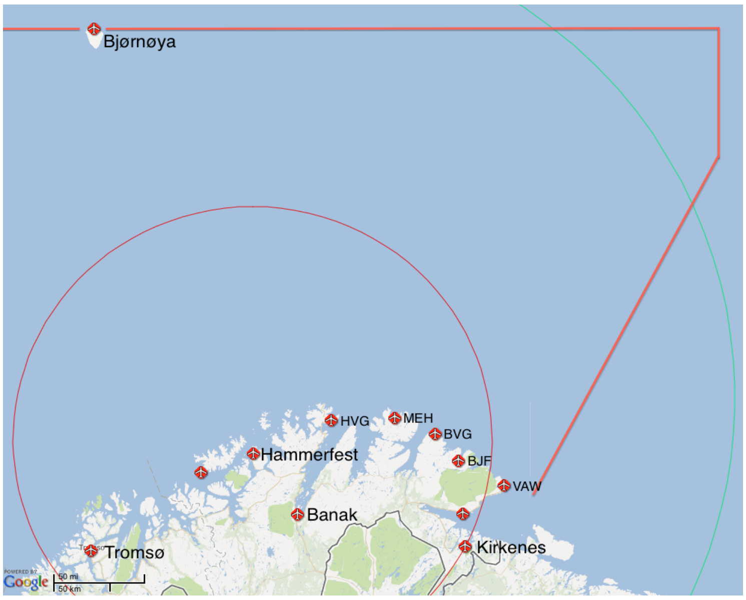

Figure 19, Airports on the coast of the Barents Sea

The smaller airports suffer from a lack of local infrastructure and investment would be required if any permanent use for helicopter transport to facilities in the Barents Sea is to be regular. A number of these airports experience difficult conditions related to traffic, especially for fixed wing aircraft, and regularity is lower than for other airports in Norway [J02]. Fog can also be a challenge to regularity at airports in coastal areas.

5.9 Helicopter operations

Helicopters are vital to transport of personnel to and from facilities operating on the Norwegian continental shelf. Considerable work has been invested in continuous safety improvement of helicopter operations. The safety status of helicopter operations has been documented and studied in three helicopter safety studies performed by SINTEF on behalf of the stakeholders in the industry. The overall objective of the studies has been to contribute to improved safety in helicopter transport of personnel. From the most recent report, the recommendations and observations that may have an effect on helicopter safety in the Barents Sea, are listed below [62 sect10]:

- Reduce flights at night, in the dark or in conditions of reduced visibility especially to moving helicopter decks.

- Continuation and replacement of the system used to track helicopters at all times during flight.
- Requirements for improved weather observations especially on remotely located facilities.
- Requirements for a hangar on offshore facilities where SAR helicopters are stationed in order to improve safety of operation.
- The provision of night vision goggles for SAR crews.
- The unique Norwegian requirement of 25% increase in helicopter deck size has been a clear improvement to safety [62 p41].

The effect of darkness on helicopter operations

Reduction of flights at night or in the dark is a special challenge in the Barents Sea as the months from November to January are predominantly dark almost all of the time. Helicopters are equipped with navigational aids and radar enabling operations in the dark or reduced visibility. The SINTEF report draws attention to the importance of good visibility especially when landing on helicopter decks affected by the motion of the sea. The risks connected with landing at night or in the dark are emphasized in particular [62 p92&148]. In order to reduce the risks during landing of helicopters on offshore facilities, especially as activity moves north into the Norwegian Sea and the Barents Sea, a regulation was unilaterally implemented in Norway requiring that the diameter of new helicopter decks be 25% greater than previously required [62 p41].

Weather forecasts for helicopter operations

Weather forecasting is a critical element for aviation. Operations depend on reliable and detailed weather forecasts in order to plan and execute a safe flight. This is especially the case for helicopters that are slow moving aircraft operating at low altitudes in the most turbulent part of the atmosphere [73]. Quality forecasts require reliable observations that can be used in the forecasting models.

Helicopter - operational limitations

Limitations for helicopter operations are stipulated in OLF guidelines no. 066 and 095 [22 & 23]. The amount of fuel a helicopter can carry is the deciding factor for the operational range. The fuel requirement is calculated based on the requirement to be able to fly to the destination, perform an approach and be able to return to the original or an alternate airport onshore and still have sufficient fuel for 30 minutes flying time [73]. These requirements are described in full in N-CAA regulation BSL D 2-2 [13]. Transport helicopters currently in use carry fuel for ca 3,5 hours flying. The required reserve of 30 minutes fuel is included. The OLF guideline 066 sets an additional requirement that the alternate airport cannot be an offshore facility [22]. This limits the possibilities for long-range flights. The approximate range available today is 175 NM [73].

Alternative solutions to providing extra fuel include installing extra onboard fuel tank capacity, landing on an installation en route for refuelling or considering the use of HIFR, helicopter in flight refuelling. It is possible to increase the range by installing additional fuel tanks on the helicopter. This will, however, increase the weight of the helicopter, reduce the payload and may not prove economical to the operator [73]. Offshore facilities with fuel depots can increase the useful range of helicopter operations by providing refuelling. The helicopter will have to land on the helideck of the facility in order to refuel. Helicopter in flight refuelling (HIFR) equipment is available on some coastguard vessels. This system does not involve landing on the vessel. A fuel hose is hoisted from the vessel to the helicopter while in flight, connected to the helicopter and refuelling is performed. [J02]

The following meteorological factors are critical for helicopter operations [22]:

- Lightning or the probability of lightning in cumulonimbus clouds (CB)
- Air turbulence, wind speed on the helideck
- Icing, unless the helicopter is specifically equipped with de-icing equipment
- Poor visibility, fog or dense snow
- Wind speed that significantly reduces or cancels headway [J07].

In the worst case, lightning may lead to an accident and helicopter wreck [30 p48]. The pilots will normally fly around areas of lightning, turbulence or icing and may even decide not to fly under these conditions. SINTEF recommend research into issues concerning helicopters' resistance to and survivability in lightning strikes [62 p144].

It has been observed that challenges related to weather conditions have become more significant as helicopter traffic has increased in the Norwegian Sea and the Barents Sea. In these areas polar lows develop with little warning and are accompanied by strong wind and large amounts of precipitation, often as snow. Although a polar low does not normally threaten the helicopter as such, it can be a challenge leading to reduced speed and increased air turbulence [J02]. Conditions are such that the helicopters are more exposed to icing, experience greater lightning activity during winter, observe stronger winds and longer hours of darkness during the winter in the Norwegian Sea compared to the North Sea. It is important to remember that in petroleum activities the area that is referred to as the Barents Sea in the southwest is actually the Norwegian Sea [62 p17].

Fuel requirements

Refuelling on an offshore facility and HIFR has inherent limitations to helicopter operations. When relying on offshore refuelling using either of the methods, the helicopter must reach the refuelling facility before it has used more fuel than required to safely return to its starting airport or alternate airport with the required 30 minutes fuel reserve as there is no guarantee that the refuelling operation can be performed successfully. After successful refuelling, the helicopter shall not fly further than for it to be able to return to an airport without additional refuelling. This is because it cannot be guaranteed that a second refuelling operation will be possible or successful. It is therefore not permitted to plan a flight that requires taking on board fuel from a second HIFR operation [J02]. Similar restrictions will apply for refuelling onboard an offshore facility. It should also be noted that HIFR is essentially a method used for military operations, typically the 330 Sea King rescue helicopter. HIFR is not considered a normal operation for civil helicopter transport.

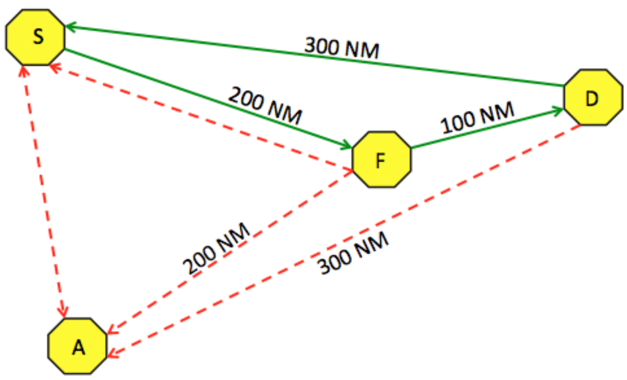

Figure 20, Extended flight range using offshore refuelling

The illustration in figure 20 shows the implication of the operational limits described. Consider a helicopter that has a total range of 400 NM. It is necessary to plan a flight from airport S (starting point) to an offshore facility D (destination). The distance from S to D is ca 300 NM. It is not possible for the helicopter to fly from S to D and return to either S or the alternate airport A with its normal fuel capacity. Refuelling on route either onboard an offshore facility or vessel equipped with HIFR will be necessary. The distance between S and F (and the distance F to A) must not exceed 200 NM miles as the helicopter must be able to return to S or A if refuelling at F is not accomplished. This situation means that the flight from S to D is aborted. The distance from F to D must not exceed 100 NM as the helicopter must be able to fly 300 NM to either S or A without refuelling at D. In this situation the helicopter could fly back to F and attempt a second refuelling but only within a fuel regime that allows the helicopter to return to S or A if the second refuelling is unsuccessful. In addition one must consider the distance between S and A. If the helicopter flies the route D to S on the return and S becomes unavailable due to weather or other reasons, it must be possible to reroute to A and still have 30 minutes fuel when landing at A, the alternate airport. The useful range of the helicopter in this example can be increased from reaching a location 200 NM from shore to ca 300 NM offshore for ideal conditions. This example illustrates that offshore refuelling may increase the range of a helicopter by ca 50%.

Tracking of helicopters

There is a requirement in Norway that helicopters shall be tracked at all times during flight to allow the immediate locating of the aircraft in the case of an accident. This greatly increases the probability of saving lives, as valuable time is not lost searching for the site of the incident. The system currently in use, Modified Automatic Dependent Surveillance (M-ADS), has become difficult to maintain due to the lack of new units and spare parts for existing equipment [62].

Limitations for rescue

A limiting factor with regard to helicopter transport is related to the ability to rescue personnel in the event of a helicopter incident leading to persons in the sea. Where rescue is based on the use of SAR helicopters, the general rule is that helicopter transport of personnel shall not be carried out if the wind on the helicopter deck where the SAR helicopter is stationed exceeds 55 knots. This is due to the fact that the SAR helicopter rotor cannot be started when the wind is above 55 knots. The platform manager, together with the SAR captain, can deviate from this guideline if the local conditions allow a deviation [23 §3.5.1]. When rescue is based solely on an ERV with an FRDC or MOB boat, the general rule is that helicopter transport shall cease when the significant wave height H_s exceeds 4,5m. When the H_s is between 4,5m and 7m the platform manager and the ERV captain shall assess safety, efficiency and robustness of the rescue operation under the prevailing weather conditions [23 §3.5.2].

5.10 Calculations

The shortest route between two locations and the heading between these locations are calculated in order to evaluate response time of emergency preparedness resources. The effects of the wind on the speed made good over the ground by a helicopter are also examined. The details of the methods used are described in the following sections.

5.10.1 Great circle calculations

In order to evaluate the time required for helicopter assisted medevac, evacuation and rescue operations it is necessary to calculate the distance between the locations. Great circle routes provide the shortest distance between to locations on the surface of the earth. The route is not necessarily a straight line on a map but it is the shortest distance. Also note that the heading along the route is not necessarily constant for the entire route. There are many ways of calculating the great circle distance. The accuracy of the result depends on the method chosen and how well the shape of the earth is taken into account. The earth is not a perfect spheroid and the radius at the equator is different from the radius at the poles.

In 1975 Thaddeus Vincenty published a method for calculating great circle distances using an iterative calculation taking into account the ellipsoid shape of the earth [56]. The method provides very accurate results.

A more traditional method within navigation is to use the Haversine formula to calculate distances [93]. This method is less accurate giving an error of up to 0,5% of the distance due to describing the earth as a spheroid. The Haversine formula provides a distance that is sufficiently accurate and the formula is easy to use in an Excel spreadsheet. The results of the calculations used in this thesis have been verified by using an Internet program based on the Vincenty method of great circle calculation [97].

The haversine, or half the versine, is used in the haversine formula for navigation. The versine or versed sine, versin(θ), is a trigonometric function:

$$\text{versin}\theta = 1 - \cos\theta = 2\sin^2(\theta/2)$$

$$\text{haversine}\theta = (\text{versin}\theta)/2 = (2\sin^2(\theta/2))/2 = \sin^2(\theta/2)$$

The following calculation method has been used for distance and heading between locations. All angles and coordinates must be converted from degrees to radians before the calculation. An example of the practical use of these formulae is included in annex A.9.

Distance formula

The distance, d, between the two locations is given by the following formula. The first formula uses the haversine and the second one is written in more conventional trigonometric terms that are used in Excel [93].

$$d = 2r \arcsin \sqrt{\text{haversin}(\phi_2 - \phi_1) + \cos(\phi_1)\cos(\phi_2)\,\text{haversin}(\psi_2 - \psi_1)}$$

$$d = 2r \arcsin \sqrt{\sin^2((\phi_2 - \phi_1)/2) + \cos(\phi_1)\cos(\phi_2)\sin^2((\psi_2 - \psi_1)/2)}$$

r = radius of the earth, 6371 km

ϕ_1 = latitude of start location

ψ_1 = longitude of start location

ϕ_2 = latitude of end location

ψ_2 = longitude of end location

Heading formula

The heading on a great circle route changes along the path. The initial heading from the starting point to the final destination is calculated using the following formula:

Bearing $\theta = \text{atan2}(x, y)$ where:

$$x = \sin(\psi_2 - \psi_1)\cos(\phi_2)$$

$$y = \cos(\phi_1)\sin(\phi_2) - \sin(\phi_1)\cos(\phi_2)\cos(\psi_2 - \psi_1)$$

Note that Excel reverses the arguments of atan2. This must be taken into account when writing the formula in Excel by reversing the order of x and y, i.e. $\theta = \text{atan2}(y, x)$ [94].

5.10.2 Effects of wind on helicopter ground speed

A helicopter travels through moving air steams that influence the actual speed made good over the ground. The direction and speed of the wind in relation to the course and speed of the helicopter need to be considered when planning a flight. The wind has a direct consequence on the amount of fuel and time consumed on the trip. The practical consequences of the effect of wind on flight duration are reviewed and exemplified in more detail in section 6.8.

In order to examine the effects of wind on the helicopter ground speed, the diagram below in figure 21 and the following formula are used. In order to find the actual ground speed of the helicopter, the sum of the wind vector and helicopter speed vector must be added. The vectors AS, WS and GS in figure 21 illustrate this. The relationship between the vectors is: GS = AS + WS. The parameters or variables shown in figure 21 are described below.

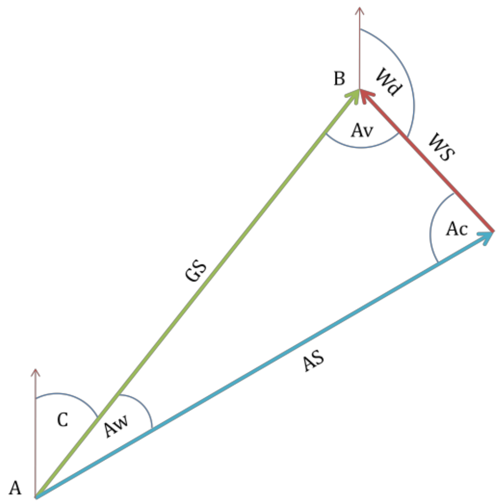

Figure 21, Wind triangle, air speed, ground speed and wind speed

AS, air speed is the speed that the helicopter is able to maintain through the air. This is normally the cruising speed of the helicopter, e.g. 145 knots.

WS, wind speed, is the speed of the wind that is used in the calculations.

GS is the ground speed. It is the actual speed made good over the ground taking into account the effect of the combination of the wind speed and the helicopter air speed. The ground speed vector, GS, has the same angular definition as the course that the helicopter needs to fly to reach its destination.

C is the course (the direction) that the helicopter pilot wishes to achieve over the ground in order to reach the destination using the shortest route.

Wd is the wind direction. The value is given in degrees and expressed as the direction from which the wind is blowing.

Aw is the angle inside the triangle between the course that is desired and the heading of the helicopter when compensating for the effect of the wind, commonly referred to as drift. To compensate for the drift, the helicopter pilot must steer a course equal to the sum of the desired course, C, and the drift-compensating angle, Aw.

Av is the angle inside the triangle between the ground speed and the wind speed.

Ac is the angle inside the triangle between the air speed and the wind speed.

$$\frac{a}{b} = \frac{\sin\alpha}{\sin\beta} \; ; \; \frac{a}{c} = \frac{\sin\alpha}{\sin\gamma} \; ; \; \frac{b}{c} = \frac{\sin\beta}{\sin\gamma}$$

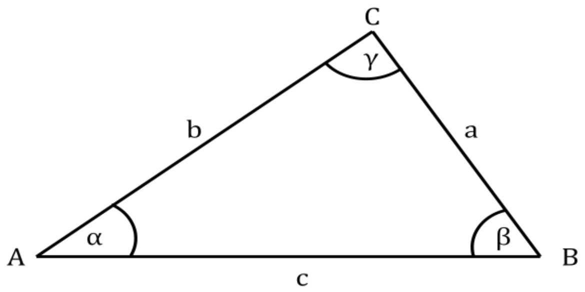

Figure 22, Sine law formula and illustration [8]

The calculation method used takes advantage of the sine law that describes the relationship between the angles and sides of a triangle [8]. The sine law is illustrated in figure 22 above. The sine law gives the relationship between the length of a side and the sine of the angle opposite. This relationship is equal for all angles and sides in the given triangle. The use of the sine law is a common application for calculating angles or sides of a triangle when:

a. One side and two angles are known,
b. Two sides and one of the external angles are known.

Calculation method

The known parameters used in the calculation are listed in the table 8 below.

Table 8, Known parameters used in the calculations

Known variable	Description	Unit
C	Heading of the ground speed vector, GS as this is the course that needs to be made over the ground	degrees
AS	Air speed of the helicopter, equivalent to the cruising speed	knots
WS	Wind speed	knots
Wd	Direction that the wind is coming from	degrees

Step 1: Calculate Av, the angle between the desired course GS over the ground and the wind direction WS. Add the red lines to assist in finding the required angle Av, see figure 23.

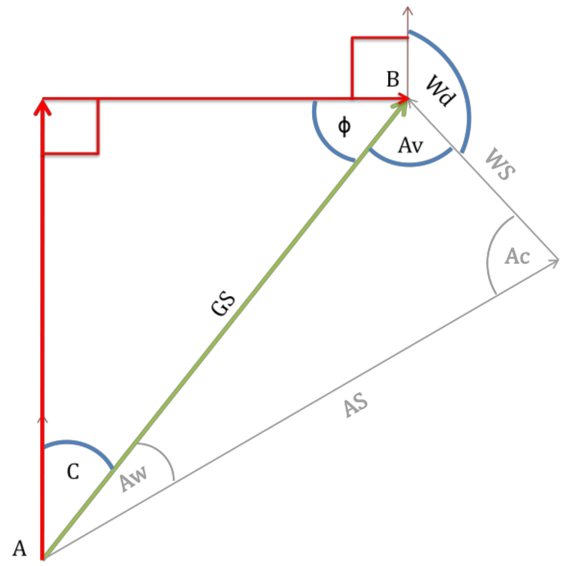

Figure 23, Lines added to calculate the angle Av

The sum of all the angles around point B on the wind triangle is 360°.

$Av + Wd + 90° + \phi = 360°$

$Av = 360° – 90° - Wd - \phi$

The angle ϕ can be calculated from the course, C, when adding a triangle with a right angle (90º), the red lines in figure 23. This is possible because both the wind direction and the course for the route are defined relative to north or 0°. The sum of the angles within the red triangle is 180°, therefore:

$\phi = 180° – C – 90° = 90° - C$

The formula for ϕ is then substituted for ϕ in the Av formula giving:

$Av = 360° – 90° – Wd – (90° - C)$

Av = 180° + C - Wd

Step 2: Calculate Aw, the drift angle using the sine law on the relationship between Av, AS and Aw, WS.

sin(Aw)=sin(Av) * WS / AS

The arcsine of the result is the value of the drift angle Aw.

Aw = arcsin(sin(Av) * WS / AS)

Step 3: Calculate Ac, the angle between the wind speed and the course or heading the helicopter must fly in order to compensate for the drift. Ac is calculated based on the fact that the sum of the three angles within a triangle is 180°, therefore:

Ac = 180° – Aw – Av

Step 4: Calculate GS, the ground speed using the sine law on the relationship between Av, AS, Ac & GS.

GS = WS * sin(Ac) / sin(Av)

The calculation method has been used to prepare the diagram in figure 24. This illustrates the effect of a direct head wind from 0° through 180° to a full tail wind for six cases of wind varying from 10 to 60 knots in 10 knot increments. A direct head wind will reduce the ground speed by the wind speed. Similarly, a direct tail wind will increase the ground speed by the same amount as the wind speed. Flying over a given distance where the wind is either exactly a head or tail wind of equal intensity will NOT cancel the effect of the wind for the complete round trip. An Internet calculator has been used to verify the method and calculation [95].

For winds between head and tail winds the effect of the wind will not be cancelled out when flying both directions in the same wind conditions. This is illustrated in figure 25 below for different velocities of the wind.

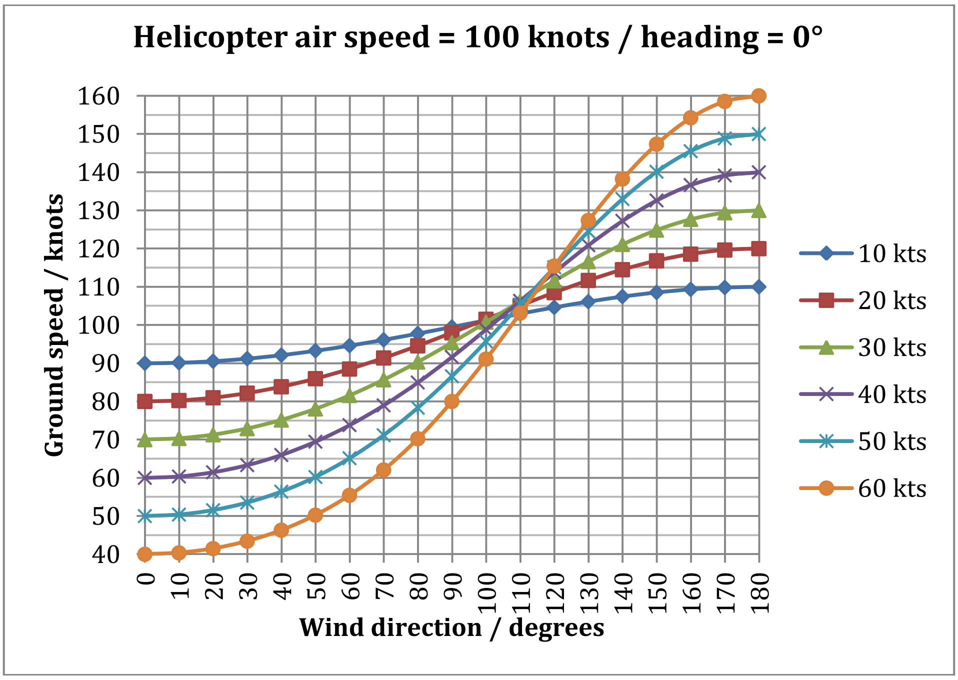

Figure 24, Effect of wind on helicopter ground speed

The horizontal red arrow illustrates the heading of the helicopter relative to the angle of the wind that has a neutral effect on the ground speed. Any side wind relative to the helicopter heading will lead to drift away from the intended course. This needs to be compensated for and results in reduced ground speed. Figure 25 indicates that for a wind speed of ca. 10 knots, the wind changes from a negative to a positive speed component when the wind comes from ca 92,5°. Similarly, for a wind of 60 knots, the neutral point moves aft to ca 107,5°. The helicopter pilots take these effects into account when planning a flight and calculating the required fuel for the trip.

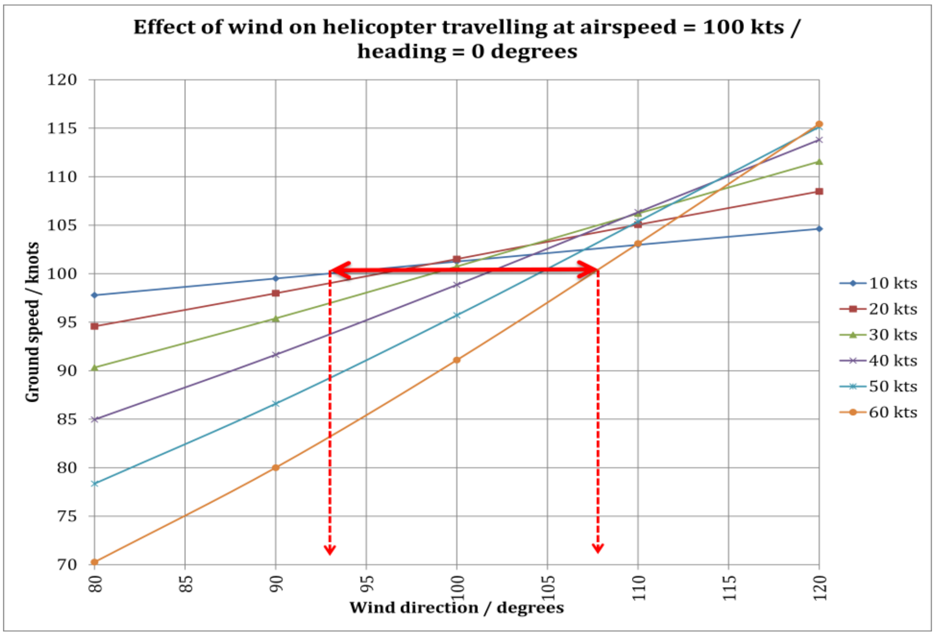

Figure 25, Effect of side wind on helicopter ground speed illustrated for varying wind speed

5.11 Effects of cold on health

Air temperature, wind and humidity are critical factors for a person's health and ability to perform in cold climates [45 p6] The climate of the Barents Sea can have a negative effect on the health of personnel, existing health problems may be aggravated and otherwise healthy persons may experience cold related illnesses. In addition to injuries as a direct result of cold, e.g. hypothermia and frostbite, it is known that the cold has an impact on the respiratory and cardiovascular system and there is an increase in the frequency of heart attacks and strokes [45 p17]. The cold may induce asthma like symptoms and problems with breathing in 4 to 5% of the population and up to 20% if they perform heavy physical work at low air temperatures. It is also known that cold has a negative effect on musculoskeletal diseases, worsening existing conditions and revealing symptoms for persons who have not previously had symptoms. Raynaud's syndrome (RS) is another cold induced illness often associated with white fingers and the loss of dexterity. Persons suffering from RS may experience constriction of blood vessels leading to headaches, breast pains and possible impairment of vision [45 p17]. Metabolism is also affected negatively by the cold.

The air temperature and the movement of air or wind affect the rate at which a person looses heat from their body. The cooling rate increases with increasing wind speed and decreasing air temperature. The effect is normally referred to as wind chill effect [45 p15]. It is necessary to protect personnel from the effects of the wind and cold air. This is often achieved by winterisation of the facility involving for example the installation of wind walls and adaptation of working clothes suited to the environment [45 p28].

The risk associated with work in areas of extreme cold require that the health of individuals needs to be screened more rigorously than previously in the petroleum industry. It is considered necessary to develop appropriate health requirements and methods to actively follow up health status and to prevent health deterioration [45 p31].

Emergency preparedness for medical situations will need to take into account the possibility that the condition of an ill or injured person may deteriorate more rapidly in a cold environment. Requirements for medical assistance onboard must be designed to compensate for the remoteness of the facility and the limited availability of medical infrastructure onshore in the northern areas of Norway. The training and competence of medical and first aid personnel is even more important than previously for offshore Barents Sea activities [45 p31].

5.12 Survival in cold water

Factors influencing survival at sea are relevant because persons may enter the sea involuntarily due to a helicopter incident, lifeboat or life raft evacuation or as a last resort if they are unable to reach and embark a suitable means of evacuation. Survival for persons who are not in a lifeboat or life raft will depend on issues like the temperature of the seawater, the air and the wind causing cooling and eventually hypothermia and the effects of the sea state or waves causing drowning. As mentioned in section 5.4, many properties of an immersion or survival suit are tested and the main criteria are related to thermal insulation protecting against hypothermia and buoyancy protecting against drowning. Thermal mannequins or individuals are used in the tests [16]. It is not considered ethically acceptable to perform test with persons regarding the risk of drowning [72].

There are a number of issues that can have a direct effect of the survivability of an immersed victim. Survival times at sea are dependent on the sea state, the temperature of the seawater and the air and the type of protection and insulation the victim is wearing. In addition personal factors like gender, body size and skin surface, physical fitness, age, shivering response and body mass index (BMI) play an important role. The thicker the layer of subcutaneous fat, fat under the skin, the better insulation will be achieved [7 p32]. If a male and a female of equal body fat percentage are immersed, the female will normally cool more quickly as the female has a greater ratio of skin surface to body than the male. This means that the female has less heat producing body mass and a greater skin area through which heat is lost [7 p129-139].

The first critical issue during immersion is the effect of cold water immersion (CWI) shock when entering the sea. If unprotected or poorly protected due to a leaking suit, the person may experience CWI shock when the cold water comes into contact with the skin causing the victim to gasp for air thereby increasing the risk of inhaling water and drowning. In addition there may be changes in the circulatory system potentially causing heart failure. The victim will normally also experience uncoordinated movements of the limbs and may not be able to keep afloat and prevent drowning. These symptoms will be experienced within the first minutes of immersion and are critical to survival [7 p59]. Fat under the skin, however, does not provide protection against the effects of cold water immersion shock [7 p65].

After surviving the initial shock of being immersed in cold water, the body will start to cool at a rate dependent on the protection provided by clothing or an immersion suit. When the ambient temperature begins to drop the body will respond by trying to conserve heat. This will first lead to a reduced blood flow to the skin and limbs. The skin and the fatty layers beneath will act as insulation. The surface temperature of the limbs and body will start to fall as the central body temperature is conserved. As body temperature falls towards 35°C shivering will start to stimulate heat production. If the body core temperature continues to fall, the person will experience reduced mental and physical activity slipping into apathy and unconsciousness. If cooling continues, the victim will experience an uneven heartbeat, arrhythmia and will risk cardiac arrest and death as the body's core temperature approaches 24°C [7 p102].

Heat loss from the head can account for over half of the total heat loss. The face and respiration system can account for a third of the heat loss. The face requires protection in addition to the head. There is no practical way to reduce heat loss through respiration. Heat exchangers have been tried but with little success [7 p49]. Protection of hands and feet are difficult to achieve. Fingered gloves provide a large surface that increase cooling. A fingerless glove or mitten provides better thermal insulation at the cost of dexterity, the use of the fingers [7 p49]. Due to the higher cooling effect (heat transfer) of water, a victim is always better off out of the water even if it may feel colder in the air [7 p48].

Seasickness or motion sickness is a common problem for persons onboard vessels, lifeboats and life rafts but also for persons in the sea in an immersion suit. Seasickness increases the rate of dehydration and impairs thermoregulation lowering deep body temperature. A person suffering from seasickness loses body heat faster than someone not suffering from motion illness. Seasick survivors are therefore more susceptible to hypothermia [7 p216].

Wetting of the inside of an immersion suit by leakage or cold induced urination will impair the thermal insulation properties [7 p129]. The effect is less in an insulated suit provided the water does not flow in and out of the suit [7 p47].

When floating vertically in the water, the hydrostatic pressure on the body will lead to an increase in the pressure of the circulation system. The body will attempt to reduce the pressure by reducing circulated fluid. This results in increased diuresis, the production of urine, and it is common for the body to produce 0,35 litres of urine within an hour of immersion [7 p53]. If urine is released inside the suit it may impair thermal insulation properties of the suit [7 p129].

There is evidence supporting that a positive mental attitude can have a strong effect on the will to survive and to do what is required in order to survive. Training and knowledge can help to maintain a positive mental state and avoid panic or depression. Awareness of common challenges and their criticality can help keeping a positive frame of mind. For example knowledge that almost all immersion suits leak some water and that the effect will not normally be lethal in the short term may prevent concern. It will also help to know how to prevent and combat seasickness [7 p137]

An unconscious person will not be able to follow waves and prevent swallowing of seawater. A conscious person will have an ability to follow the waves and synchronise breathing to avoid swallowing seawater, however this may prove exhausting in time. Provision and use of splashguards will improve survival at sea [7 p111]

There are reported cases of rescue collapse, persons losing consciousness and even dying during a vertical lift to a rescue vessel or helicopter [7 p250]. It has been observed that as many as 20% of persons rescued from cold water, below 10°C, die within 24 hours, especially in the period from 20 to 90 minutes after rescue, irrespective of their being conscious or unconscious at the time of rescue [7 p247&248]. When lifting a person who has hypothermia and has been floating vertically in the water, they may experience a sudden drop in blood pressure if lifted in a vertical position. This may be a contributing factor to rescue collapse and death and is particularly evident when the water is cold [7 p246]. Analysis of actual rescue survival and tests performed in controlled situations indicate that victims should be lifted from the sea in a horizontal posture to avoid collapse and fatality [7 p262].

Many of the activities critical to survival in the sea are dependent on the use of hands, arms or legs. These activities may include closing zippers on survival equipment, pulling on a hood, filling air in a floatation device, grabbing a rope, swimming and climbing into a life raft. As the skin, nerves and muscles of the limbs are cooled, the ability to use and move them, dexterity, is reduce or even lost [7 p69]. Dexterity is reduced already at skin temperatures between 15-20°C and pain, reduced muscle strength and coordination of the hand may be experienced at 10-15°C [45 p20].

Those who design and manufacture rescue equipment should understand and take into consideration the physiological threats that may reduce the survivor's capability to use or operate the equipment. This also applies to those providing training in survival at sea [7 p15].

It is generally considered that the period of useful consciousness for a person submersed in seawater at a temperature of 5°C is ca. 30 to 40 minutes for a naked person and increases towards 6 hours for a person with dry underclothing in an insulated immersion suit [7 p131]. This emphasises the importance of the work currently being performed by participants in the petroleum industry to improve the immersions suits used during helicopter transport and for survival in the sea [85]. This work is discussed briefly in section 5.4.

6 ANALYSIS & RESULTS

6.1 Barrier analysis of Medevac

A situation on an offshore facility requiring medical evacuation (medevac) of an ill or injured person is analysed in this section using the bow tie method. The analysis is performed in two tiers or levels as described in section 5.3 and figure 10. The first tier analyses the situation of an illness or injury occurring at an offshore location and leading to the need for a medevac. The second tier considers the medevac and the probability of a successful operation.

Level 1 – avoiding the need for a medevac

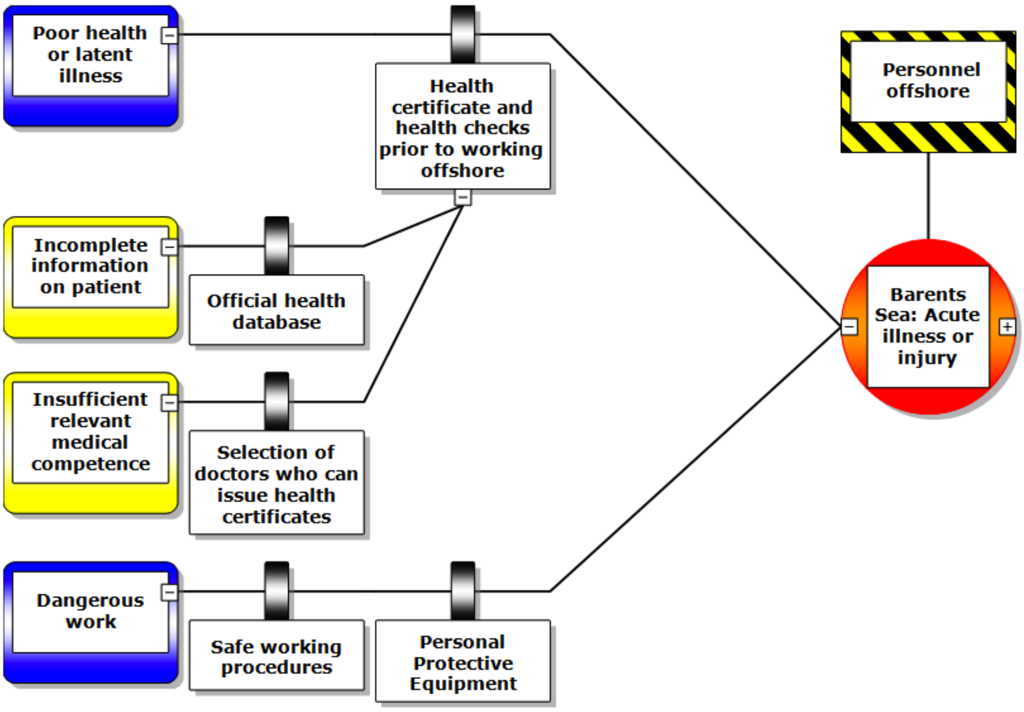

Figure 26, Threats leading to an incident requiring medical attention

There are basically two situations that can initiate the need for medical assistance offshore as illustrated in the diagram above, figure 26. A person can experience a health problem or be injured. According to the bow tie method the hazard in this case is defined as "personnel offshore". The fact that personnel are on the installation inherently means that someone can become ill or get injured. Illness or injury is then defined as being the top event. The threats in this case are simplified for illustration purpose to being either an acute health problem or an accident in connection with dangerous work. In the case of poor health a threat control is in place in an attempt to eliminate the problem. There is a requirement for health screening and a valid health certificate for personnel travelling to an offshore facility. There is an escalation factor that needs consideration in connection with health certificates. If a doctor should decide that a person does not fulfil the requirements for a valid health certificate, there is no mechanism in place today to register the rejection. There is also no common system for gathering all patient data and making it available to any doctor. The person can approach another doctor and apply for a health certificate. There is no link to the previous rejection and if the person withholds information, the doctor may issue a health certificate on incomplete background information. It is also important that the doctor issuing the health certificate is competent and aware of the special issues related to offshore work in remote and cold climates. In the case of dangerous work, safe working procedures are normally in place as a threat control to eliminate accident or injury. In addition it is normal to wear protective clothing as a threat control to prevent or reduce the extent of injury. The barriers in place to avoid an injury during work may also be weakened or compromised if procedures are not followed or personal protection equipment is not used or used incorrectly. These breaches would be defined as escalating factors. Escalation factor controls like buddy checks, colleagues helping each other, and procedure awareness programs may be typical measures put in place to avoid barrier defeat.

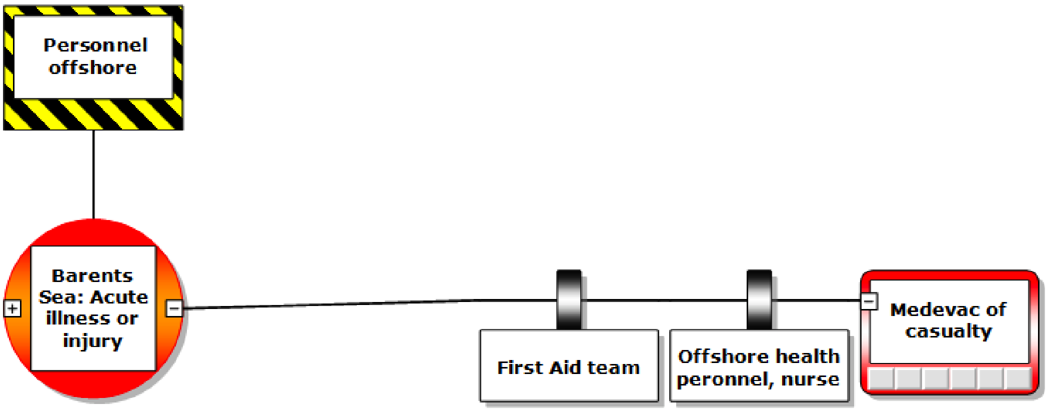

Figure 27, Consequences of an acute illness or injury

Recovery measures are considered on the right hand side of the bow tie as shown in figure 27 above. In case of cardiac arrest, as an example, the first aid team will start cardiopulmonary resuscitation (CPR) and may use a heart defibrillator. These recovery measures may be defined as reducing the immediate consequences. The offshore medical personnel, nurse or medic, may be considered a recovery measure, mitigating or lessening the consequences by administering thrombolytic treatment in consultation with the duty doctor onshore. The offshore medical personnel would prepare the patient for medevac and the duty doctor would request the helicopter for transport of the patient to a hospital onshore for further treatment and hopefully full recovery.

This case is used to illustrate the bow tie method and as an introduction to examining the next level where the medevac operation is analysed. In the analysis a selection of critical hazards, threats, barriers and escalation factors are mentioned as examples. The bow tie diagram can be developed to a higher level of detail in a full study of all issues in place to avoid illness or injury on an offshore facility. The intention here is to evaluate the critical issues and demonstrate application of the bow tie method to issues related to emergency preparedness.

Level 2 – performing the medevac

The analysis continues on a second level and considers issues related to the helicopter transport during the medevac. There are many critical issues related to helicopter transport that are of a generic nature. In this analysis the aim is to examine issues that are of particular importance to operations in the Barents Sea. The hazard in this bow tie is the medevac operation. The top event is an unsuccessful medevac where it may not be possible to transport the patient to an onshore hospital or medical facility.

On the left hand side of the bow tie, figure 28 on the next page, the threats that may lead to an unsuccessful or delayed medevac are considered. The main threats that will be considered here are weather conditions, planning of medevac capability and available helicopter resources. Escalation factors, issues that can weaken or defeat threat controls (barriers), are introduced and analysed. The analysis could include more threats, but the intention is to focus on those that may be critical and investigate how they can be dealt with.

The weather is a threat to all helicopter transport and reliable weather reports are critical to operations [73]. It is difficult (not possible) to eliminate the threat posed by the weather but it is possible to put in place preventive threat control measures. In the case of a medevac situation, the weather will be taken into account when planning the flight. Activity planning onboard the facility has been included as a preventive threat control in the sense that consideration could (and should) be given to the combination of the risk for injury to personnel due to the planned activity and the effect of prevailing weather conditions on the feasibility of a medevac. It is fair to argue that this combination can be taken into account because the activities planned on the facility are under the control of the persons onboard. The need for medevac due to health reasons is under less control once personnel are offshore and the need may arise any time during the day or night.

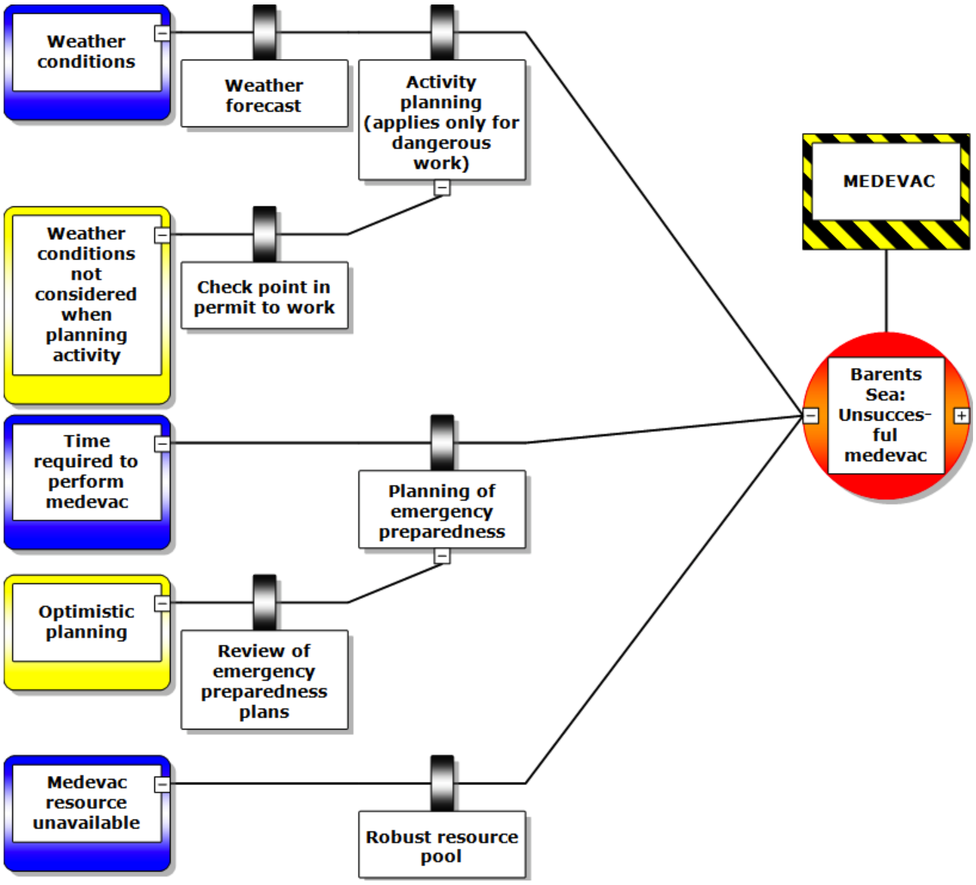

Figure 28, Threats that may lead to an unsuccessful or delayed Medevac

Another threat that may lead to an unsuccessful medevac is the time required to perform the operation. The industry has agreed on 3 hours as a performance requirement for transport of a patient from an offshore location to a hospital or medical facility onshore [20 p55]. There are no clear medical grounds for the selection of 3 hours and this performance requirement is, to a certain extent, challenged [72]. The 3 hours start from the point in time where the need for a medevac is identified until the patient is at the hospital. It may be necessary to agree on a common approach, however, 3 hours does not take into account the potential for varying urgency for transport to hospital. This performance requirement may indicate more what is reasonably possible than what is necessary in each individual case. When planning an activity at an offshore location it will be found that there are areas in the Barents Sea and Norwegian Sea where it is not possible to meet the agreed performance requirement due to distance unless the helicopter is based offshore on or close to the remote facility. Even then it is possible to experience limitations related to maximum wind speeds for start up of the helicopter rotors resulting in an unsuccessful medevac. In this analysis optimistic planning of emergency preparedness is identified as an escalation factor. Escalation factor control may include an independent review of an operator’s emergency preparedness plans and the assumptions in place in risk and emergency preparedness analysis. Remote locations will require special considerations on the right hand side of the bow tie in order to compensate for the time required to complete a medevac when the helicopter is based onshore.

The helicopter resources available for performing medevac in the Barents Sea are currently limited to one transport helicopter and one AWSAR helicopter stationed in Hammerfest and controlled by the petroleum industry [74]. In addition there is the Norwegian Search and Rescue Service Sea King helicopter stationed at Banak. The Sea King at Banak is located inland and needs 30 to 40 minutes to reach the coast. The Sea King is not equipped with de-icing equipment and the pilot may have to make special considerations during a flight or even abort the operation if icing conditions are present. With the current activity level of normally only one exploration facility working in the Barents Sea, access to resources is not critical but may become so if activity increases.

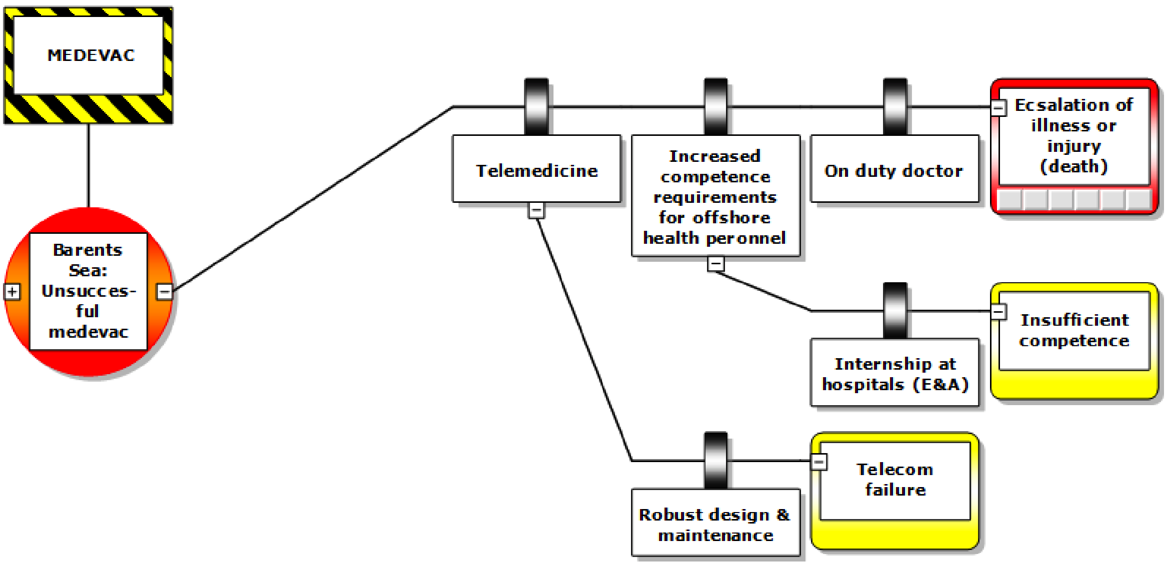

Figure 29, Unsuccessful Medevac, barriers to reduce and mitigate consequences

On the right hand side of the bow tie, figure 29, the consequences of an unsuccessful or delayed medevac are considered. If it should prove impossible to perform the medevac there is limited assistance available to the patient at the offshore location. The consequences may be that the illness or injury is of a nature that could result in a fatality if not treated in a hospital. Recovery measures to both reduce and mitigate the ultimate consequence of a fatality may involve a trauma team and an offshore hospital with operating theatre on the facility. There are a number of recovery measures that are considered as a standard today. These include a contract between the operating company and a provider of 24/7 on duty doctors for consultation on the telephone and who are able to mobilise within given time limits to travel to the facility. Another recovery measure may be increased training and competence for the offshore medical personnel and some members of the first aid teams working on facilities in the Barents Sea. This includes starting treatment of certain illness and injuries as indicated previously in the example of administering thrombolytic treatment to heart attack patients. Lack of competence is indicated as an escalation factor as the exposure of the offshore medical personnel to many and varied illnesses and injuries are limited. This can be countered by increasing the requirement for internship at hospitals for the medic. Increased training and exposure of the first aid teams to emergency health related situations might also be necessary to consider. Telemedicine can also be defined and used as a barrier in this case. The use of telemedicine provides direct contact between the patient and medical personnel offshore and a doctor or hospital onshore [75]. This has increased the repertoire of recovery measures available offshore. This barrier, telemedicine, may be defeated if the communication systems and equipment used are not evaluated carefully with regard to competence of the users, reliability, redundancy and maintenance in order to counteract malfunction.

Summary of the identified barriers

Barriers to reduce the need for medevac

- Health requirements for personnel working offshore in the Barents Sea in order to avoid, as far as reasonably possible, the need to perform a medevac.
- Procedures to ensure safe working so as to eliminate or prevent the need to perform a medevac.

Barriers to avoid unsuccessful medevac

- Operational procedures to eliminate or prevent the need to perform a medevac in adverse weather conditions.
- Sound planning and review of emergency preparedness for medevac.
- Robust access to helicopter resources.

Barriers to avoid escalation of injury, illness or fatality

- Improve competence of first aid teams and medic/nurse.
- Secure access to on duty doctor.
- Provision of telemedicine equipment on the offshore facility.

This barrier analysis has addressed the following issues:

- What is the barrier? (System and elements)

    - A system to avoid illness or injury of personnel, provide medical assistance on an offshore facility and transport to a hospital onshore for treatment.
    - The elements in the barrier system are health certificates, procedures for safe work, medical expertise and helicopter transport.
- What shall the barrier eliminate or prevent (left hand side)?
    - The barrier system shall eliminate and prevent the need for a medevac. If a medevac should be required the barrier system shall ensure that it is possible to perform the required operation by helicopter, i.e. eliminate and prevent not being able to perform the operation by helicopter.
- What shall the barrier reduce or mitigate (right hand side)?
    - Ultimately the barrier system shall reduce and mitigate the deterioration of the condition that potentially may lead to a fatality.
- How can the barrier be weakened or defeated? (Escalation factor)
    - Insufficient health controls and lack of competence regarding special issues related to work in remote and cold climates,
    - Lack of or non-adherence to procedures for safe working,
    - Adverse weather conditions,
    - Optimistic or unrealistic planning of emergency preparedness,
    - Insufficient competence of offshore medical personnel,
    - Insufficient competence or malfunction of telemedicine equipment.
- How can weakening or defeating of the barrier be eliminated or prevented? (Escalation factor control)
    - Improve requirements and control of system for issuing health certificates,
    - Systems to ensure adherence to working procedures,
    - Operational limitations for dangerous activity onboard during marginal weather conditions for helicopter transport,
    - Review of emergency preparedness analysis and plans,
    - Improve competence requirements for offshore medical and first aid personnel,
    - Robust design and maintenance of telemedicine system.
- What are the performance requirements of the barrier system?
    - The overall performance requirement of this barrier system is that personnel in need of medical assistance at a hospital shall be transported and arrive at the hospital within 3 hours of the need being identified.

    - Performance requirements should be defined for the individual elements of the barrier system.
- How can the barrier and performance requirements be tested?
    - Performing emergency preparedness exercises under varying conditions can test the barriers and the performance requirements.
    - Processes for auditing the performance of the individual elements of the barrier system.
- Are there dependencies between the various barriers in the protection system or barriers being used more than once?
    - Offshore medical resources are limited and appear more than once as a barrier in the analysis.

Recommendations arising from this case

- It may be prudent to implement more stringent health requirements and screening of personnel who are to work on offshore facilities in the Barents Sea. This recommendation may lead to debate amongst the parties involved in the petroleum industry. There is a tradition in the industry to have the same basic requirements on the entire Norwegian continental shelf.
- It may be advantageous to coordinate the activities in the Barents Sea. There are few helicopters to cover a very large area. Consider activities in the vicinity of each other and optimise the sequence and locations of exploration rather than spreading activity over time and large distances.

Threats not discussed in this bow tie analysis

- Weather threats: Visibility, not possible to land or hover over helideck if visibility is low, e.g. fog and intense rain or snow showers.
- Availability of accessible helideck: Movement of helideck on floating installations, not possible to land or hoist patient by winch. Ice or snow on helicopter deck, not possible to land or dangerous for personnel to move on helideck.

6.2 Barrier analysis of helicopter in sea

In this section an incident involving an emergency landing of a helicopter in the sea is analysed. There is a significant difference between a crash, involving uncontrolled entry into the sea, and an emergency landing or ditching, that may be a controlled entry to the sea. There are lessons to be learned from the investigation of helicopter accidents. Before performing the bow tie analysis, three reports are evaluated; the Cormorant A accident on the UK sector in 1992, the accident in 2009 off the coast of Newfoundland and a ditching off the coast of Norway in 1996.

Cormorant A, 1992

This accident occurred on the evening of 14th March 1992 at 1950 hours east of Shetland in the North Sea. A Eurocopter AS 332 L with 15 passengers and 2 pilots crashed into the sea while transferring personnel from Cormorant A to a nearby floatel facility. The wind had generally been at 40 to 50 knots but had increased to 50 to 53 knots before the accident. There were also snow showers passing the area. The air temperature was recorded to be 0°C [37 p14]. The aircraft lost speed while climbing and turning after take off and crashed into the sea, capsized and sank within one or two minutes. Of the 12 who escaped before the helicopter sank, only 6 were rescued alive. Some of the remaining 6 who escaped had survived for a considerable time in the hostile conditions but died before being rescued. One of the survivors was seriously injured. There were a total of 11 fatalities in the accident. The accident occurred in darkness [37 p2].

Two survivors, A and B, were interviewed by the HSE after the accident. The following information has been collected from the HSE report on helicopter safety [63]. Both had recently attended safety refresher courses prior to the accident. In the case of survivor A, only one month had elapsed. Both considered that the training had aided their survival. Both wore a zip up neck seal immersion suit. Neither of the two survivors had used the spray hood mounted on the immersion suit as it deprived them of vision and hearing which they regarded as essential in their fight against the elements and they wanted to stay in touch with the other survivors [63 p44-46].

Survivor A had not zipped up the suit entirely due to discomfort and the suit took in some water when he entered the sea. This person had become aware of an imminent crash just prior to the accident. He escaped through a window that had blown into the aircraft upon impact. Survivor A had problems inflating the lifesaving jacket and experienced that he almost lost it several times due to the lack of a crotch strap to keep it from slipping over his head. This survivor remained in the water and paddled continuously to keep his head above the water. This person suffered badly from cold and was unable to use his hands to put on his gloves. He used a lot of energy to keep afloat and protect himself from the sea. He believes that he was nearing the end of his endurance before being rescued. The person was eventually rescued by twisting an arm and leg into a rope passed down to him from a rescue vessel and was subsequently hauled aboard [63 p44-46].

Survivor B had zipped up the suit correctly and had inflated his lifesaving jacket. He was wearing jeans, a long sleeve shirt, sweatshirt and a working thermal under the immersion suit. This person had no awareness of a developing incident until the aircraft crashed into the sea and started filling with water. He was able to take a couple of deep breaths before going under water. He attempted to escape without releasing his safety belt and succeeded after releasing the belt. This survivor made his way to a damaged and partially inflated life raft where he remained for most of the time until his rescue. Together with 3 other persons, they managed to stabilise the raft. He did not experience cold for the first half hour but his hands eventually became numb and it was necessary to cling to the raft with his arms. As time lapsed and especially after being the only remaining person on the raft, he became increasingly demoralised, frustrated by the lack of rescue and felt the onset of hypothermia. He was finally rescued by a helicopter hoist and returned to the Cormorant A. He was the last survivor to be rescued and was in the best physical condition. The fact that he was able to stay mostly out of the water is considered to have contributed significantly to his survival [63 p44-46].

The investigation group consider it significant that the survivors stamina, clarity of mind, strong ability to swim, ability to control breathing when under water, their proximity to escape windows and recent refresher safety training had been essential factors leading to their survival [63 p46].

Newfoundland 2009

On the 12th March 2009 at 0956 hrs a Sikorsky S-92A on a flight to the Hibernia platform lost all oil from the main gearbox. The crew descended to 800 feet and turned towards St. John’s. When attempting to ditch the helicopter ca 35 NM from St. John's, the helicopter crashed into the sea at a high velocity. One passenger survived with serious injuries and the other 15 passengers and 2 crew died of drowning. Apart from the survivor, only one other person managed to escape from the wreck, however, this person also drowned [39]. The accident occurred in daylight.

The aircraft probably struck the sea at a forward speed of 55 to 60 knots. The impact with the water is estimated to have been 20g to 25g. The collapsing of structural elements of the aircraft, the seats and the 4 points harnesses has attenuated the forces. It is expected that the persons onboard have been exposed to acceleration forces in the range of 5g to 8g. Many of the passengers on this flight experienced serious fractures to the lower limbs on impact with the sea. This may have added to the psychological and physical stress during the initial phase of the accident. In addition the aircraft frame was seriously damaged and sank rapidly. All personnel onboard were wearing immersion suits and apart from the survivor and one person found on the surface, the remaining persons were in their seats with the safety harness closed. Research has shown that only 10-15% of individuals involved in this type of helicopter accident are able to effectively perform the necessary actions to escape [39 p29-31]. The weather at the scene of the accident is estimated with a sea temperature of 0,1 to 0,3°C, air temperature of ca 2°C, wind at 14 knots gusting to 20 knots and a wave height of ca 2,5 meters [39 p19].

The sole survivor of this accident escaped through a window that was knocked out during the impact and he was brought to the surface by the buoyancy of his survival suit. He probably escaped when the helicopter hull was at 20 to 30 feet below the surface of the sea. The other person who had escaped from the helicopter had probably not been able to hold her breath and drowned shortly after reaching the surface [39 p124]. The survivor's suit was one size to large and he took water into the suit [39 p30]. During the time in the water his core temperature fell by 7,2°C and his heart rate became irregular. Considering the rate at which his temperature fell, it has been calculated that he would have reached a critical core temperature of 24°C within 2,5 hours and not survived for longer [39 p124]. The survivor was a small boat sailing instructor, familiar with submersion in cold water, escaping from under capsized boats, fit, mentally prepared, had a strong will to survive and had recently performed safety training [39 p137]. This may have contributed to a physical and psychological advantage aiding in his survival.

Norway 1996

On the 18th January 1996 at 0845 hours it was reported that a Super Puma helicopter had ditched in the North Sea ca 30 NM from Egersund off the south west coast of Norway. There were 16 passengers and 2 pilots onboard of which all were rescued. The controlled emergency landing was performed due to vibration in the rotor system. The helicopter capsized during the night but stayed afloat for ca 35 hours from the ditching until it finally sank at 1700 hours on the 19th January [38 p3]. The wind was 25 to 30 knots, the wave height was 3 to 4 meters, the sea temperature was 5 to 6°C and the air temperature was 4 to 5°C [38 p5&12]. The accident occurred in daylight.

All of the passengers wore immersion suits of varying types and the pilots had non-insulated survival suits [38 p17]. The passengers observed that the pilots soon suffered from the cold [38 p20]. A life raft was deployed and all went aboard. This life raft drifted under the tail boom and was punctured by the tail rotor. This life raft was abandoned and all returned to the helicopter. A second life raft was deployed with 4 persons onboard, however, it was difficult to keep control of the raft under the weather conditions and it drifted away. All 14 persons remaining in the helicopter were then dependent on the floatation equipment of the helicopter and their own immersion suits. Helicopter fuel leaked into the cabin. The fuel combined with the motion of the helicopter in the sea caused some persons to become seasick. A helicopter arrived at the scene shortly after the ditching. Even though this helicopter did not have a hoist, the persons in the ditched helicopter felt it reassuring that another helicopter was standing by [38 p20]. Two Sea King helicopters were deployed from Sola to the scene of the incident and all personnel were rescued and returned to Sola within approximately 1,5 hours from the ditching occurred [38 p22].

Observations

Cormorant A

- Sealed and dry immersion suit with correct underclothing can enhance survival.
- When in the sea, it is better to stay out of the water due to a lower cooling rate in air.
- Training and mental capacity to handle the challenges of the situation are critical to survival.
- It can be essential to retain mobility and dexterity of hands and fingers in order to be able to assist in one’s own rescue.
- This accident, with significant loss of life, occurred in conditions within but close to the limits for helicopter operations stipulated by OLF [23].

Newfoundland

- Correct size of immersion suit is critical to avoid water leaking into the suit.
- Mental and physical preparedness may enhance survivability.
- Passengers are at a disadvantage when entering very cold seawater under severe circumstances and escape will probably not be effective.

Norway

- The helicopter stayed afloat for a long time in 4 to 5 meters wave conditions.
- The helicopter can be used as a survival craft when ditching under suitable conditions.
- Life rafts are difficult to use and control effectively in waves and wind.

- Seasickness can be expected amongst survivors.
- The protective clothing for the pilots may have proved insufficient in time.

Recommendations arising from reports on helicopter safety

The HSE report on helicopter safety draws attention to the importance of considering the surface conditions with regard to the capability to rescue survivors along the whole route rather than only at each end [63 p13]. The report rejects the suggestion that flights should be suspended if conditions are not suitable for ditching but argues that methods should be improved to ensure that survivors of a ditching or crash in the sea can have a reasonable expectation of being rescued alive [63 p28]. The importance of providing guidance to managers concerning departure criteria in adverse weather conditions with regard to survival and rescue times is emphasised [63 p35].

After the Newfoundland accident, the Transport Safety Board of Canada recommended prohibiting operation of transport helicopters over water when the sea state would not permit safe ditching and successful evacuation [39 p149]. The aircraft involved in the Newfoundland accident was certified for sea state 4 [39 p16]. S-92A helicopters operated in Norway are equipped with improved floatation equipment certified for sea state 6 (Beaufort 7 to 8) [39 p17]. This is a sea state that is more benign than the limits set by OLF guidelines that allow helicopter operations up to 55 knot wind, corresponding to sea state 8 (Beaufort 10) [95].

Event tree

The escape from the hull of a crashed helicopter is considered one of the most critical issues related to survival [63 p22]. Accident reports show that after a severe crash helicopters often capsize and sink. This allows little time for the survivors to escape [63 p24]. The two possible branches of helicopter floating or sinking are used as the starting point for the event tree.

The possible development of an incident where a helicopter ditches in the sea is analysed in the event tree in figure 30 below. This is a simplified event tree and would be further developed during thorough risk and emergency preparedness analyses. In this event tree "helicopter floats," means that the floatation aids are deployed and the helicopter is stable in the sea in an upright position. "Helicopter sinks," means that the individuals onboard must make their escape from underwater. The helicopter may have capsized, floatation may be keeping the helicopter afloat but upturned or the helicopter could be fully submerged and sinking. The helicopter could also crash into the sea with a higher probability of fatalities or injuries. A crash event is not discussed in this section, as the situation for survivors would be similar to the ditch event. However, it may be more difficult to take care of themselves due to injuries.

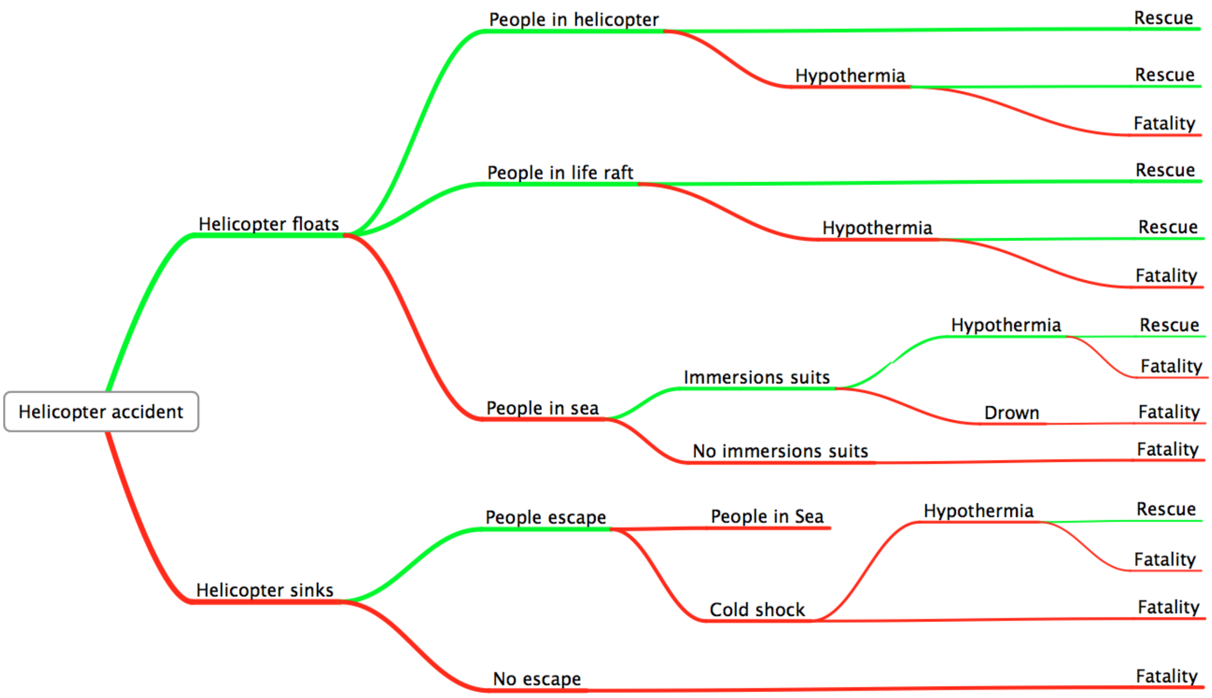

Figure 30, Event tree for helicopter accident in the sea

The causes leading to a helicopter ditching in the sea are not considered in this analysis. Barriers to prevent an emergency landing on the sea may include issues like design of the helicopter, operation, maintenance, inspection and competence of the crew and are all a prerequisite for helicopter transport.

In this event tree there are two main paths that are analysed. The paths are:

1. Helicopter floating and allowing a controlled escape without the need for underwater escape.
2. Helicopter filling or filled with water, capsized, submerged or sinking leading to an uncontrolled situation where everyone must take control of their own escape.

Event tree path 1 – helicopter floats

In path 1, as shown in figure 28, when the helicopter is floating in the sea, there are three new paths that may be followed:

1.a Presonnel stay in the helicopter
1.b Personnel evacuate to a life raft
1.c Personnel escape and are in the sea

Path 1a: If the helicopter is floating in a stable position in the sea personnel could remain aboard, as this will provide some protection from the elements. This may be a possible approach in sea conditions that are within the helicopters stability certification. One would need to prepare to exit at short notice if the helicopter lost stability and started to capsize. Some individuals may suffer from seasickness in a situation like this. Depending on time until rescue, persons may start to cool and suffer hypothermia. Fatalities in this situation are a possibility, but one would not expect a high probability. A reference case here would be the incident on 18th January 1996 where a Supa Puma 332L1 ditched in the North Sea [38].

Path 1b: If the persons choose to or are forced to leave the helicopter, it would be expected that they could deploy the life rafts and board them. The life raft would provide some shelter, however the probability of cooling and hypothermia may increase as the persons may have been in the sea. This path in the event tree would have a similar progression as the one described for the persons remaining in the helicopter. The option of using a life raft eliminates the risk of being trapped in the helicopter if it should suddenly capsize.

Path 1c: The final sub path considers persons being in the sea. This may happen if the helicopter sinks and for some reason the life rafts are not deployed. The life rafts are extremely susceptible to wind and may blow away and some or all persons may not be able to board one. It is a prerequisite for survival in this situation that the persons are wearing immersion suits, a regulatory requirement for helicopter transport in Norway.

Event tree path 2 – helicopter sinks

In the 2nd main path, the situation of the helicopter sinking is considered. There are two sub paths, one where persons escape and the other is that they do not escape from the helicopter. For those who do not escape from a sinking helicopter, the consequence is fatality. There are a number of issues that are immediately critical as the helicopter begins to sink. The first issue is to ensure that the immersion suit is correctly sealed to avoid water entering. The person must be able to breathe and operate the breathing lung on the immersion suit to aid escape as the helicopter goes under water. If the suit is not properly sealed and cold water enters, the person may suffer from cold water immersion shock (CWI), which can lead to cardiac arrest and drowning. If the person has water in the suit, the onset of hypothermia will be quicker than for a person who has sealed their suit and is dry. Seasickness, hypothermia, and drowning, as discussed in section 5.12, are possible consequences that can escalate to fatality in this situation [7].

Bow tie analysis

According to the bow tie method the hazard in this case is defined as "helicopter transport". The fact that personnel are transported by helicopter inherently means that an incident can occur where a helicopter makes an emergency landing in the sea. An emergency landing of this type is commonly referred to as a ditching. Alternatively, the helicopter may crash into the sea. This analysis is also performed in two tiers or levels as described in section 5.3 and figure 10. The first tier analyses the situation of threats posed to persons in the sea and exposed to the elements. The second tier considers the rescue operation and the threats that may lead to an unsuccessful rescue and ultimately fatalities.

Level 1 – persons in the sea

This level is illustrated in figure 31 & 32 and follows an incident where the helicopter has ditched into the sea. As discussed above in the event tree in figure 30, the helicopter is in the sea and persons may be exposed to the elements unless properly protected.

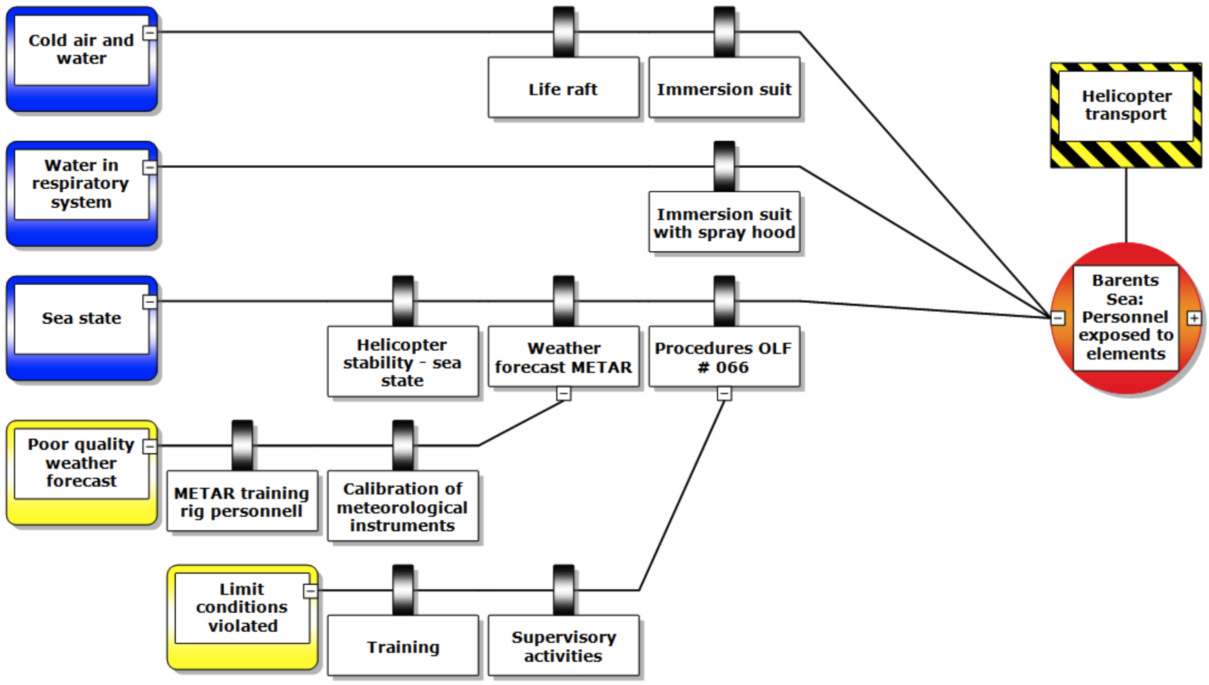

Figure 31, Threats to persons in the sea and exposed to the elements

In figure 31 above, the top event is defined as "personell in the sea exposed to elements". The threats that they must be protected against are simplified to cold air and water, water in respiratory system and the sea state. The threat controls in place to prevent exposure are availability of weather forecasts, procedures governing departure criteria, the provision of immersion suits with spray hoods, life rafts and the emergency floatation system of the helicopter. Weather forecasts and use of OLF procedures for operational limitations are intended to ensure a reasonable probability of rescue in the case of an accident within the 500 meters safety zone. There are escalation factors that may defeat or weaken the established barriers. The quality of the weather forecast is critical for a correct decision regarding fulfilment of the departure criteria. The local weather can be measured automatically or by competent observers on the offshore facility. In both cases training of the observers, maintenance and calibration of the meteorological equipment are important escalation control factors. It is important to bare in mind that the quality of weather forecasts for the Barents Sea are generally not as accurate as for other areas of the Norwegian continental shelf and one should possibly lean towards conservative use rather than optimistic. The limit conditions for the departure criteria may be unintentionally violated if personnel are not competent to interpret the weather forecast within its limitations. The departure criteria may also be wilfully violated by a tendency to stretch the limits in order to keep up regularity of the flights. In both cases training and supervisory activities may be escalation factor controls. Moving on to the right hand side of the bow tie in figure 32, the barriers in place to mitigate and reduce the consequences after ditching are analysed. The first critical issue is that personnel must be able to escape from the helicopter. Various possibilities have been discussed in the event tree in figure 30. If the helicopter is submerged, the persons will need to take responsibility for their own escape. The recovery measure in this case is the helicopter underwater escape training (HUET) that is required for personnel travelling by helicopter to an offshore facility. This barrier may be defeated if escalation factor controls are not in place to ensure that all personnel travelling offshore have the required HUET training and re-training. Another recovery measure for the same consequence is the breathing equipment built into the immersion suit. Escalation factors defeating or weakening this barrier may be that the breathing equipment is defective or that the person does not have the necessary competence to operate it. The escalation control factors in place in this instance are, in addition to HUET, the video that is shown prior to departure with instruction on how to use the immersion suit and maintenance of the immersion suit.

An important recovery measure to mitigate hypothermia and drowning is to rescue the persons. Rescue may be defeated for many reasons and will be analysed in the next level and bow tie diagram in figure 33. Recovery measures to reduce the effect of exposure to the cold water and air are the immersion suit with spray hood and the use of protective warm clothing under the suit.

With regard to the consequences of cold water immersion, it is critical that the recovery measure of a properly worn and watertight immersion suit is in place. In addition, if the suit should leak, wearing warm protective clothing under the suit may reduce the effect. If the suit is not worn and used correctly, this would be an escalation factor that may defeat the recovery control measure. An escalation factor control that is in place is, once again, the video that is shown prior to departure.

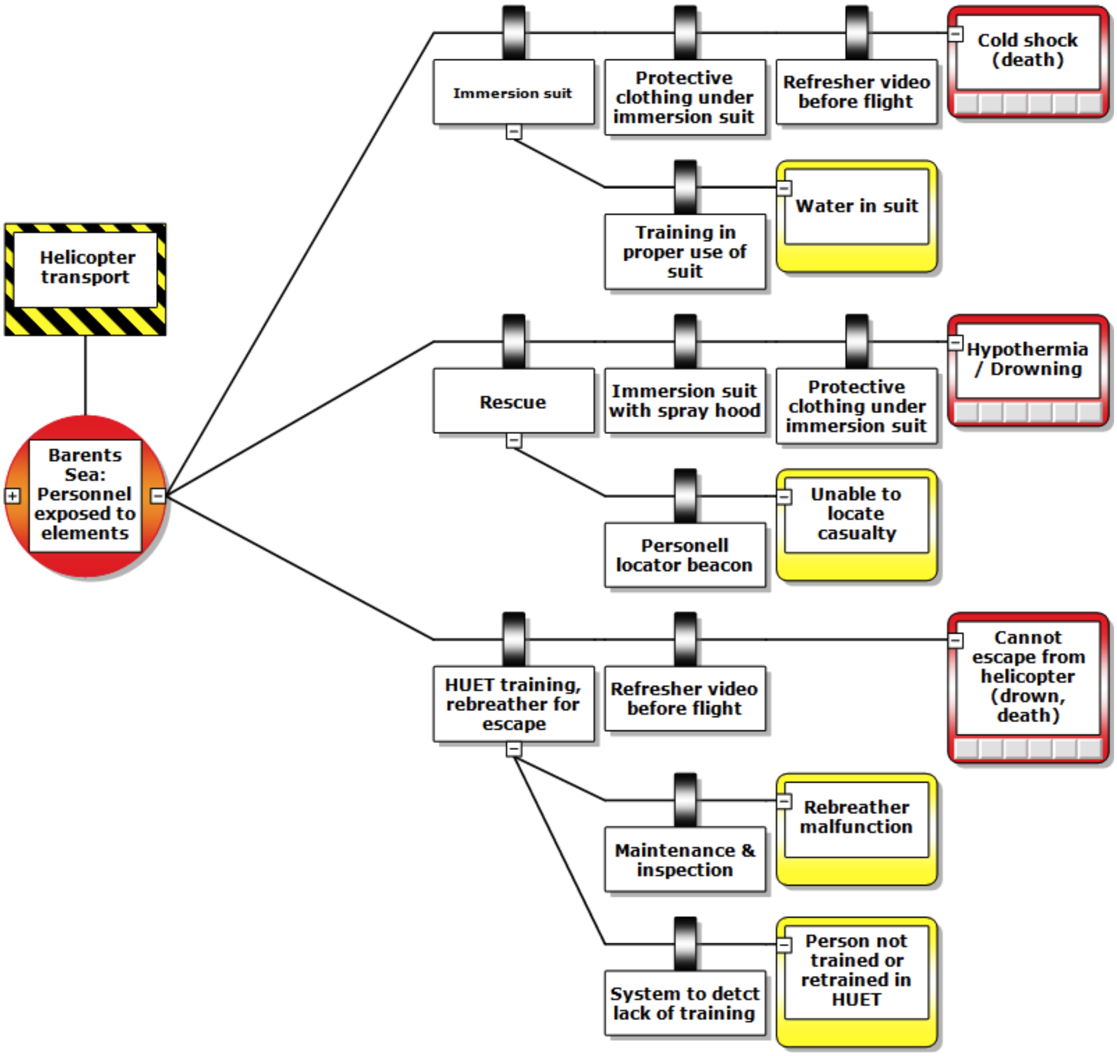

Figure 32, Consequences of exposure to sea and the elements

Level 2 – rescue operation

The bow tie in figure 33 is intended for the analysis of the threats that may lead to failure to rescue the persons in the sea after a helicopter ditching. The hazard in this diagram is considered to be a rescue operation after a helicopter ditch event. The top event is the inability to rescue the survivors.

The threats that can lead to a failed rescue operation are many and a selection is considered. The threat posed by poor visibility and light conditions may be controlled with barriers like the use of a personal locator beacon (PLB), night vision goggles and forward looking infrared camera/radar (FLIR). Examples of performance requirements for these barriers could be the range of the PLB, the FLIR's ability to detect small temperature differences and the performance specifications for the night vision goggles. It must be possible to rescue persons before there is a high probability that they will have succumbed to the effects of the elements.

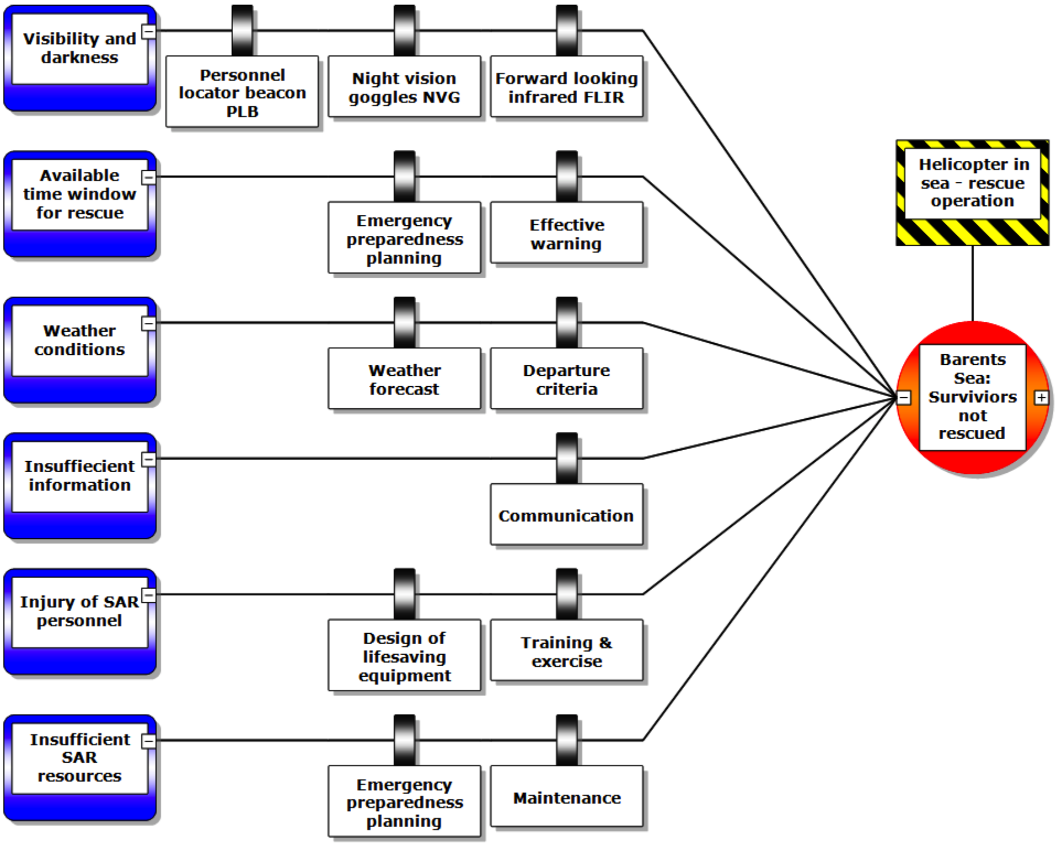

Figure 33, Threats that may lead to an unsuccessful rescue of survivors in the sea

The barriers may be the emergency preparedness planning and an effective alert that an incident has occurred allowing the mobilisation of rescue resources. The weather conditions are a threat that can reduce the probability of survival. The availability of reliable weather observations and forecasts coupled with departure criteria can secure a fair probability that a rescue operation is feasible. Insufficient information is a challenge to many rescue operations and efficient communication between rescue resources, incident controlling centres and the casualties is paramount [J07]. The rescue man on a SAR helicopter is a single resource that is critical to the operation. The importance of training of the rescue man, survivors and the design of the equipment these may be exposed to is a critical issue. A performance requirement may be the weather limits for a rescue operation and the physical fitness of the rescue man providing sufficient endurance to rescue all the survivors. Performance requirements in this instant would be the 120 minutes requirement to rescue 21 persons from the sea and that the rescue man is physically and mentally fit to endure the effort required [J07]. Finally the availability of SAR resources is a threat to a rescue operation. Through emergency planning the resources required to provide a robust service are put in place. The maintenance of these resources, including the competence of all involved in the rescue operation, are barriers in place to ensure success.

Summary of the identified barriers

Barriers to prevent exposure to the elements

- Properly fitting immersion suits with correct use of undergarments.
- Helicopter with appropriate floatation certification for the conditions in area of use.
- Procedures to ensure flights are only commenced when rescue is possible.

Barriers to avoid escalation of incident to hypothermia or fatality

- Properly fitting immersion suits with correct use of undergarments.
- Training and competence related to escape from a submerged helicopter.

Barriers to avoid unsuccessful rescue

- Reliable weather forecasts and departure criteria.
- Sound emergency preparedness planning erring toward caution.

This barrier analysis has addressed the following issues:

- What is the barrier? (System and elements)
    - The barrier system is a combination of operational and technical barriers to ensure that, in the case of a helicopter having to make an emergency landing in the sea, personnel will have a reasonable chance to survive and be rescued.
- What shall the barrier eliminate or prevent (left hand side)?
    - The barriers shall eliminate or prevent unprotected exposure of persons to the elements/weather if the helicopter ditches in the sea.
    - The barriers shall ensure that flights only depart when there is a reasonable probability that personnel can be rescued if there is an incident resulting in the helicopter ditching (or crashing) in the sea.
    - The barriers shall ensure that there are sufficient, competent and co-ordinated resources available to eliminate or prevent a failed rescue operation.
- What shall the barrier reduce or mitigate (right hand side)?
    - A barrier shall be in place to rescue personnel.
    - The barrier shall ensure that persons are competent and able to escape from the helicopter.

    - The barriers shall mitigate or reduce the consequences of personnel suffering from cold water immersion shock.
    - The barriers shall mitigate or reduce the consequences of personnel suffering from hypothermia or drowning.
- How can the barrier be weakened or defeated? (Escalation factor)
    - Poor quality weather observations and forecasts,
    - Allowing a flight to commence if weather criteria for departure are violated,
    - Incorrect use of immersion suits allowing water to enter the suit,
    - Malfunction or incorrect use of the breathing equipment in the immersion suit,
    - Personnel not trained or attended refresher HUET training,
    - Rescue personnel are unable to locate the survivors.
- How can weakening or defeating of the barrier be eliminated or prevented? (Escalation factor control)
    - Personnel are sufficiently trained to make reliable weather observation, interpret weather forecasts and make prudent decisions regarding departure criteria fulfilment prior to a flight commencing,
    - Supervisory activities are performed to ensure that competence is in place and that procedure requirements are followed,
    - Personnel are trained and competent in the correct use of immersion suits and that warm protective clothing is worn under the suit,
    - That there are sufficient resources available to rescue personnel in the sea,
    - That immersion suits are correctly maintained and functioning,
    - That the refresher video before flights is paid attention to by the passengers.
- What are the performance requirements of the barrier system?
    - Personnel shall have immersion suits that sustain life for the time required to complete a rescue operation.
    - Breathing system for underwater escape is dimensioned to provide sufficient air for the time it is reasonable to expect personnel will need to escape safely.
    - The resources can be mobilised to the site of the incident and perform a successful rescue before the persons succumb to the effects of adverse weather.
- How can the barrier and performance requirements be tested?
    - The immersion suit and breathing system can be tested in a laboratory.

    - The rescue system can be tested by effective exercise under conditions as realistic as possible involving the use of identified resources and mannequins.
- Are there dependencies between the various barriers in the protection system or barriers being used more than once
    - The immersion suit is on both sides of the bow tie and in a number of the barrier paths. This is effectively only one barrier. The provision of the immersion suit, training and competence is on the left hand side while the use of the suit appears after the incident on the right hand side of the bow tie.

Recommendations arising from this case

- The 120 minutes requirement to rescue persons from the sea should apply for the entire helicopter transport route. This will require that new resources are made available for rescue in the Barents Sea especially for long haul flights exceeding ca. 120 – 140 nautical miles from SAR helicopters based onshore.
- Departure criteria should be developed for the entire flight path with regard to being able to rescue persons in the case of a ditching or accident rather than only for the 500 meters safety zone around the facility. The departure criteria should be based on limiting parameters like; sea state, helicopter stability with floatation deployed, wind direction and speed, air and sea temp, visibility, lightning forecast, polar low forecast, availability and operational limitations of air and sea rescue resources.
- Consider providing a voluntary training course where personnel can familiarise themselves with the effects of cold water immersion (CWI), develop tolerance to cold water and more realistic conditions when training for escape from a submerged helicopter. This could include wind, waves, simulated rain, darkness and sound effects. There may be a case to review how personnel can prepare themselves for a situation where escape and evacuation from a helicopter is necessary. Exposing oneself to cold water at increasingly lower temperatures can improve tolerance to the effects of cold water immersion [7 & 45]. Preparing oneself mentally for the situation may also improve probability of survival. Another issue is that one should be physically fit to deal with the effort that is required to perform a successful escape under water [7 & 45]. It is important to show care when drawing conclusions from observations in actual accident situations. The sole survivor of the Newfoundland helicopter may illustrate the benefits of familiarisation with and tolerance of cold-water immersion situations [39 p124].

Threats not discussed in this bow tie analysis

- The threats that may result in a helicopter ditching or crashing in the sea are not included in this analysis.

6.3 Barrier analysis of lifeboat evacuation

There are important lessons that can be learnt from previous evacuations where lifeboats have been launched or attempted launched. The following historical events will be taken into consideration: evacuation of Alexander Kielland [6 & 34], Ocean Ranger [35] and West Gamma [6]. The incidents of release mechanism malfunction on Veslefrikk B & Kristin will also be considered [36]. Finally experience with the rescue of persons in connection with the loss of the ferry Estonia is considered [7].

Alexander Kielland

The semi-submersible accommodation facility, Alexander Kielland capsized during a severe gale on 27th March 1980 when it lost one of five pontoon legs. The rig capsized within ca 20 minutes of a leg breaking away providing little time for an orderly evacuation. There were 123 fatalities and 89 survivors of the accident [6 p100]. The wind was 16-20 m/s with waves between 6 to 8 meters [34 p14].

Lifeboats were attempted launched but suffered severe accidents due to failure of release hooks and insufficient ability to manoeuvre away from the platform resulting in severe damage to the lifeboats. Four lifeboats were launched of which one was released successfully after the wheelhouse was crushed giving access to a hook that had not released. The three other lifeboats were crushed when colliding with the platform prior to release. A fifth lifeboat was released after the rig had capsized. The fifth lifeboat was also capsized but persons in the sea swam to the boat and righted it [34 p16]. The incident demonstrated that in harsh weather conditions davit launched lifeboats may be difficult to release satisfactorily and that it is difficult to rescue personnel from lifeboats using traditional standby or platform support vessels [6 p101]. The release hook design has been changed since the accident. However, hook release is critical in a two fall system were both hooks need to be released almost simultaneously. This is still an issue with today's davit launched lifeboats and extensive work has been done studying the issues critical to successful release [76]. Insufficient propulsion of the lifeboats led to collisions with the platform and many were damaged. The issues related to lifeboats in this accident increased the momentum to develop free fall lifeboats as an alternative to davit launched lifeboats [6 p101]. Lifeboat redundancy or over capacity requirements should be the same for all types of offshore facilities [34 p53].

Safety training was identified as deficient and unsatisfactory. The amount of safety training for persons involved in the accident varied widely. The statistical material available is too limited to draw qualified conclusions on the effect of safety training on the survivability of personnel in this particular accident [34 p65]. However, the commission did agree that the safety level would increase if all personnel attended safety training [34 p68]. The investigation report recommends enhanced safety and professional training [34 p6].

Other observations from the Alexander Kielland accident are addressed briefly here. It was observed that 8 persons used survival suits, 7 of them survived. Of the 8 persons using survival suits, only one person wore it correctly [34 p58]. Standby vessels were unable to perform their intended task due to weather conditions. The effort of the crews on helicopters in the rescue operation, were considerable and in the autumn of 1981 a permanent 24 hours helicopter rescue service was implemented at the Ekofisk field [34 p9].

West Gamma

The jack-up rig, West Gamma, was lost in a storm on 21st August 1990 while being towed in the North Sea. The maximum wave height was reported to be ca. 16m and deteriorating to a significant wave height H_s of over 10 meters. The helideck had collapsed and it was considered unsafe to launch lifeboats due to the sea breaking over the main deck. The personnel on board performed an improvised evacuation by donning survival suits and jumping into the sea where Fast Recovery Craft (FRC) rescued them. All 49 crew onboard West Gamma were rescued [6 p106]. Weather according to Esvagt web site: waves up to 9-12 meters, wind 55-60 knots. Esvagt took part in the rescue operation [100].

Ocean Ranger

The Ocean Ranger capsized 15th February 1982 in a severe storm off New Foundland. In the case of the Ocean Ranger it was attempted to bring a lifeboat alongside an ERV in maximum combined sea conditions of 55 ft (16,8m) waves, occasionally up to 65 ft (19,8m) waves [35 p55] and ca 75 knot winds [35 p58]. These weather conditions are classified as hurricane or force 12 on the Beaufort scale. In an attempt to transfer persons from a lifeboat to the standby vessel Seaforth Highlander, the two collided several times. The motion of the standby vessel and sea pressed the lifeboat away. It proved difficult to bring the lifeboat along side and it was not possible to rescue personnel to the standby vessel. Men climbed out of the lifeboat resulting in a loss of stability and it rolled over and capsized [35 p62]. The lifeboat was found later on with signs of extensive damage, a large hole in the bow, a crack down the bottom of the hull and water was flowing freely through the lifeboat [35 p 67]. There were 84 persons on the Ocean Ranger, none of who survived [35].

Estonia

The Estonia ferry disaster in the Baltic Sea on a route between Tallinn and Stockholm occurred on 28th September 1994 at approximately 0115 hrs when the vessel took in water, lost stability, rolled onto its starboard side and sank. This happened within a time span of ca 30 minutes. The sea temperature was ca 12°C, the wind was about gale force at 18 – 20 m/s and the significant wave height was between 3 and 4 meters. Lifeboats could not be launched due to a severe list and life rafts were deployed with varying success. Mainly SAR helicopters and rescue men performed the rescue of persons in the sea. During the rescue operation most of the rescue men became fatigued while being buffeted by waves and when helping cold and incapacitated survivors. In addition some of the rescue men were injured in collisions with lifeboats while searching for survivors. Only 137 of the 989 persons onboard the Estonia survived the disaster [7 p4-8].

West Vanguard

It is only fair to mention that during the shallow gas blow out on the West Vanguard on 6th October 1985, personnel evacuated in two lifeboats and were subsequently transferred to the standby vessel in good weather conditions [6 p84].

Veslefrikk B/Kristin

During testing of the release mechanism for free fall lifeboats on Veslefrikk B & Kristin in December 2008 and January 2009 it was discovered that it was not possible to release and launch the lifeboats. The lifeboats had originally been installed, tested and commissioned in 2005. They had been sent onshore for modification due to weaknesses identified in the lifeboat superstructure. This had increased the weight of the boats and when returned to the offshore facility, they were not installed in their original positions. Mechanical alignment of the release mechanism was shown to be critical. In this case, necessary barriers were in place to eliminate the chance of failure to launch in an emergency situation [36].

Observations

Alexander Kielland:

- Davit launched lifeboats difficult to launch. Hook improvements made post accident.

- The accident accelerated the development of free fall lifeboats.
- The effect of safety training on survivability of personnel considered but no conclusive evidence of effect. Safety training requirements enforced after accident.
- Weather: wind 16–20 m/s, waves 6-8 m.

West Gamma:

- Rescue from sea by FRC/MOB boat was possible. Lifeboats inaccessible, helideck damaged, helicopter rescue from facility not possible due to motion of legs.
- Weather: wind 55-60 knots, waves up to 9-12 meters.

Ocean Ranger:

- Lifeboat damaged in collision with standby vessel. Personnel released seat belts and climbed out causing lifeboat to capsize. All men were subsequently lost.
- Lifeboats are designed to be self-righting if all personnel are strapped into their seats and no significant amount of water in the boat [35 p19].
- Hurricane weather is a limiting factor for transfer of personnel from LB to ERV. The safe option may be to ride out the storm even with 3rd generation ERVs.
- Weather: Hurricane, wind speed up to 75 knots, wave height 16,8 to 19,8 meters.

Estonia:

- Rescue men became fatigued.
- Rescue men injured by collision with lifeboats.
- Weather: gale force 18 – 20 m/s, significant wave height 3 – 4 m.

West Vanguard

- Successful evacuation was achieved with davit launched lifeboats. No casualties in connection with the use of the lifeboats.

Veslefrikk B & Kristin

- Release mechanism failure detected before an incident requiring evacuation. This demonstrates the importance of barriers to detect similar situations.

Summary

- Ride out a storm if unsafe to transfer personnel from lifeboats to vessels or helicopters.
- Caution to be taken as sea conditions deteriorate in order to avoid collision between ERV and lifeboats.

- FRC/MOB boat rescue of persons is possible to a certain extent in adverse weather conditions.
- Caution to be taken when helicopter rescue men approach a lifeboat in the sea.

Analysis of lifeboat evacuation

In this section an evacuation involving the use of lifeboats is analysed. Two methods of analysis, event tree and bow tie, will be used in support of each other to illustrate the case. The event tree is shown in figure 34 and the bow tie in the diagrams in figures 35 to 38. This case only considers the situation from the point in time where it becomes necessary to evacuate the installation. It is, of course, important to operate the facility with the utmost caution in order to avoid the need for evacuation and subsequent rescue of personnel.

This is a simplified event tree and would be further developed during thorough risk and emergency preparedness analyses. Three initial paths are identified in the event tree:

1. Lifeboats launched successfully, sail to emergency response vessel,
2. Lifeboats launched successfully and experience ice accretion,
3. Not possible to launch lifeboats due to ice/snow or failed release mechanisms.

In the event tree in figure 34, the outcomes are “rescue” or “fatalities”. The outcome “rescue” indicates success in rescuing the personnel who have evacuated in lifeboats. The outcome “fatalities” indicates that there is a probability that rescue may be significantly delayed or not possible leading eventually in both cases to potential fatalities.

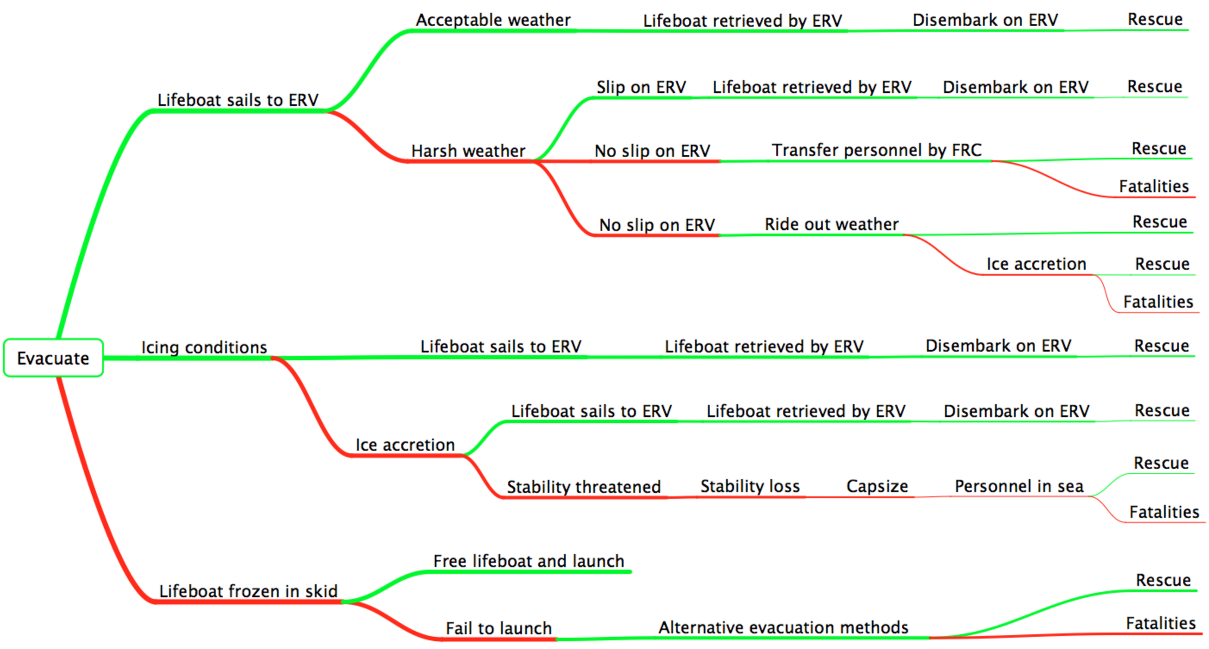

Figure 34, Event tree for lifeboat evacuation

First the paths 1, lifeboats launched successfully, sail to emergency response vessel, and path 2, lifeboats launched successfully and experience ice accretion, will be analysed using event tree and bow tie. Secondly the consequences of an unsuccessful rescue will be analysed using bow tie alone. Finally path 3, not possible to launch lifeboats due to ice/snow or failed release mechanisms, will be analysed using both event tree and bow tie.

Event tree path 1 - Lifeboats launched successfully, sail to emergency response vessel

The desired path in an evacuation situation is shown in the top path in the event tree in figure 34. The lifeboats are launched, manoeuvred away from the stricken facility, meet up with an ERV and personnel are transferred from the lifeboats to the vessel. Alternatively personnel are rescued by helicopter from the lifeboats and transferred to either the ERV, another facility in the vicinity or to the shore. If the weather is harsh special consideration will need to be given to the method of transfer of personnel from the lifeboat to the ERV. If the ERV is equipped with a slipway in the stern for retrieval of lifeboats from the sea, this will be the preferred method of disembarking personnel. ERVs equipped with a slipway are able to perform lifeboat retrieval in conditions up to wave heights of 11 to 12 m. [J03] The decision to transfer personnel will be taken by the captain of the ERV based on the sea state. Special attention will need to be given to avoid collision between lifeboat and MOB boat or the ERV. Attention is drawn to the experience during the Ocean Ranger and Alexander Kielland accidents [6]. Transfer directly between a lifeboat and an ERV that is not equipped with a slipway may not be feasible once the waves have passed 5 to 6 m. Caution must be exercised if attempting a transfer in these conditions. The issue of lifeboat stability and self-righting properties are also important. Loss of life has occurred when persons unfasten their seat belts and move to the exterior of a lifeboat. Ocean Ranger incident is a reference case [35].

Attention must also be given to the safety of the helicopter rescue man and the personnel who are lifted either directly from the lifeboat or from the sea. There are issues threatening the safety of the rescue man e.g. sharp deluge nozzles and inaccessible hatches on existing lifeboats models [J07]. These issues may be resolved by close cooperation between rescue personnel, designers and manufacturers of lifeboats. Injury of the rescue man if colliding with the lifeboat may also be of concern as was observed in the Estonia disaster [7]. If it is necessary to retrieve personnel from lifeboats in harsh conditions, it may be necessary for persons to leave the lifeboat and enter the sea for rescue by MOB boat or FRDC. This is potentially a less safe situation than staying onboard the lifeboat especially in rough sea or very cold conditions. A dry situation is preferred to a wet evacuation. Care would need to taken that the person does not drift off and become lost.

In situations of harsh weather it may be necessary to ride out the weather and wait for a better operational window to rescue personnel from lifeboats. This may be a situation lasting from hours to days and needs to be considered when equipping lifeboats for prolonged survival onboard. The issue of ice accretion may be a threat when riding out a storm and is discussed in event path 2 below.

Event tree path 2 - Lifeboats launched successfully and experience ice accretion

The stability of lifeboats could be impaired due to ice accretion. The icing may not be serious enough to impair stability and the lifeboat could sail to the ERV and follow the analysis in path 1 in figure 34. If ice accretion is serious and a threatening layer is built up, the lifeboat may experience reduced stability. Air captured in the ice will normally mean that the ice has a lower density than seawater. Capsizing may not be likely but cannot be excluded. However, an unstable situation with the lifeboat potentially lying on its side and rolling slowly can be expected. This situation is particularly dangerous if the lifeboat is damaged and there is free water inside. This type of situation may threaten stability even further if passengers release their seat belts. The self-righting property of lifeboats is dependent on the occupants remaining strapped into their seats. A worst case scenario may be one of serious impairment of stability, persons releasing seatbelts further reducing stability and self-righting ability leading eventually to a situation out of control and persons leaving the lifeboat, possibly in panic. It is important that the behaviour of a lifeboat experiencing ice accretion is known and that personnel are prepared to deal with the situation before it becomes a threat.

If icing conditions prevail at the time of an evacuation, this may also affect the performance of MOB boats, FRDCs and ERV. It is of equal importance that the stability of these vessels is studied for ice accretion and measures are taken to mitigate and reduce the consequences.

Bow tie analysis of path 1 and 2

The bow tie analysis in figure 35 examines means to prevent the negative development of path 1 and 2 in the event tree, figure 34. According to the bow tie method the hazard is defined as “evacuation”. The fact that personnel are on a facility offshore inherently means that they may at some time need to be evacuated as the result of another threatening incident. If an evacuation becomes necessary the persons will need to be rescued and taken care of. The top event is therefore “unable to rescue persons”. The threats are simplified to sea state, ice accretion conditions and visibility. Any one of these threats could lead to delay or failure of a successful rescue.

The sea state is a threat to the rescue operation and may not allow the transfer of personnel to the ERV. If a SAR helicopter is used as a threat control to rescue persons from the lifeboat an escalation factor may be violent movement of the lifeboat threatening the safety of the rescue man and person to be hoisted. In the same manner, an ERV may be used to rescue personnel from the lifeboat. An escalation factor defeating the use of the ERV may be the operational window for personnel transfer from the lifeboat. The sea state could render personnel transfer to the ERV unsafe or even impossible. For both cases, SAR and ERV rescue, an escalation control factor could be training personnel to leave the lifeboat in an orderly manner and swim away for hoisting to the helicopter or rescue by a MOB boat. A preferred escalation control factor would be to increase the operation window of the ERV by selecting a vessel that has a stern slipway for retrieval of the lifeboat.

Ice accretion on the lifeboat is a threat that may lead to an unsafe situation. As a threat control in the case of ice accretion on the lifeboat, ice may be removed manually, the lifeboat may be protected with an ice repellent coating or de-icing heating may be installed to avoid ice accretion [43]. Other threat controls or barriers in this case would be to rescue the persons from the lifeboat before the ice accretion leads to situations described in the event tree path 2. An escalation factor defeating the SAR and ERV would be that icing conditions could potentially threaten both. The escalation factor control is then to have de-icing in operation on the helicopter and icing protection measures on the ERV. In addition the stability tolerance of the ERV must be known. This would define the operational window for the ERV in ice accretion conditions.

Visibility is a prerequisite to perform a rescue operation and poor visibility is shown as a potential threat. Poor visibility is a threat to all operations involving the transfer of personnel from a lifeboat to either a SAR helicopter, ERV or a MOB boat. Particularly in the case of a polar low or heavy snow showers during evacuation, visibility would probably be impaired. Visual aids in the form of radar, night vision goggles (NVG) or forward-looking infrared cameras (FLIR) are threat controls that may prevent the top event, unsuccessful rescue.

There are many barriers that may prevent the top event in this case, however one does not have the means to totally eliminate the threats. The successful use of technical barriers is dependent on operational barriers like adequate maintenance, training and competence. In addition consideration may be given to implementing additional operational barriers taking into account the weather forecast and planned activity in order to reduce the combined probability of an evacuation, poor weather and low visibility. This also applies for the situation of harsh weather and icing conditions. These operational barriers would also rely on training and competence of the personnel interpreting weather forecasts, planning activities and making informed decisions on operations allowed under the prevailing conditions.

Typical performance requirements for these barriers may be a minimum operational window for the ERV, e.g. possible to pull a lifeboat into the stern slipway in wave heights up to 11-12 meters. The Norwegian Meteorological Institutes data for the Barents sea indicates that significant wave height H_s is greater than 5 meters in 4,6% of the year in the east (72.58°N, 33.10°E) and 6,61% of the year in the south west (71.58°N, 19.53°E), predominantly in the period October to March [51]. Performance requirements would need to be defined in more detail in the emergency preparedness analysis for all of the barriers involved in the total evacuation and rescue system.

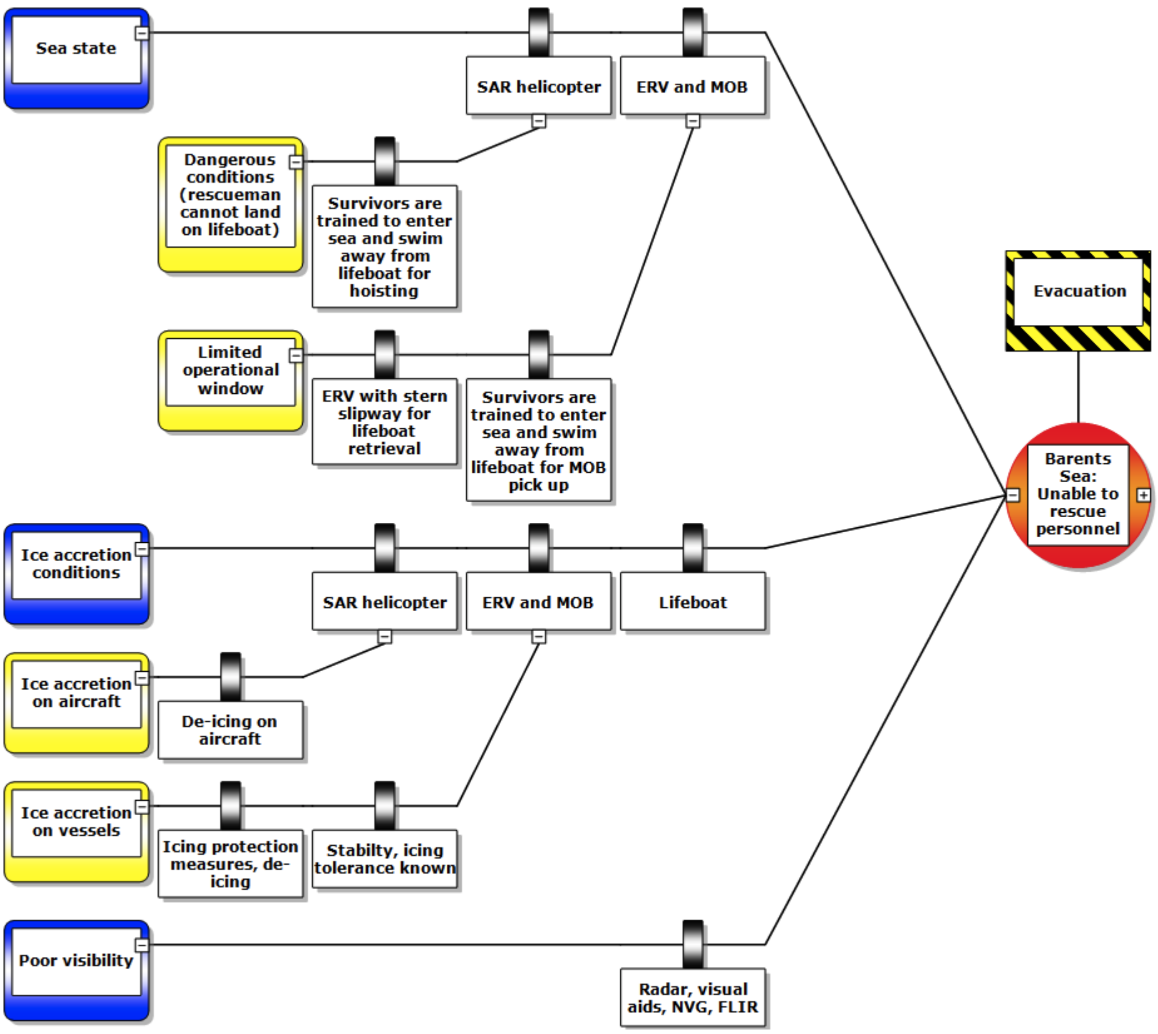

Figure 35, Threats that may hinder the rescue of persons evacuated in lifeboats

The consequences of delayed or failure to rescue the personnel in the lifeboat are examined in figure 36. If an evacuation is necessary and persons have to spend time in a lifeboat before being rescued there are a number of physiological issues that may arise, e.g. seasickness, dehydration, hunger, hypothermia and potentially fatality. Some or all of the persons in the lifeboat would almost certainly experience some of these consequences if it became necessary to ride out the weather while waiting for a window to rescue them. Depending on the operational window of the ERV and the SAR helicopter, it could be necessary to wait for a period of hours to days. In this case anti-seasickness medication, water, food, immersion suits and warm clothing are required as recovery measures to mitigate and reduce the consequences. Seasickness if untreated will lead to dehydration and faster loss of body heat potentially resulting in hypothermia. Water is essential in this situation, preferably warmed and mixed with nutrients. Food is not an immediate issue but will increase the well being of the occupants. One should bear in mind that personnel have an increased energy requirement in cold environments. This should be reviewed when equipping lifeboats for operation in cold and harsh environments. It is normal for personnel to wear immersion suits when mustering prior to evacuation and there are normally extra suits available at the lifeboat station. Spare suits and blankets should be considered stored in the lifeboat in order to allow for damaged suits or the need for extra insulation. This may be a particular issue when operating towards the northeast where air temperatures below -30°C can be expected. In addition to the physiological consequences discussed above, ice accretion could become a threat at any time while riding out the weather depending on the prevailing conditions.

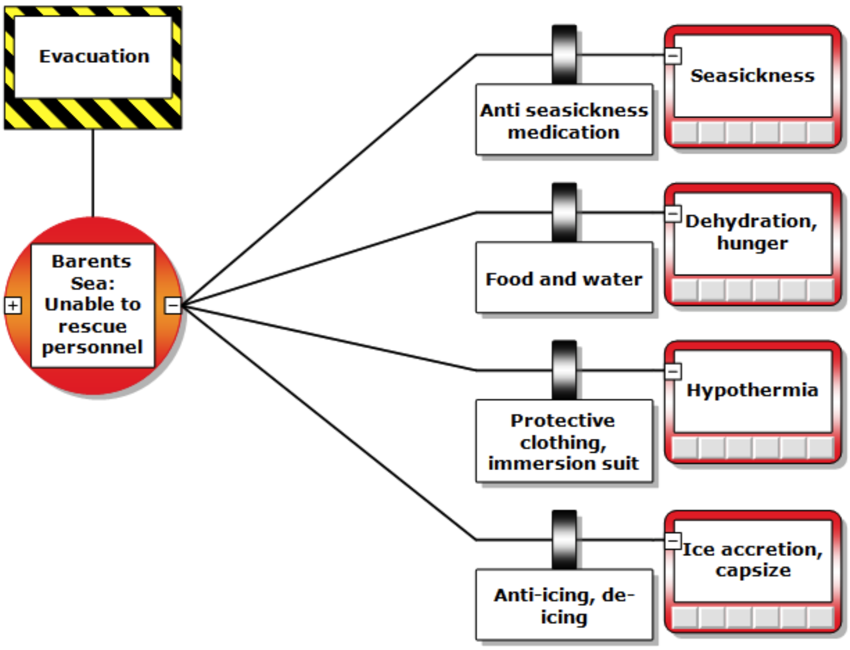

Figure 36, Consequences of not rescuing persons evacuated in lifeboats

Event tree path 3 - Not possible to launch lifeboats due to ice/snow or failed release mechanisms

The "fail to launch" event is identified as a possible top event and is illustrated in path 3 of the event tree in figure 34 and in bow tie diagrams in figure 37 & 38. The threats in this case are simplified to the lifeboat freezing fast in the davit or launching skid and failure of the release mechanism. These are critical events and barriers need to be identified to eliminate and prevent the threats. Numerous methods, like manual removal of ice and snow, infrared heating, hot water or steam removal of snow or ice and repellent coatings have been identified and function as barriers to eliminate and prevent the top event [43]. Ideally, the lifeboats should be installed in a shelter on the facility as has been done on some platforms, e.g. Polar Pioneer and Goliat FPSO. A dual release mechanism should be installed as a threat control barrier to eliminate the threat of failure to release. An example of an escalation factor for the dual release mechanism could be insufficient temperature tolerance of the hydraulic fluid used in the release mechanism thereby defeating the barrier. Both of the technical barriers need to be supported by preventive threat controls like inspection and maintenance that are operational barriers. Escalation factors could typically be insufficient maintenance procedures or lack of competence among technicians. Typical performance requirements for these barriers may be the amount of ice that can be removed by a heating system, the lowest temperature at which the release mechanism is operable, frequency of inspection and maintenance and defined maximum overrun of due date for this work.

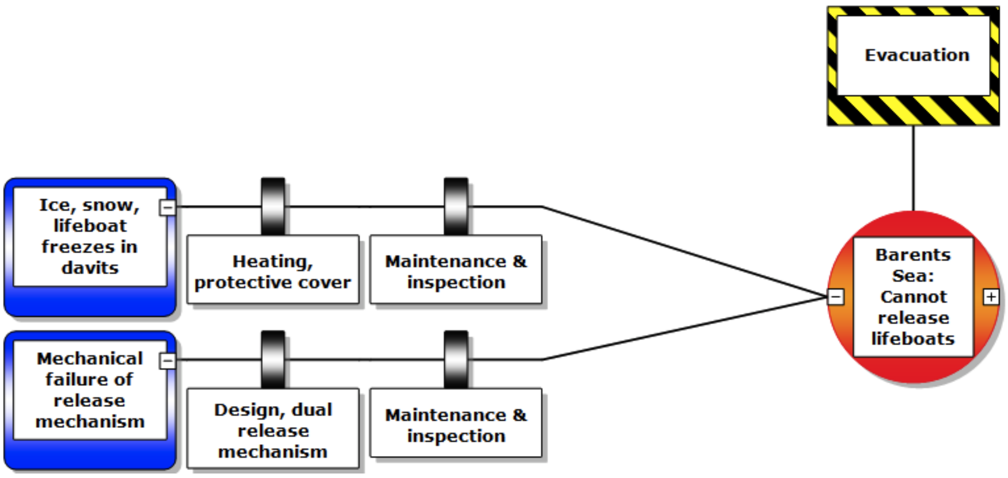

Figure 37, Barriers to eliminate and prevent failure to launch lifeboats

It is also necessary to identify barriers in order to reduce or mitigate the consequences. A "failure to launch" situation is critical and there are alternative means of evacuation, for example escape chutes, life rafts and ladders to the sea for this event or for personnel who are unable to reach the lifeboats. This is a final barrier against personnel being stranded on the stricken facility without a means to evacuate. Examples of performance requirements for these barriers would typically be the operational window and time to deploy. Failure of the release mechanism is particularly critical if all personnel are in the lifeboat, the release mechanism is activated but the lifeboat does not launch [36 p15].

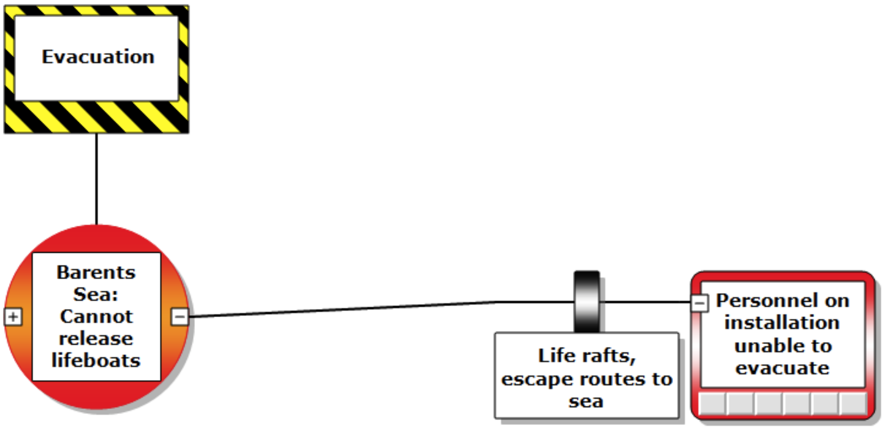

Figure 38, Barriers to mitigate the consequences of failure to launch lifeboats

In this situation it is impossible to know why the lifeboat has failed to launch and it is not clear what is a safe way to proceed. The lifeboat could be launched suddenly due to vibration or weight shift of personnel moving. Single mode of failure and deficient maintenance of the release mechanism was identified in the fail to launch incidents on Veslefrikk B and Kristin.

Summary of the identified barriers

Barriers to avoid unsuccessful evacuation and rescue

- Protection and maintenance of lifeboats to ensure availability and reliability for evacuation.
- Training and competence of personnel in issues specific to operation, evacuation, rescue and survival in the Barents Sea.
- Provision of sufficient resources to aid in a rescue operation.

Barriers to avoid escalation of situation

- Protection against and detection of ice accretion.
- Means to prevent seasickness, dehydration and hypothermia amongst survivors Provide alternatives to lifeboat evacuation.

This barrier analysis has addressed the following issues:

- What is the barrier? (System and elements)
    - A system to evacuate and rescue personnel from a stricken facility.

    - The elements in the barrier system are lifeboats, life rafts, helicopters, emergency response vessels, MOB boats, FRDCs, procedures and emergency preparedness plans.
- What shall the barrier eliminate or prevent (left hand side)?
    - The barrier system shall eliminate and prevent the failure to evacuate from a facility.
    - The barrier system shall provide suitable means to rescue personnel and avoid a situation where it is not possible to perform a rescue operation.
- What shall the barrier reduce or mitigate (right hand side)?
    - The barrier system shall ultimately prevent the loss of life in connection with an incident requiring evacuation of a facility.
    - The barrier system shall ensure that personnel can survive for a prolonged period in a lifeboat in adverse conditions.
- How can the barrier be weakened or defeated? (Escalation factor)
    - Ice accretion affecting the performance of a lifeboat, helicopter or an ERV and its support vessels can defeat the ability to rescue personnel,
    - Poor visibility making it difficult to see and find lifeboats and personnel,
    - Not taking into account the weather forecast.
- How can weakening or defeating of the barrier be eliminated or prevented? (Escalation factor control)
    - Ensure competence on issues specific to operation, evacuation, rescue and survival in the Barents Sea,
    - Implement operational limitations for activities on the facility when conditions may lead to unsuccessful evacuation and rescue,
    - Provision of sufficient SAR helicopters with de-icing equipment,
    - Provision of ERV with stern slipway,
    - Study stability of all vessels and craft for effects of ice accretion and identify limiting operation conditions,
    - Provision of vision aids and training of personnel to use them,
    - Training of personnel in retrieval of lifeboats onto stern slipway of ERV,
    - Training of personnel to enter sea to assist in their own rescue,
    - Training of rescue men, MOB boat and FRDC crew to pick up personnel in harsh conditions,

  - Protection of lifeboats to avoid freezing in launch system,
  - Design and maintenance of lifeboat and release mechanism.
- What are the performance requirements of the barrier system?
  - Minimum operational window for helicopter and ERV to enable rescue of personnel from lifeboats or sea.
  - Minimum requirements for survival time for personnel in a lifeboat.
  - Defined performance requirements for availability and reliability of the equipment.
  - Performance requirements would need to be defined for the individual elements of the barrier system in a thorough emergency preparedness analysis.
- How can the barrier and performance requirements be tested?
  - Performing emergency preparedness exercises under varying conditions to monitor the operational barriers.
  - Testing and maintenance of the equipment to monitor the technical barriers
- Are there dependencies between the various barriers in the protection system or barriers being used more than once?
  - The operation of the MOB boat and FRDC are dependent an operational ERV.
  - The SAR helicopter and ERV appear as a barrier both against a sea state and ice accretion threatening the personnel in the lifeboat. The barriers for avoiding a failed rescue are limited.

Recommendations arising from this case

- Operations should be planned in order to avoid evacuation in adverse conditions. All activities should be planned such that accidents do not occur, however some operations have a greater inherent risk than others and this should be given particular consideration.
- Increase helicopter resources in area, SAR helicopters should have all-weather capability, i.e. AWSAR helicopter.
- Train and exercise maritime rescue personnel to operate vessels, ERVs, FRDCs and MOB boats in harsh weather and when ice accretion occurs.
- All activities in the Barents Sea should be supported by ERVs with stern slipway.
- Involve rescue men in the design of lifeboats in order to increase safety during rescue.

- Identify resources that may be available to assist in a rescue operation even though they are not under the control of the operator of the facility. These may be coast guard, fishing or merchant vessels in the vicinity.
- Lifeboats should not be brought alongside an ERV if H_s is over ca. 4m.
- It is important that passengers in lifeboats follow commands of coxswain so as not to impair stability.
- Due consideration and caution should be used if deciding to leave a lifeboat and enter sea for pick up by helicopter, FRDC or MOB boat in cold and harsh weather.

Threats and barriers not discussed in this bow tie analysis

- The potential threat posed by sea ice to the use of lifeboats, ERVs and support craft.
- Operational procedures to eliminate or prevent the need to perform an evacuation and subsequent rescue operation.
- The availability of other resources, e.g. coast guard vessels, fishing vessels and other maritime resources and aircraft for surveillance of the situation has not been addressed. These resources are not under the control of the operator of the facility and their position in the event of an incident is random.
- Sufficient propulsion, including reliability of engine, to safely manoeuvre lifeboat away from the facility after launch.

6.4 Evacuation

Evacuation is normally carried out according to a predefined and prioritised method as described in section 5.4. In the Barents Sea there are currently few helicopter resources to assist in both precautionary and emergency evacuations. There may therefore be a higher probability than in other areas of the Norwegian continental shelf, that lifeboats may be used at some time for a precautionary evacuation where this would have been conducted using helicopters elsewhere [J08]. The person responsible during a situation may be in a position where he/she has to make a decision between launching lifeboats as a precautionary evacuation or not doing so and exposing more persons than necessary to the risk of the incident. It is important that the possibility is given due consideration and the emergency preparedness plans take this into account. Being able to retrieve personnel safely from lifeboats in the sea is of the utmost importance. The issues of ice accretion are an aggravating factor that may impair the use of the lifeboats and emergency response vessels [43 & 65].

6.5 Rescue

It is generally recognised that helicopters can operate and rescue persons from the sea in almost any weather condition, except in fog or low visibility as discussed in section 5.6.3, whereas the capability and performance of rescue vessels is limited by deteriorating sea states [63 p76]. It was already identified in the investigation report after the Alexander Kielland accident that helicopters from onshore arrived too late to rescue survivors from the sea. The commission recommended that rescue helicopters be stationed offshore [34 p70]. There are challenges regarding having a SAR helicopter stationed on an offshore facility, especially if there isn't a hangar available for the helicopter. The challenges include wind, motion of the platform, corrosion, snow and ice and some parties in the industry do not recommend stationing of SAR helicopters offshore due to safety issues [74]. However, offshore SAR helicopters have been operated successfully for many years on facilities with a hangar. There is general agreement that the SAR helicopters are a considerable strengthening of offshore emergency preparedness. It is unfortunate for the industry as a whole that this service is not available for all fields and areas [41 p2].

6.6 Helicopter transport

Helicopter transport poses a significant contribution to the total risk for a person employed offshore. It is the government's ambition that helicopter safety on the Norwegian Continental shelf shall be a leading reference standard with regard to risk reducing measures [28 p315].

Regulation of helicopter transport

The regulation of helicopters as aircraft and their operation is organised within the responsibility of the Norwegian Civil Aviation Authority, not as part of petroleum activities regulated by the Petroleum Safety Authority. However, there is a general requirement in the petroleum regulations that transport to facilities involved in the petroleum activities shall be carried out in a prudent manner [28 p315]. The Activities Regulation § 17 states that: *"The operator shall ensure that personnel and supplies can be transported safely to, from and between facilities and vessels during placement, installation and use, and for the chosen disposal alternative. Transport shall be coordinated with emergency preparedness."* A white paper from 2001 expands on the responsibilities of the petroleum authorities (NPD in 2001, PSA from 2004) related to helicopter traffic. Operators shall ensure that they have sufficient and proper transportation arrangements so that safety is maintained in the petroleum industry. The PSA is to regulate the safety requirements for helicopter activity that is clearly related to the facility's safety [29 p31-33].

The Norwegian government's vision for the safety of helicopter transport on the Norwegian continental shelf has been stated as follows: *"Passenger transport by helicopter in connection with petroleum activities on the Norwegian continental shelf shall not result in loss of life or serious injury"* [30 p36].

Helicopter activities outside of the 500 meters safety zone are not considered part of petroleum activities and the operator is only responsible for rescue within the 500 meters safety zone around the offshore facility. The responsibility for emergency preparedness related to the helicopter when it is in transit between the airport and the 500 meters safety zone falls outside petroleum legislation. It is considered an aviation operation and emergency response is governed by aviation regulations and civil rescue services [29 p106]. From a regulatory viewpoint, the Norwegian search and rescue service is responsible for rescuing persons in case of a helicopter accident in transit between an airport and the boundary of the 500 meters safety zone around the offshore petroleum facility. This means that the rescue operation will be coordinated by one of the two Joint Rescue Coordination Centres, Sola and Bodø, and draw on resources from the 330 squadron Sea King helicopters, the SAR helicopters operated by the petroleum industry and vessels in the vicinity of the incident.

In a white paper to Parliament, the government has stated an intention regarding emergency preparedness in the northern areas (Barents Sea); "*It is therefore important that participating companies and their sector organizations work systematically to reduce the risk of accidents and in the event of an incident and are able to handle (resolve/deal with) a crisis with their own resources to a greater extent than is necessary in other sea areas"* [27 p101]. It is important to be aware that a white paper from the Government to Parliament is not law but a proposal or recommendation on a way forward and may be included in law at some stage. Currently no change is made in this area of legislation.

In connection with exploration and operations in the Barents Sea, Statoil and ENI have established a SAR helicopter service in Hammerfest. There is 15 minutes mobilisation time when passenger transport flights are performed. Otherwise the mobilisation time for the SAR crew and helicopter is 60 minutes, however, they are usually airborne within 40 minutes [74].

The white paper of 2001 to Parliament regarding helicopter safety states that in the future it will be natural to evaluate the needs for search and rescue services that should be covered by private interests as exploration activity moves further out on the continental shelf [29 p41].

In the white paper of 2001 regarding the future of the helicopter rescue service it is pointed out that the current regulations for petroleum activities on the Norwegian continental shelf give the authorities the necessary legal basis to require that rescue helicopters be stationed on facilities and define the functions such a helicopter should have. To date, no such requirements have been imposed on the industry. A prerequisite for such requirements being imposed is that it is considered necessary in order to ensure safety [32 p48-49].

Performance requirements for rescue of personnel from the sea

The petroleum industry has identified the need to be able to rescue persons from the sea within 120 minutes inside the 500 meters safety zone [21]. This performance requirement is based on the limitations and safety margins related to immersion suits in use during helicopter transport. The OLF guideline indicates a pick up time of 3 minutes per person [74] from the sea leading to a total pick up time of ca 63 minutes for a helicopter with maximum 19 passengers and 2 pilots. The sea conditions are directly comparable within the 500 meters safety zone and the sea over which the helicopter flies in order to reach the offshore facility. There is no logical safety reason why the 120 minutes requirement should not apply for the entire transport of personnel over water. The capability to rescue persons from the sea within 120 minutes should be considered as a normal requirement for the entire helicopter flight path. However, there may be practical challenges providing a rescue capability within 120 minutes in remote areas of the Barents Sea and the Norwegian Sea.

In connection with the planned replacement of the Sea King helicopters in the public search and rescue service, a rescue ambition has been developed based on society's goal that it shall be possible to start the rescue of 20 persons in distress within two hours at every point 150 nautical miles beyond the baseline off the Norwegian coast. In addition, it should be possible to rescue two persons in distress all the way toward the outer boundary of the rescue responsibility area [31 p17].

Taking into consideration that the petroleum industry has identified a need to rescue persons from the sea within 120 minutes due to limitations and safety margins related to immersion suits, it would appear that there is a critical discrepancy between the performance requirements that industry have set for their rescue capability and the requirement that Norwegian authorities have set for the public rescue service.

If persons in a transport helicopter ditch/crash in the sea, they are wearing an immersion suit for protection. The public travelling on ships or civil aircraft are not protected apart from having flotation aid in the form of a life jacket. Offshore workers are more prepared and protected for an incident. There is, however, an important difference between persons travelling in civilian aircraft, passenger ships or ferries and the persons travelling on a helicopter to or from an offshore installation. The offshore workers on the helicopter have this as the sole mode of transport to and from their place of work and they are unable to choose otherwise [30 p36].

6.7 Helicopter coverage

The map in figure 40 shows the one hours flying range from Hammerfest, the Skrugard field and a hypothetical location in the east at 72,5°N/29°E. Hammerfest is shown because this is the current base for a transport and a SAR helicopter to cover operations in the Barents Sea [74]. Skrugard is expected to be developed and in operation by 2018 [77]. Skrugard has a strategically important location about halfway between the Norwegian coast and Bjørnøya. Almost all areas of the western part of the Norwegian Barents Sea sector and the Norwegian mainland can be reached within one hour from Skrugard. When this field is developed it will provide a unique possibility for refuelling of helicopters operating in this part of the Barents Sea. The national SAR helicopters will benefit and the capability to rescue persons far out to sea will be greatly improved. All fields that may be discovered within the range of Skrugard will also benefit. As mentioned in section 6.5 with reference to the 2008 report made for PSA regarding emergency preparedness, the offshore SAR helicopters have provided an important enhancement to emergency preparedness as mentioned in the 2008 report made for PSA [41].

Due to the location of Skrugard the facility should be built with a helicopter hanger so that it is possible either from the start of operation or at some later date to station a SAR helicopter onboard. Skrugard will most likely be able to achieve satisfactory coverage from a SAR helicopter in Hammerfest and a hangar on the facility may be difficult to justify economically unless considering the broader issues of rescue service to the north and west. An alternative to Skrugard would be to consider a SAR helicopter stationed on Bjørnøya. However, Bjørnøya is far from the mainland and there are challenges related to fog there.

When considering wave data for the Barents Sea it can be expected that a SAR on Skrugard may be unavailable approximately 5 to 7% of the time assuming that when H_s is over 5 m the movement of the facility and wind may be approaching the limits for unfolding the rotor and using the helideck. [51]. This is an extremely uncertain assumption as the exact met ocean data for Skrugard are not available in the public domain and the motion characteristics of the facility are not known yet. The potential for reduced visibility due to fog or heavy snow showers is also of concern. The time a SAR helicopter on Skrugard may be unavailable due to weather, however, is a far lesser fraction of the time compared to the greater fraction of the time when it would be available.

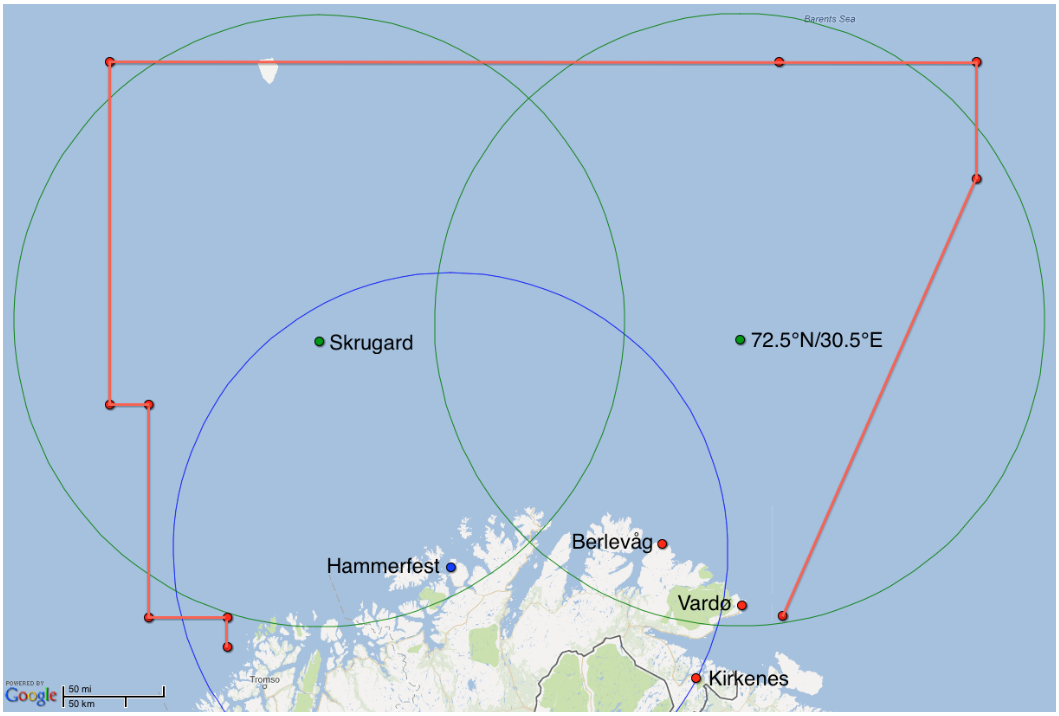

Figure 40, Helicopter coverage with Skrugard and a facility in the east as offshore heliports

As the petroleum activities move towards the east it will be necessary to establish a base for helicopter operations at airports like Berlevåg or Vardø, especially when considering the extremely remote locations towards 74,5°N/37°E. Both of these airports, Berlevåg and Vardø, have good regularity [J02]. Kirkenes is also an option, however, it would add ca 45 NM to the flight path compared to Vardø. An offshore facility located in the area of 72,5°N/29°E would provide similar benefits as Skrugard. At the present time there are no discoveries in the immediate vicinity.

6.8 *Effects of wind on helicopter flight*

The effect of wind on a flight from the coast to the extreme location in the northeast at 74,5°N/37°E is considered in this section. The route from Berlevåg (BVG) to the remote location is considered. The distance one way is 260 NM, which is of interest in light of operational limitations and departure criteria for transport flights to this location. Flight times are based on a no wind situation and then being reviewed taking into account the effect of wind on the ground speed of the helicopter using the calculations discussed in section 5.10.2. The flight is studied with three hypothetical wind cases of no wind, side wind and head/tail wind for a helicopter with a cruising speed of 145 knots and wind speeds between 20 and 50 knots. Great circle routes have been used to calculate distance and headings. The flight path has been divided into four flight legs, two in each direction, of approximately equal length. As the heading changes continuously along a great circle route, an average heading for each leg has been used corresponding to the heading at the midpoint of each flight leg. This approach is considered acceptable as it provides a close estimate. The aim of the calculations is to illustrate the effect of wind on helicopter flight. The results need to be taken into account when evaluating the robustness of emergency preparedness, planning helicopter flights and defining departure criteria. The flight path is shown in figure 41 where routes are also shown from Hammerfest (HFT), Lakselv (LKL) and Kirkenes (KKN). The results of the calculations are shown in figures 42 & 43.

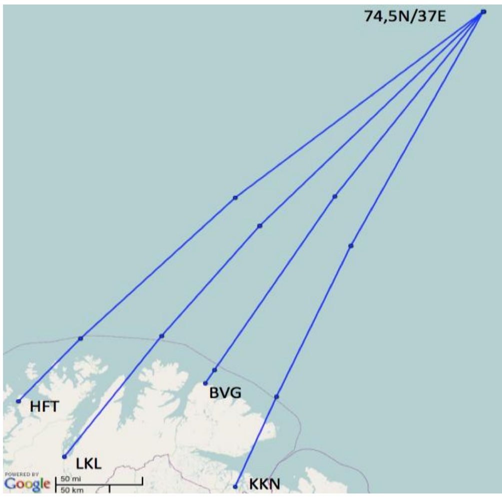

Figure 41, Routes to location 74,5°N/37°E

Mobilisation time, the time required to assemble the crew and get the helicopter airborne and the time on deck at the offshore facility, is not included in the analysis in this section. The total round trip flying time for 520 NM at 145 knots with various wind speeds is shown in figure 42. This information is of interest when evaluating medevac flight times and capability. The performance requirement is that the person should be in hospital within three hours [21]. The difference in time for the flight to reach the facility and return to the shore is not of interest in this case so long as the round trip time meets the performance requirement. As can be seen for this location, it is not possible to meet the performance requirement of transporting the patient to a hospital within 3 hours and compensating measures will need to be evaluated. The problem for this location is the distance, which is aggravated by wind. The calculations show that in a constant head/tail wind situation, i.e. wind blowing along or in parallel with the route, ca 30 minutes will be added to the round trip time when the wind speed is 50 knots. For the case of a side wind blowing across the route, ca 15 minutes will be added to the round trip time for a wind speed of 50 knots.

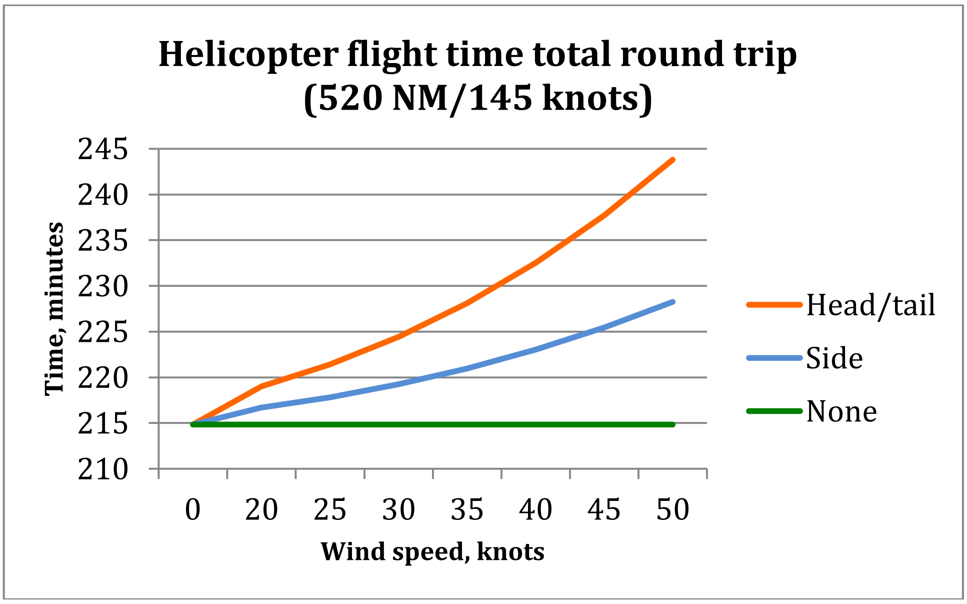

Figure 42, Flight duration between BVG and 74,5°N/37°E with head/tail, side and no wind

In figure 43, the difference between the flight times for one direction (260 NM) is shown when taking into account a head or tail wind. These results are of interest when evaluating the rescue capability of a SAR helicopter under given conditions on the day of a planned transport flight. The number of passengers that the transport helicopter can carry will be driven by the performance requirement that all personnel shall be rescued from the sea within 120 minutes of an incident occurring [21]. The faster the SAR helicopter can arrive at the scene of the incident the more persons can be rescued within the 120 minutes limit. The time taken to rescue one person is set to an average of 3 minutes [74]. A head wind on the flight to the scene of the incident will reduce the number of persons who can be rescued within the performance requirement of 120 minutes. A tail wind will lead to an increased number of persons who can be rescued within the performance requirement.

It is also fair to consider the actual weather on the day of the flight. In calm weather with good visibility it may be possible to rescue a person in less than 3 minutes per locating and pick up of the individual. Similarly, as the weather deteriorates it may be prudent to consider more than 3 minutes per individual rescue. This should be a part of the departure criteria and assessed prior to the helicopter departing from the shore. This section has demonstrated how the effects of wind should be taken into account when planning and optimising helicopter operations in an area with few available resources and relatively long routes.

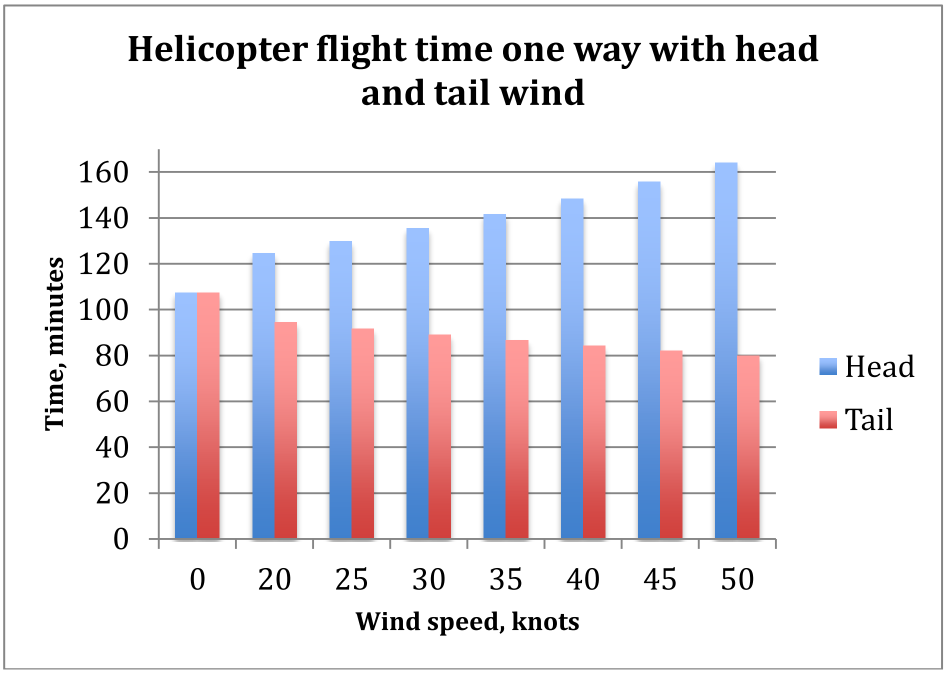

Figure 43, flight duration between BVG and 74,5N°/37°E with head/tail winds

6.9 Analysis of rescue capability en route for long-range locations

A potential solution in order to provide rescue capability for persons in the sea due to a helicopter ditching on long-range flights to remote locations is analysed below. This case considers a helicopter flight from Berlevåg airport (BVG) to a petroleum facility located at 74,5°N/37°E. The example uses Berlevåg as the chosen airport due to it being an easily accessible airport with good availability regarding weather. Berlevåg is also the closest airport to the location 74,5°N/37°E. The distance from Berlevåg to the location is 260 NM. The reason for choosing the location 74,5°N/37°E is because it potentially is one of the most remote locations that may be considered for exploration in the near future. If it is possible to develop a procedure for rescue en-route to this location, rescue for all other locations will also be feasible.

The proposed scheme requires a SAR helicopter at Berlevåg, an ERV en-route to the facility and an ERV at the facility. This is illustrated on the map in figure 44 below. The ERV located at the facility covers a number of emergency preparedness roles for example, detection and intervention of vessels on collision course with the facility, rescue of man-over-board and rescue of persons in the sea due to a helicopter accident on or near the facility.

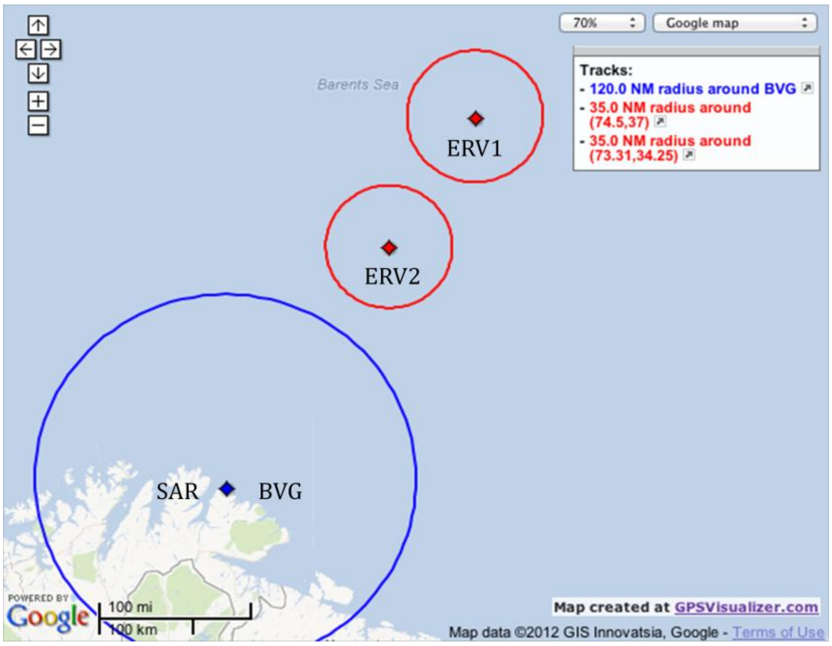

Figure 44, Location of rescue resources

It is currently considered possible for a SAR helicopter to locate and rescue a person from the sea in 3 minutes on average [74]. The time taken to locate and rescue persons in the sea using an ERV, FRDC or a MOB boat is considered to be longer than the 3 minutes required per pick up by a helicopter. In addition it should be taken into consideration that the time to locate and rescue a person increases as the weather deteriorates [40 p92]. It is not unreasonable to allow 5 minutes per person for rescue by a boat as it is potentially more difficult to observe individuals in the sea from a low position as is the case from the bridge of an ERV or even lower in the case of a FRDC and MOB boat. Location of persons in the sea becomes increasingly difficult as sea conditions deteriorate. If the weather is calm and the visibility is good, it may be possible to consider a shorter time for location and rescue of persons from the sea by FRDC or MOB boat.

The following general assumptions apply for the case:

- All persons are to be rescued from the sea within 120 minutes [20],
- The maximum capacity of a transport helicopter is 19 passengers and 2 pilots,
- The company performing a petroleum activity at the remote location is willing to relocate a SAR helicopter to the closest airport,
- The company performing a petroleum activity at the remote location is willing to incur the operational cost of emergency response vessels equipped as described in this case,
- There are benefits for the company in adopting this procedure (see pros and cons),

- Safety delegates and representatives of trade unions are involved in the process of developing the procedure.

Rescue capacity for emergency response vessel

The rescue capacity of an ERV equipped with a FRDC, and a MOB boat is taken from data sheets for existing vessels [103-107]. An ERV supported by a FRDC and MOB boat can rescue 18 persons from the sea within 120 minutes within a radius of 35 NM from its station. This is demonstrated by considering an incident at 35 NM from the ERV. The ERV is assumed to be on standby when the flight is taking place and can set sail for the incident site immediately upon receiving notification of the need for a rescue operation. The crews of the FRDC and MOB boat are to be alerted upon receipt of the notification. The FRDC is launched within 5 minutes and the MOB boat is launched within 10 minutes. The FRDC will reach the site of the incident within 65 minutes allowing 55 minutes to rescue 11 persons. The MOB boat will arrive within 85 minutes allowing 35 minutes to rescue 7 persons. The ERV will arrive at the scene within 105 minutes allowing 15 minutes to coordinate the retrieval of the FRDC and MOB boat together with the rescued persons. This is illustrated in figure 45 where the elapsed time is shown along the horizontal axis. The lines and the left hand axis show the distances travelled by the vessel and rescue craft. The number of persons picked up (PUmob & PUfrdc) by the rescue craft are shown by the columns and the right hand axis.

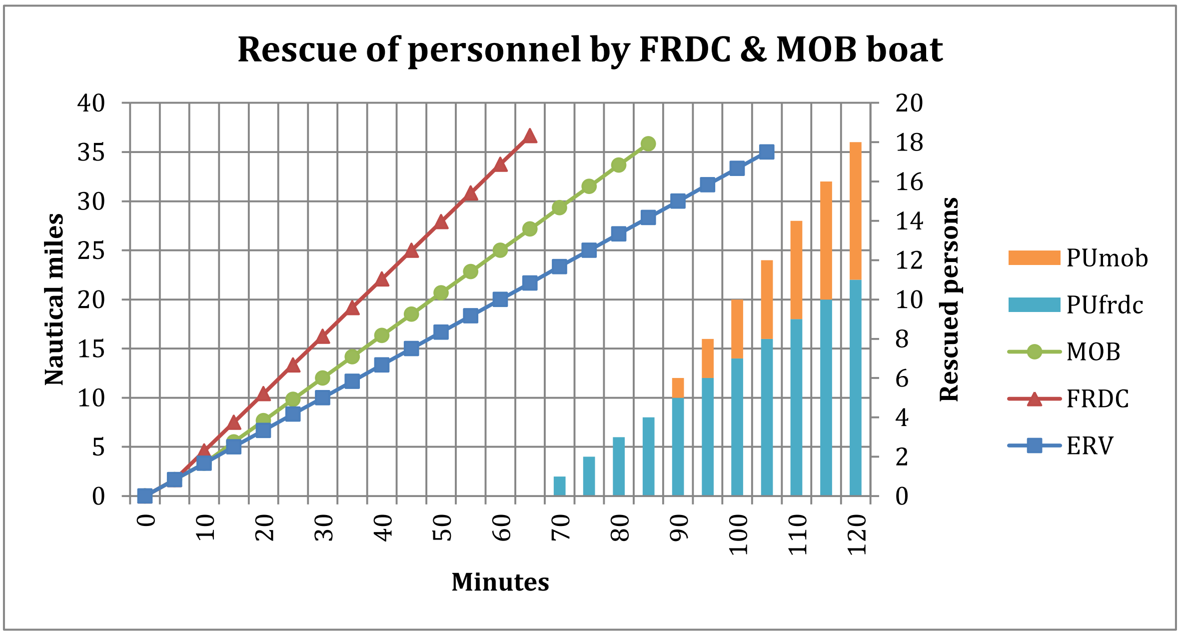

Figure 45, Time to travel 35 NM and rescue persons by ERV, FRDC & MOB boat

The following assumptions apply for the ERV, FRDC and MOB boat:

- ERV can operate at 20 knots in calm weather [103],

- ERV is equipped with 1 FRDC (e.g. MS DC12) that can operate at 35 knots, capacity 24 persons (3 crew, 21 rescued persons), range 150 NM [104 & 105],
- ERV is equipped with 1 MOB boat (e.g. MP-741) that can operate at 26 knots, capacity 10 persons (3 crew, 7 rescued persons), the range of this craft is unknown, but it is an assumption in this case that the craft can carry fuel to travel up to 50 NM and perform a rescue operation [104 & 107],
- The sea state is such that performance of the ERV and the rescue craft is not impaired, i.e. significant wave height H_s should probably be less than 3 meters [103],
- The FRDC and the MOB boat are equipped with necessary navigation aids to operate in the dark,
- There is sufficient visibility to perform the rescue operation, i.e. there is no fog or snow showers and there is sufficient light or visual aids to locate the survivors in the sea even if it is dark,
- FRDC and MOB boats require 5 minutes to locate and rescue a person from the sea,
- The crew of the FRDC and MOB boats are trained and competent to navigate and operate these craft independently of the ERV,
- The rescue craft perform a continuous rescue operation until all persons are rescued or reaching their capacity before returning to the ERV for offloading,
- The rescue craft will not have to travel the same distance back to the ERV, as the ERV will sail towards the site of the incident.

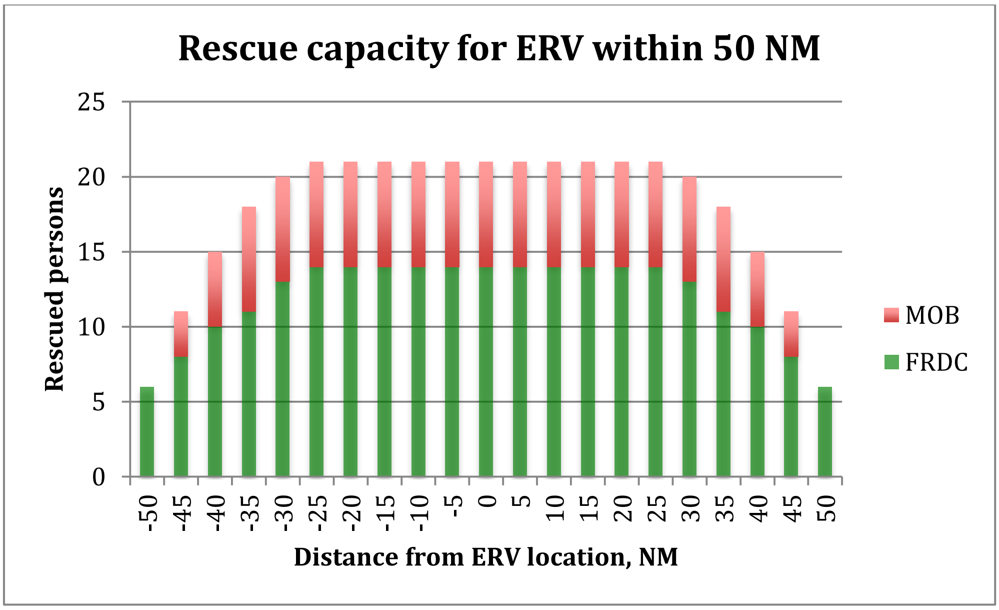

Figure 46 Combined rescue capacity for ERV with FRDC and MOB boat deployed

Figure 46 illustrates the rescue capacity for the ERV configuration for ranges between 0 and 50 NM and a time limit of 120 minutes. Note that the capacity is capped at 21 persons as this case examines a helicopter incident. The FRDC is designed to rescue 21 persons within 120 minutes inside of the 500 meters zone around the facility.

Rescue capacity of a SAR helicopter

The rescue capacity of a SAR helicopter can be assessed based on the time to mobilise the helicopter, time to fly to the scene of the incident and the number of persons to be rescued within the 120 minutes limit defined in the OLF guidelines [20].

The following assumptions apply for the SAR helicopter:

- SAR helicopter cruises at 145 knots [J05],
- SAR helicopter can take off within 15 minutes (or less) after notification [74],
- SAR helicopter requires 3 minutes to locate and rescue one person from the sea [74].

The ability to locate and rescue a person in 3 minutes is based on the survivor wearing an immersion suit fitted with a personal radio locator beacon (PLB), a strobe light and reflective material.

A mobilisation time of 15 minutes leaves 105 minutes available to fly to the scene and rescue persons within a total of 120 minutes from entering the sea. A SAR helicopter travelling at 145 knots can fly ca 250 NM in 105 minutes. The number of persons who can be rescued within the limit is decreased the further the helicopter has to fly. The capacity in relation to flown distance and rescued persons is illustrated in figure 47.

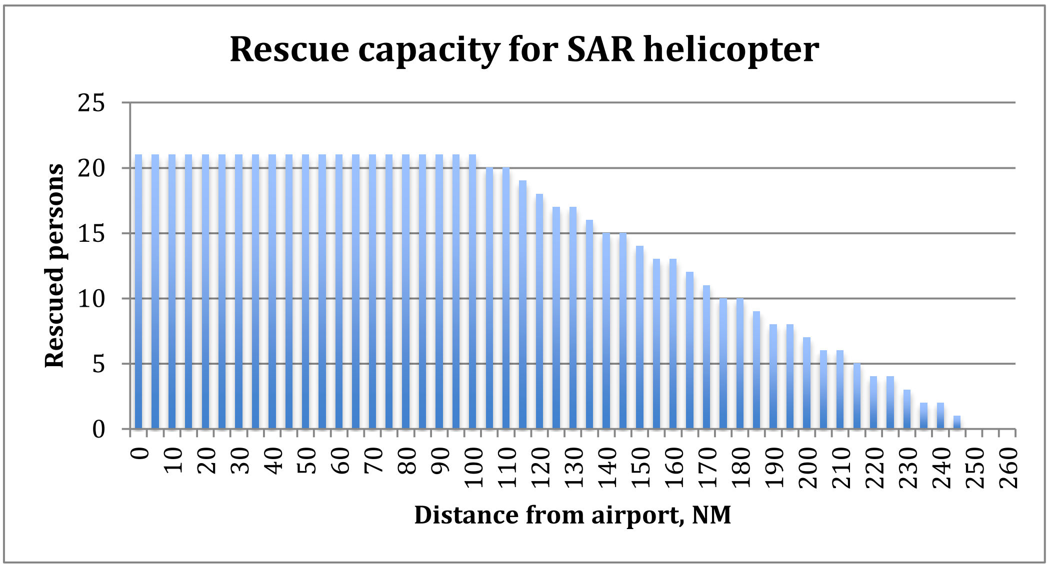

Figure 47, Rescue capacity for SAR helicopter along 260 NM route

Rescue scheme for a 260 NM long-range route

Figure 44 earlier in this section, illustrates the location of the airport, SAR helicopter and the emergency response vessels. ERV1 is located at the facility while ERV2 is located 85 NM along the route from the facility. The circles indicate the area where any one resource can rescue 18 persons alone. The areas between the circles require a combined effort from more than one resource. Figure 48 illustrates how the resources can be utilised to provide rescue for a total of 18 persons, from the sea within 120 minutes for all locations along this 260 NM route.

Some improvements can be made to increase the robustness of the proposed rescue system. The ERV could be equipped with 2 fast rescue daughter craft instead of 1 FRDC and 1 MOB boat. This would improve the pick up capacity and the speed at which the craft would reach the incident scene. Also the crew are protected on a FRDC as it has a wheelhouse. Mobilisation time for the resources could be improved and both FRDCs could be launched within 5 minutes. These improvements could also be used to extend the range of the FRDCs and potentially achieve a higher passenger capacity along the route.

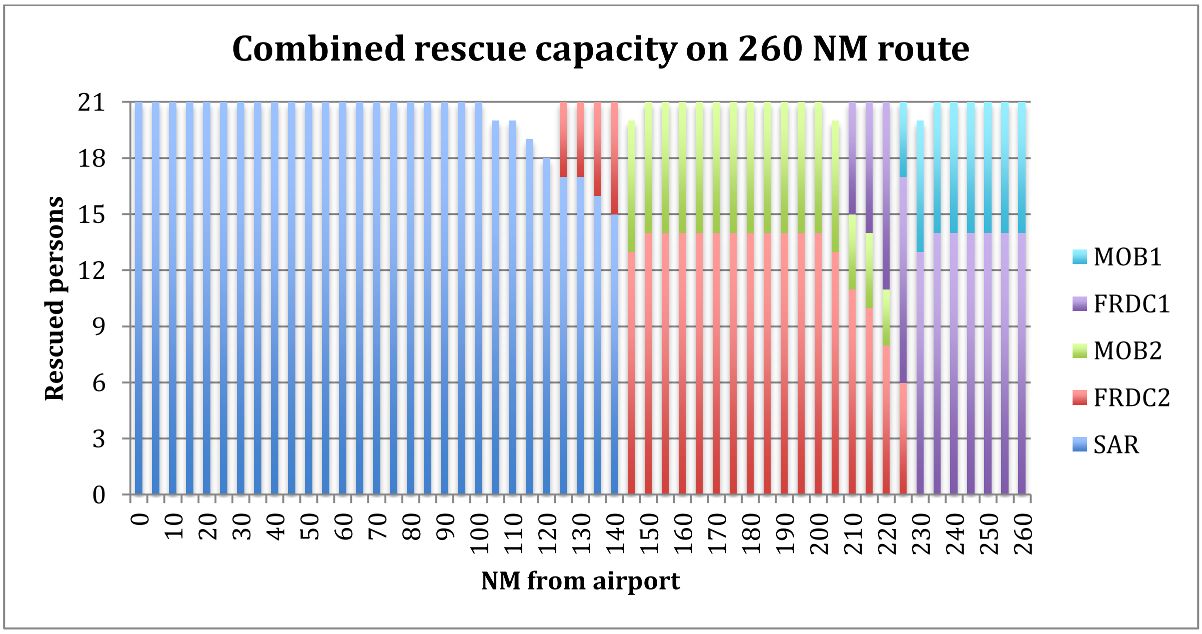

Figure 48, ERV at 0 & 85 NM from facility, ERV speed 20knots, FRDC speed 35knots, MOB speed 26 knots, SAR speed 145 knots

Location specific conditions

- Low sea and air temperature in this area during winter.
- Sea conditions are less severe than in the Norwegian Sea and western part of the Barents Sea.
- Ice accretion due to sea spray or precipitation may be an issue.

- Special considerations should be given to the protective clothing worn by the crew of the FRDC and especially the MOB boat that is an open craft.
- Attention must be paid to the weather conditions and a reliable weather forecast must be consulted prior to commencing the helicopter flight.
- Sea ice occurs infrequently in the vicinity of the facility. There has been sea ice and icebergs in the vicinity of this location as recently as 2003 [46 p17].

Pros and cons for this solution

Positive issues:

- Rescue of persons in the sea is planned and available along the entire route,
- Helicopter passenger capacity and range may be increased,
- The second ERV can be a shared resource if exploration activity is planned by more than one operator within a reasonable area.

Negative issues:

- Extra cost is incurred for the second ERV,
- There are extra costs associated with crew for both FRDC and MOB boat.

Weakness with the case

- This case does not assess the problems related to fuel requirements or alternative landing sites that are mandatory for the helicopter transport. These challenges are dealt with in section 5.9.
- Time for vessels and helicopters to achieve cruising or maximum speed is not taken into account. This gives a slightly optimistic result.
- The case does not assess the consequences of sea ice or icebergs in the area.
- The risks of sending two small craft on a long-range rescue operation, potentially 50 NM from the mother vessel, are not fully analysed or assessed.
- The issue of finding crew members who are willing to perform this type of rescue operation has not been considered.

Critical barriers for the success of this rescue scheme

- Weather observations and forecasts providing reliable information about the sea state, ice accretion or sea ice and fog and snow showers affecting visibility.
- Planning of the operation and the decision process before departure of the helicopter.
- Training and exercise of personnel including maritime personnel to operate the vessels and the emergency preparedness personnel controlling the operation.

- Maintenance of the systems.

Recommendations arising from this case

Considerations should be given to building an ERV specially designed for support and rescue service for long-range flights in the Barents Sea. The vessel should be equipped with 2 FRDCs and with helicopter in flight refuelling, HIFR. This will increase the robustness of the scheme and the safety level.

For the case of Skrugard/Havis development in the western Norwegian sector of the Barents Sea the need for helicopter refuelling, a helicopter hanger and a permanent AWSAR helicopter on the installation should be considered. If and when a permanent installation is installed in the eastern part of the Norwegian area of the Barents Sea, its strategic position with regard to rescue operations should be considered in a similar manner to the recommendation for Skrugard/Havis.

As a general safety precaution a limiting sea state should be evaluated and defined for this rescue scheme. OLF stipulates that when rescue of persons in the sea relies only on the use of an ERV, i.e. a SAR helicopter is not available, special considerations should be given to the use of this resource when the significant wave height is between 4,5 and 7 meters [23 p5]. It may not be prudent to plan a helicopter operation that may result in a long-range rescue operation in significant wave heights of 7 meters or more with an FRDC or a MOB boat.

Discussion at Simon Møkster Shipping AS

This section of the report regarding a rescue scheme using two ERV for rescue purposes on long-range helicopter flights was discussed with personnel at Simon Møkster Shipping AS. This was done in order to test the feasibility of the scheme and benefit from the experience the company has with operating vessels of a similar type considered deployed in the scheme.

The company has good experience with the operation of the ERV's Stril Poseidon, Stril Herkules and Stril Merkur. The ERVs are equipped with a slip for retrieval of the vessel's FRDC and MOB boat. The slip is also designed for retrieval of lifeboats from an offshore facility. Retrieval of craft from the sea using the stern slipway has been accomplished in sea conditions of 11 to 12 meter wave heights. Over 2000 of these operations have been performed in training and exercise without injury to personnel or significant damage to the craft. The FRDC and MOB boat maintain a speed higher than that of the ERV and sail into the slipway. In an emergency situation, lifeboats from an offshore facility can be pulled in on the stern slipway allowing transfer of the persons to the ERV. The lifeboat is then dumped before pulling the next one in for transfer of persons.

Standby duty alone is monotonous and additional tasks help to motivate the crew. Emergency preparedness or standby duty in the open sea both far from shore and an offshore installation may be a challenge to attracting and retaining crew. Where possible it is important that the crew on the vessel are involved in operations of the fields in addition to emergency preparedness duties. This breaks the monotony and increases crew motivation. In addition to daily operations onboard, training and exercise of emergency preparedness and oil response duties, two of the vessels are used in operations to connect shuttle tankers to the off-loading system for shipping of stabilised crude from the field where they are stationed.

The proposed scheme may require an increased number of crew on the ERV as both the FRDC and MOB boat are considered used in a rescue operation. The ERV would need to have sufficient crew remaining onboard to allow operation of the vessel in a rescue mode.

The FRDC and MOB boat need to reduce speed when sea conditions dictate. Speed reduction is necessary for safety reasons in order to avoid injuries and physical exhaustion of the crew. Breaking waves and the craft slamming in the sea would call for speed reduction. This can typically occur already at significant wave heights of 2 to 3 meter for the FRDC and MOB boat. As the sea state worsens, there will be a “break even” wave height after which the ERV will be able to maintain a higher speed than the FRDC or MOB boat under the prevailing conditions. As the sea state deteriorates it may be a better solution to keep the FRDC and MOB boat onboard the ERV while it sails towards the scene of the incident. The FRDC and MOB boat would only be deployed shortly before reaching the scene of the accident. This would reduce the range that the vessel can cover within the 120 minutes limit for rescuing persons from the sea to the region of 20 to 25 nautical miles.

Operational limitations of the scheme need to be evaluated and understood prior to any decision to employ this or a similar method. Understanding of the operational limitations would need to be maintained and adhered to if the scheme is to be employed. The sea state would need to be evaluated thoroughly by the captain of the ERV before a flight to the installation is initiated. The captain would need to make a decision on the rescue capability with the current and forecast weather. There is concern that this may pressure the captain towards an optimistic rather than a realistic and sound decision.

If this scheme were used, the FRDC would not be more than ca 15 NM from the ERV at any time. The MOB boat would be closer to the ERV due to it travelling somewhat slower than the FRDC. The crew of the FRDC and MOB boat would need additional competence in navigational skills and seamanship, as the craft would be operating to a certain degree independently of each other and the ERV.

Fuel capacity will need to be carefully considered. The ERV uses about one third of the fuel when cruising at 12 knots compared to 20 knots, i.e. the ERV fuel consumption is approximately three times greater when operating at 20 knots. The FRDC (MS DC12) on Stril Merkur [104] has a top speed of 43 knots and a range of 150 NM with 2 persons onboard [105]. The range of the MOB boat (GTC 900 2 VD) is not given [105].

In an emergency situation it is possible to use the ERV as a command centre to control the resources involved in the operation. This would also be possible in the proposed scheme as long as the ERV has radar and radio contact with the FRDC and the MOB boat. This would need to be considered when equipping the craft and the ERV for this type of operation.

It is not generally considered to be a desirable solution to deploy a MOB boat for an operation at 35 to 50 NM from its “mother” vessel. The MOB boat is open and provides no protection for the crew against weather. If a rescue scheme of this type is to be used, it would be preferable to consider having a purpose built ERV equipped with two purpose built FRDCs. Experience from the design and operation of BP’s Jigsaw project may be beneficial to the design of a scheme similar to this suggestion. The size and type of FRDC could possibly be somewhere between the daughter craft used today and the BP Jigsaw autonomous rescue and recovery craft (ARRC) [108].

Advantages with 2 FRDCs:

- Travel together providing a degree of safety and back up for each other,
- FRDCs have a larger capacity for passengers, rescued persons, than MOB boats,
- Each FRDC is designed to rescue 21 persons so there is no capacity limit if one craft picks up more than the other. MOB boats are limited to 7 to 10 persons.

One of the persons participating in the discussion has worked in arctic waters and has experience with icing (ice accretion). He confirmed that icing conditions are experienced in the Barents Sea and that operation of the vessel, i.e. speed relative to wind and waves, is critical to the rate of icing. SMSAS new builds for deployment in the Barents Sea are equipped with means of protection against icing.

If considering a semisubmersible platform or rig (semi-sub) instead of the ERV in the "mid-position", the costs would be higher than an ERV based solution. Rig rates compared to standby vessel rates are in the region of 10 to 15 times higher at the present time (2Q 2012). The semi-sub may need a SAR helicopter stationed onboard or a similar scheme of FRDCs that could operate independently over the entire range of the rescue area and be able to return to the semi-sub when the persons have been rescued from the sea.

Post meeting notes and comments

One FRDC has the capacity to rescue 21 as it is certified to carry 24 persons. However, using the time estimated to find and rescue each person from the sea, it would not be possible to rescue all 21 persons within 120 minutes at a range of 50 NM. It would be necessary with two rescue boats to achieve the performance standard.

A semi-sub would be able to start sailing towards the scene of the accident, however the transit speed is considerably lower than for an ERV. There may be issues related to DP or anchored operations and time required to trim the semi-sub from operation draft to transit draft before it can sail. It takes 3 to 4 hours to de-ballast a semi-sub from operation to transit draught [J04].

Ice class for the ERV will need to be considered in certain northern and eastern parts. This scheme is not necessarily practical if there is ice in the sea, as large distances require high cruising speeds that are not compatible with ice conditions.

Preliminary conclusions

The MOB boat is probably not suited to a long-range rescue operation and should not be considered as part of the scheme.

If the performance criteria of 120 minutes limit time for rescue of all persons is to be achieved, two FRDCs are required for the range of 35 to 50 NM. The advantages of using two FRDCs should be considered if this scheme is to be employed.

Existing vessels may be used for shorter stretches but a new or modified vessel would be needed for a 260 NM flight path.

There may be advantages using a larger rescue boat similar to the BP Jigsaw ARRC and this option should be considered.

Sea ice conditions may defeat this scheme entirely as it could be unsafe operating vessels or craft at high speed in ice infested waters.

6.10 Trial of immersion suit

During a course, “Enjoy the Cold”, arranged by NTNU at Ny-Ålesund on Svalbard in March 2012, it was possible for some of the participants to experience the use of the HellyHansen SeaAir immersion suit. This suit has been specially developed for the petroleum industry in Norway. The suit is normally used when travelling by helicopter between shore and an offshore facility. The suit was originally designed for conditions in the Norwegian Sea and the North Sea and was tested according to OLF guideline no. 094 and ISO 15027-3. The persons were equipped with temperature logging sensors and spent approximately 90 minutes in the sea. The sea temperature was 0,6°C and the air temperature was -4°C. There was no wind or waves during the trial. Temperature was monitored on the skin surface of the neck, armpit, upper arm, wrist, and chest and inside thigh. The results are shown in figures 49 & 50.

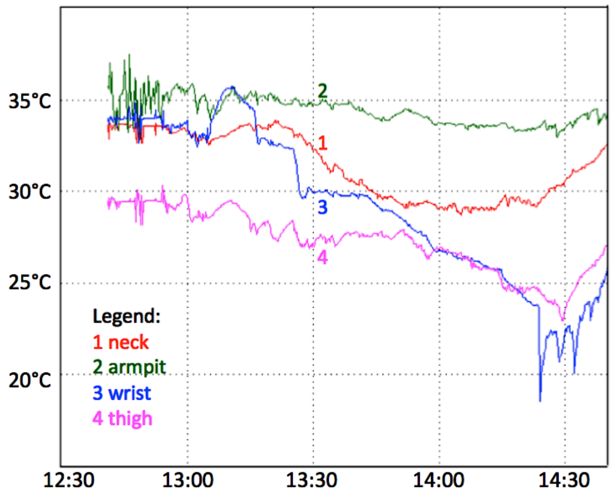

Figure 49, Temperature log of person A in an immersion suit in the sea at Svalbard

Person A, a female, wore an Aclima woolnet shirt and long pants, a thin jersey of synthetic material and a pair of woollen socks. The person entered the sea at ca 1300 hours and went on land at ca 1430 hours. The log for person A is shown in figure 49.

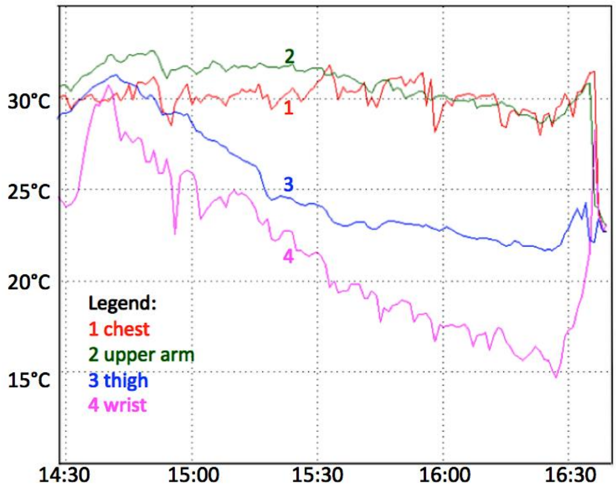

Figure 50, Temperature log of person B in an immersion suit in the sea at Svalbard

Person B, a male, wore an Aclima woolnet shirt and long pants, cotton briefs and short cotton socks. Person B chose to wear only one layer of clothing. The person entered the sea at ca 1440 hours and went on land at ca 1625 hours. The log for person B is shown in figure 50.

Table 9, Comparison of temperature changes experienced by test persons

	Person A female	Person B male	Requirement, OLF 094 & ISO 15027
Armpit/upper arm	36°C to 33°C, -3°C	32°C to 28°C, -4°C	
Thigh	29°C to 24°C, -5°C	31°C to 22°C, -9°C	
Wrist	34°C to 22°C, -8°C	30°C to 15°C, -15°C	Min. allowed 15°C
Neck	33°C to 29°C, -4°C		Min. allowed 25°C
Chest		31°C to 28°C, -3°C	

The temperatures for the trial persons are compared in table 9 and show the approximate initial temperature, lowest measured temperature and the temperature drop. Person B may experience problems with the use of fingers. Person B did not experience problems with dexterity. Person B experienced somewhat lower temperatures than person A and this can probably be assigned to the lack of an intermediate layer of clothing. Person A has maintained a higher temperature and is cooled less than person B even though there has been little movement and use of muscles to generate heat. Person B was less well clothed and experienced a general feeling of cold already after 30 minutes. The relatively large drop in temperature of person B's wrist may indicate that the body was reducing circulation to the limbs in order to maintain core temperature. Person A appears to have had a slower rate of temperature decrease, at least initially, compared to person B. There also appears to be smaller fluctuations in the temperature of person A compared to person B. This may be assigned to the fact that person A moved very little while person B moved large muscle groups regularly to generate heat. No critical temperatures were reached during the trial although one could normally expect problems with use of fingers when the skin temperature is as low as 15°C.

The persons were questioned on their experience during the trial. Their comments are summarised in table 10.

Table 10, Summary of experience during the trial of immersion suits

	Person A	**Person B**
Comfort *Are there any areas that are more uncomfortable (cold) than others?*	The gloves and feet of the suit leaked. The person lay still as movement increased water flow through leaks. Experienced cold on hands, forearms, feet and crotch.	Back and legs felt colder than the rest of the body. Primary discomfort was related to general feeling of coldness.
Movement in suit *How easy is it to move the hands, arms and legs?*	Too large mittens and very cold hands reduce ability to move. Suit is stiff with many gadgets. Movement is relatively limited.	Sufficient - not good - but enough to do all changes of position in the sea.
Movement to generate heat *How much or how often did you move to generate heat?*	Minimal movement in order to avoid water flow in leaking areas.	Approximately every 10 minutes, powerful movements of legs (primary) and arms because the cold feeling was too strong. About 2 minutes of activity worked well enough.
Exhaustion *Did being in the sea tire you? If so, when did you start to notice it?*	No experience of exhaustion but almost fell asleep.	Absolutely no experience of exhaustion.
How was the experience of lying in the water for 90 minutes under the prevailing circumstances?	Much better than feared or expected.	Cold after only 30 minutes, but fully able to take care of own safety and to help with the safety of others even after 90 min.
Other comments *Is there anything else you would like to tell about the experience?*	It would probably be much more tiring in rough seas.	Intentionally minimal clothing. Unrealistic clothing that left little insulation. Under real conditions better insulation would have been achieved even with everyday

		clothing. In a real situation contact with others would have meant more. The feeling of lying alone would require more mental effort to do the right things. It is important that those who receive safety training should be informed that it is OK to move from time to time. The feeling of cold would have been much worse if muscles are not used to generate heat. Unrealistically benign conditions compared to marine climate that may be experienced during rig or helicopter evacuation.
Clothing	Inner layer: Aclima mesh underwear pants (long legs), Aclima mesh underwear shirt (long arm), brief Intermediate layer: Thin jersey of synthetic material Outer layer: Immersion suit Hands/feet: One pair of woollen socks	Inner layer: Aclima mesh underwear pants (long legs), Aclima mesh underwear shirt (long arm), cotton brief (short) Intermediate layer: None Outer layer: Immersion suit Hands/feet: Cotton socks (short)

Even though this trial was conducted in benign conditions a number of observations are aligned with experience from professionally performed tests under controlled conditions in cold climate chambers with wind and waves. The important observations are:

- An intermediate layer of clothing will normally enhance heat conservation,
- Intermittent movement of large muscle groups in order to generate heat may compensate for cooling of the body,
- The suit should be the correct size so as not to hinder movement,
- The suit should be the correct size in order to avoid leaks at sealing points,

- Both persons have not experienced any serious loss of dexterity or the ability to “stay in control” of their situation,
- Both persons have en expectation that their situation would probably be more challenging under more realistic conditions at sea.

There is a paradox in the comments received from the test persons. Normally it could be anticipated that a female would feel the cold sooner than a male. The difference in the clothing worn by the persons may explain the deviation from what could be expected, however the difference in clothing is small. Normally males are more tolerant to cold than females. Also males loose heat more slowly than females because the ratio of body surface area to body volume is smaller in males than in females, i.e. females have a greater surface area and loose heat quicker than males.

Another possibility is that as the male exercised large muscle groups in the water to generate heat, warm blood may have started flowing to cooled limbs and effectively increased the cooling process in spite of the fact that the person felt as though it was beneficial.

The BMI of the persons was not examined or recorded. It is therefore not possible to say if subcutaneous fat , section 5.12, has had any influence on the observed results in this case.

The results of this trial illustrate the variances that can be found between individuals. In total the results are within the expected outcome window and confirm sound practice with regard to use of immersion suits. A conclusion that can be drawn from the observations is that it is wise to wear sufficient layered clothing under the immersion suit and that some movement will improve comfort.

6.11 Medical doctor onboard facilities

One recovery measure to reduce the probability of a fatality offshore in a situation where it is not possible to perform a medevac would be to have a medical doctor permanently employed on facilities working in the Barents Sea. The Barents 2020 project and others have raised this issue. Such a measure needs to be considered very carefully in a broader perspective including the consequences for society. An offshore doctor would require 3 persons per facility to fill an offshore rota of 2 weeks on duty and 4 weeks free. This would provide 24/7 doctor availability for:

- typically 80 to 140 persons on exploration facilities including a standby vessel,
- typically 50 to 300 persons on a permanently installed production facility including a standby vessel.

It has correctly been indicated that, "*Even with a doctor on the installation there are limitations to what can be resolved locally"* [75]. Taking into consideration the scarcity of medical resources in the county of Finnmark, it may be argued that for the society it would be better use of a scarce medical resource to increase the availability of doctors and medical persons onshore rather than offshore. On the other hand, a doctor on a facility in the Barents Sea would be a resource in the vicinity for other seafarers in need of medical assistance. This would also improve the resource situation for the JRCC in Bodø when dealing with situations in the Barents Sea. No conclusion is drawn at this stage, as the issue deserves to be the subject of an independent study.

6.12 Operational planning

In a report dealing with constraints on evacuation means issued by the NPD and DNV in 1998, it was argued that the operational window for the evacuation means should be known and that activities that require evacuation should be terminated when the "window" is exceeded [40 p 28]. As argued in this thesis lifeboats and rescue helicopters are considered as barriers to eliminate or prevent the loss of life in accident situations. The Management Regulation § 5 concerning barriers require that the responsible party is aware of the limitations of barriers and that compensating measures are put in place when a barrier is missing or impaired [10]. In 2010 the PSA published explanatory information regarding requirements to availability of evacuation means and the type of analysis that is required to document evacuation capability [83]. A holistic approach is recommended to operational limits imposed by weather and sea conditions on the ability to evacuate or rescue persons. This has consequences when planning flights to offshore locations and the entire operation of an offshore facility. Flights should only be planned if passengers can have a reasonable expectation of being rescued alive. Similarly, activities onboard a facility should be considered in conjunction with the weather forecast, the inherent risk of the activity and the probability of performing a successful evacuation and subsequent rescue operation. This will require the development of departure criteria for helicopter transport and guidance on acceptable weather criteria for operations and activities on facilities taking into account the specific threats at the location.

6.13 Selection of personnel for work in the Barents Sea

The issue of selection criteria for personnel who are to work in the petroleum industry in the Barents Sea is very delicate. There are health issues that are aggravated by the cold and the risk of severe illness increases in low air temperatures. The access to medical resources both on the facility and onshore in northern Norway is limited. In addition there are long flight times to the most remote locations exceeding the industry's agreed performance criteria. Reduction of the need for medical assistance or evacuation due to cold related illness by improving health screening is preferred rather than not being able to assist personnel in an acute health situation. It has also been shown that good physical and mental health is critical for survival in accidents in cold air and water. The health criteria for personnel working on facilities in the Barents Sea will need to be reviewed. This should be done in close cooperation with the work force as required by the Frame Regulation § 13 regarding employee participation in issues related to health, safety and the environment [9].

6.14 Critical issues related to helicopter transport, evacuation and rescue

As previously discussed, departure criteria for safe helicopter transport have been recommended after investigation into helicopter incidents with fatalities. Issues that require evaluation are listed in table 11 below. Where possible, criteria have been proposed based on information gathered on factors limiting safe helicopter and rescue operations. These would need to be evaluated by aviation and rescue experts and included in a guideline.

Table 11, Proposed departure criteria for helicopter transport over sea

Issue	Criteria	Route	Local	Comment
Weather forecast	Reliable weather forecast available	X	X	Weather forecast for route and for terminal (TAF) ie airport and facility helicopter deck
Weather forecast	No forecast of polar low conditions	X	X	Polar low outbreak may defeat rescue operation
Lightning	No forecast of lightning	X	X	Flight allowed if 5 NM separation from CB can be maintained [22]
Alternate airport	Available			For long routes an offshore alternate may have to be accepted.
Sea state	≤ SS6	X	X	SS6 is the current certified limit for floatation system
Significant wave	≤ 5m (SS6)	X	X	H_s of ca 5m occurs at SS6
Wind on helideck	≤ 60 knots		X	OLF guideline limit
Air temperature, at sea level	≥ test temperature, certification of immersion suit	X	X	Air temperature must not reduce survival time or lead to ice accretion on

	(≥ -2°C, ice accretion)			immersion suit
Sea temperature	≥ test temperature, certification of immersion suit	X	X	Sea temperature must not impair survival time in immersion suit
Visibility	Minimum visibility requirements to be met, e.g. OGP 369 § 3 [24]	X	X	Visibility must allow safe landing/take off conditions and location of survivors
Darkness	Functioning navigational aids, radar and floodlights	X	X	This applies to systems on the aircraft, the facility and the helicopter deck
Rescue provisions	Reasonable expectation of rescue in the event of a forced landing.	X	X	OGP 369 § 3.5.2 [24]
SAR helicopter	Available	X	(X)	Rescue resource must be available for duration of flight. Sea King unavailable in icing conditions
ERV/FRDC/MOB	Available	(X)	X	Rescue resource must be available and able to operate
Maximum number of passengers	Calculated based on rescue capacity within 120 minutes for weather conditions at time of flight	X	X	Pilots to be included in calculation, i.e. no. of passengers + 2 pilots. Average pick-up time of 3 minutes to be adjusted for actual conditions
Icing conditions	Within design limits of anti-icing equipment installed on helicopter	X	X	Helicopter without anti-icing cannot be used in icing conditions
Helicopter deck movements	Pitch, roll & heave limits		X	OGP 369 §4 [24]

Many of these issues are addressed in OLF guideline no. 066 & 095 [22 & 23] and OGP report no. 369 Aviation weather guidelines [24]. The requirements should be evaluated for helicopter operations in the Barents Sea and a separate document developed.

When planning operations onboard a facility, there should be raised awareness to the conditions that may have a negative effect on the ability to evacuate and rescue persons. Issues that may be limiting factors for the success of evacuation and rescue are listed table in 12 on the following page.

Table 12, Issues threatening success of evacuation and rescue

Issue	Threatens or impairs	Comments
Lightning	Use of helicopters	May cause damage to helicopter, both mechanical and electronic components
Ice accretion	Stability of vessels	May lead to dangerous situations for lifeboat, ERV, FRDC and MOB boats
Low air temperature	Survivability of persons	Very low temperatures may reduce the survivability of persons, especially in sea
Polar lows (PL)	Visibility Use of immersion suit	May be difficult to locate persons PL may present an increased risk of drowning
Significant wave height ≥ 4m	Transfer of persons to ERV without stern slipway. Hoisting of persons from lifeboats	May damage lifeboat and injure persons May injure persons if attempting to hoist from lifeboat
Darkness	Safe landing on helicopter deck Location of persons in the sea	There are risks associated with landing on helicopter decks in the dark, especially on facilities that are affected by the motion of the sea May be difficult to locate persons in the sea in the dark if they are not equipped with a PLB, strobe light or reflective material

Limiting issues that responsible parties in industry and the public are, or should be, aware of

- It is most likely not possible to rescue persons from a lifeboat in hurricane conditions, Beaufort scale 12 and beyond. In these conditions it may be necessary to ride out the storm and remain in the lifeboats. The weather must improve before rescue can be attempted or accomplished.
- It may not be possible to retrieve a lifeboat from the sea onto the slipway of an ERV if wave heights are above ca 12 meters. This corresponds to a violent storm, Beaufort force 11 and beyond. In these conditions it may be necessary to ride out the storm and remain in the lifeboats. The weather must improve before rescue can be attempted or accomplished.

- Helicopters, if able to start rotor, can operate in almost any weather conditions. However, there is a risk of injuring the rescue man and survivor if attempting to land the rescue man on a lifeboat for hoisting a survivor. In these conditions it may be necessary for persons to jump into the sea and swim away from the lifeboat for pick up from the sea. This is not an ideal situation in very cold conditions and carries inherent risks. As observed during the Estonia accident, it could be dangerous for the rescue man to come close to a lifeboat already in 3 – 4 meter waves, corresponding to Beaufort scale 6 -7, strong breeze to near gale.
- Due to the current limited access to helicopter resources in the Barents Sea, helicopter evacuation of the entire crew on a facility will be time consuming. Resources may well prove insufficient depending on the situation leading to the evacuation. A precautionary evacuation of a facility in the Barents Sea is likely to involve the use of lifeboats.
- It will not be possible to transport personnel to hospital within 3 hours if the facility is more than 150 to 175 NM from the hospital and there is no helicopter based on or near the facility.
- Helicopter transport is currently performed in conditions that are beyond the floatation system certification, i.e. it is likely that the helicopter will capsize shortly after ditching in the sea when sea state is above 6, corresponding approximately to H_s = 5 m
- Tests specification ISO 15027-3 [16] for certification for immersions suits specifies an air temperature that is higher than can be expected in the Barents Sea.
- Rescue and medical resources are limited in northern Norway, the Barents Sea and the area of Svalbard. An accident involving many persons may stretch capabilities of the rescue and medical services to the limit of what is possible.

6.15 Risk management

Sound processes to identify and manage risk are required when operating in the Barents Sea. A continuous alertness to the risks and active processes to identify risk reducing and compensating measures in order to reduce risk to a level as low as reasonably practicable (ALARP) in all circumstances is the very basis of Norwegian regulation [10]. It must not be forgotten that the minimum requirements in the regulations shall be met and then the ALARP requirement shall be applied additionally. In the petroleum industry it is the responsible operator that must define the risk acceptance criteria for the activity, cf. the Management Regulation § 9, [10]. The regulations have limited definition of specific risk acceptance criteria. This can make it complicated for all involved to relate to the results of a risk analysis and to deal with probabilities expressed numerically for very low frequency events. Individuals may base their assessment of risk on factors that are defined within the concept of perceived risk and are more concerned about the consequences of worst-case outcome than the probability of the event. In this context, we can find an expectation that there should be emergency preparedness for worst-case events, but it is accepted to a certain degree that all situations may not be possible to deal with.

When looking at presentations held within industry conferences, there seems to be a large degree of agreement on the challenges and risks to operations in the Barents Sea. Media coverage of risks appears to focus mainly on environmental issues. Problems related to the safety of personnel working in the Barents Sea and the lack of emergency preparedness resources may "come as a surprise" to the public if there is an incident that puts rescue services to a severe test.

The intention of addressing the issue of risk communication has been to increase openness and awareness of the challenges to evacuation and rescue in the Barents Sea. Sound management and communication of risk can save lives, improve overall performance and safety levels, enhance experience transfer and avoid a media crisis or public outrage in the case of an incident.

7 CONCLUSIONS

The Barents Sea is currently an undeveloped petroleum province with little infrastructure and special weather conditions that need to be considered. The situation will improve as fields are discovered and developed introducing resources and infrastructure. Performance requirements defined for barriers in other areas of the Norwegian continental shelf may prove impossible to uphold in the Barents Sea, at least initially. The most obvious example here is the requirement to medevac a person to hospital within three hours [21]. Similarly, operational limitations imposed on helicopter transport may prove difficult to comply with. The most obvious examples in this case are the limitation on scheduled flights at night (in the dark) and that an offshore alternate landing site is not permitted when planning required fuel for a flight [22].

7.1 Evacuation

There are issues related to the evacuation of a facility that require special attention. This is particularly related to icing on lifeboats and the scarce helicopter resources currently available for evacuation of petroleum facilities in the Barents Sea. It is therefore not unlikely that we may see a precautionary evacuation of a facility involving the use of lifeboats, where in a similar situation further south on the Norwegian continental shelf, this may have been possible to perform using helicopters. A situation with personnel in lifeboats in the sea may require a rapid recovery of the persons and transfer to a safe place like an emergency response vessel.

7.2 Rescue

Resources for rescue operations in the Barents Sea are currently few, far apart and can only provide a limited service compared to the North Sea. Rescue of persons from the sea in the case of a helicopter incident will stretch the capability of current resources especially as exploration once again will take place at locations further from the coast than has been normal in the most recent years. It is important to develop robust rescue solutions taking into account the specific challenges of the Barents Sea. When there is activity towards the north east, the deployment of a SAR helicopter at an accessible airport like Berlevåg or Vardø, should be considered.

7.3 Medical resources

Medical resources in the county of Finnmark are limited. In the event of an incident involving serious injury of many persons, there may be serious challenges to provide required medical treatment. In such a situation it can be expected that transport of injured persons to hospitals in Tromsø and elsewhere in Norway will be necessary.

7.4 Regulatory requirements

The currents regulations are functional and risk based allowing for tailored solutions. Furthermore, the application of the requirements to barriers as defined in the Management Regulation § 5 and applied in this thesis, is a sufficiently specific requirement that shall be met by the responsible operators in the Barents Sea. The regulatory regime is therefore considered sufficient to safeguard evacuation and rescue in the Barents Sea. The guidelines to the regulations need to be complemented with references to standards like ISO-19906. The work done within the Barents 2020 project may provide a useful guidance for the Barents Sea. This work has been handed over to International Standards Organisation Technical Committee 67 / Sub Committee 8, Arctic Operations (ISO TC67/SC 8) for incorporation into ISO 19906. The impact of ice accretion and possibly sea ice or icebergs on activities in the Norwegian sector of the Barents Sea will need special considerations. The functional requirements in the regulations regarding evacuation are applicable for facilities where sea ice can occur, although, at the present time, they do not refer to any standard or technical solution. ISO 19906 is relevant in this respect.

7.5 Risk communication and risk perception

The public find it hard to relate to quantitative risk acceptance criteria. They base their assessment of risk on factors that are defined within the concept of perceived risk. They are often preoccupied with the worst-case scenario rather than the probability of occurrence. An expectation that there should be emergency response measures for the worst-case incident may be found among the public. It may be fair to expect public outrage if an accident should occur and that weaknesses identified by stakeholders in the petroleum industry have not been sufficiently taken care of.

7.6 Final conclusion

In response to the opening questions raised in this thesis:

What critical factors influence emergency preparedness, rescue operations and survival in the Barents Sea? Critical factors influencing emergency preparedness in the area are issues related to survival of persons in the sea, appropriate immersion suits, lifeboats and other vessels that can operate in conditions with ice accretion and solutions to rescue capability over long stretches of open sea.

Can these critical factors be managed effectively? The critical issues can be managed but they will require attention and the provision of suitable resources in the area.

How are limitations in emergency preparedness response communicated? There is an awareness of the issues within the industry as seen in presentations at conferences. Apart from issues related to pollution and oil spill response, there appears to be little communication to the general public regarding risks to persons. There is room for improvement in light of the government's ambition regarding transparency about the challenges.

With regard to the hypothesis "All year petroleum activity is not possible everywhere in the Barents Sea with regard to emergency preparedness unless sufficient attention is given to critical factors influencing evacuation and rescue" it may be concluded that the hypothesis stands and that there are issues that must be resolved in order to facilitate all year activity.

7.7 Recommendations

The following recommendations are put forward for consideration:

1. Departure criteria for helicopter flights in the Barents Sea should be established based on limiting parameters like; sea state, helicopter stability with floatation deployed, wind direction and speed, air and sea temp, visibility including fog, snow and degree of darkness, lightning forecast, polar low forecast, availability and limitations of air and sea rescue resources.
2. Operational limitations should be developed for activities on a facility in the Barents Sea taking into account the inherent risk and the ability to evacuate and rescue persons in the forecast weather conditions.
3. The effect of ice accretion on stability and performance needs to be studied for each individual vessel, craft or lifeboat deployed in activities in the Barents Sea.
4. Although the Norwegian area currently opened for exploration is considered an ice-free area, any development will need to consider actions of sea ice and icebergs for design loads and operational strategies for structures, vessels and evacuation means.
5. Emergency response vessels with a stern slipway for recovery of MOB boats, fast recovery daughter craft (FRDC) and lifeboats should become mandatory for support in

the Barents Sea. This is recommended so as to facilitate a rapid recovery and rescue of personnel evacuated in lifeboats in a broader range of sea states.

6. Health and fitness requirements for personnel working on facilities in cold, harsh and remote locations should be evaluated. The aim is to reduce the need for medical assistance where a health situation could have been foreseen and to ensure that individuals are as fit as reasonably possible in order to increase the probability of survival if involved in an evacuation or helicopter incident under harsh conditions.
7. The facility to be installed on the Skrugard field in block 7220 in the Barents Sea should be built with a helicopter hangar so as not to exclude the stationing of a SAR helicopter either from the start of the operation or at a later date. This recommendation is made based on the strategic position of the facility and the good experience, so far, of placing SAR helicopters offshore on installations equipped with a hangar.
8. There should be requirements to the use of a minimum standard of clothing under immersion suits when travelling in the Barents Sea. Special care should be taken to ensure that helicopter passengers wear correctly sized and watertight immersion suits.
9. The possibility of building one or more dedicated rescue vessels for the Barents Sea should be evaluated. This vessel may need to be a joint venture between the authorities/navy and the petroleum industry.
10. The need for refuelling facilities en route to remote locations, i.e. more than 150-170 NM from an onshore airport should be evaluated.
11. One should evaluate the content of basic safety training courses and consider enhancing the syllabus with issues critical for cold, harsh and remote locations.
12. Consider providing a voluntary course where
    a. Personnel are exposed to cold water, experience the effects and become familiar with their own reaction
    b. Personnel are exposed to simulated conditions that may be experienced in an evacuation involving wind, precipitation, varying light and visibility and potentially claustrophobic situations.

    Based on experience and participant feedback, consider developing a compulsory version of the training.

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9 APPENDICIES

A.1 Abbreviations

A.2 Beaufort scale for wind and sea conditions

A.3 Polar lows in Barents Sea 2000 to 2010

A.4 Ice accretion on aircraft, statistics for route Hammerfest to Bjørnøya

A.5 Overview of exploration activity 1980 to 2011

A.6 22nd licence round

A.7 Network – facility evacuation

A.8 Calculations of helicopter ground speed taking into account the effect of wind

A.9 Calculation of helicopter round trip between Berlevåg and 74,5°N/37°E

A.1 Abbreviations

ALARP As Low As Reasonable Practicable

ARRC Autonomous Rescue and Recovery Craft

AWSAR All Weather Search and Rescue

BHS Norwegian Board of Health Supervision

BJF Båtsfjord airport

BVG Berlevåg airport

CPA Norwegian Climate and Pollution Agency

CPR cardiopulmonary resuscitation

ENBJ Bjørnøya airport

FLIR Forward looking infrared camera/radar

HFT Hammerfest airport

HUET Helicopter Underwater Escape Training

DNMI Norwegian Meteorological Institute

DSHA Defined Situation of Hazard and Accident

ERV Emergency Response Vessel

FRC Fast Recovery Craft

FRDC Fast Recovery Daughter Craft

g Gravitational acceleration, $g = 9{,}81\ m/s^2$

KKN Kirkenes airport

km kilometer

kts knots. Nautical miles per hour

LKL Lakselv airport (Banak)

m meter

M-ADS Modified Automatic Dependent Surveillance

MEH Mehamn airport

MOB man overboard

NM nautical mile

NTNU Norwegian University of Science and Technology

OED Norwegian Ministry of Oil and Energy

OGP International Association of Oil & Gas Producers

PL Polar low

PLB Personal locator beacon

PSA Norwegian Petroleum Safety Authority

RS Raynaud's syndrome

SAR Search and Rescue

SMSAS Simon Møkster Shipping AS

VAW Vardø airport

A.2 Beaufort scale

Table A.2, Beaufort Scale [89]

Beau-fort wind scale	Mean Wind Speed		Limits of wind speed		Wind descript-ive terms	Hs* m	Max wave* m	Sea state	Sea descriptive terms
	Knots	m/s	Knots	m/s					
0	0	0	<1	0–0.2	Calm	-	-	**0**	Calm (glassy)
1	2	0.8	1–3	0.3–1.5	Light air	0.1	0.1	**1**	Calm (rippled)
2	5	2.4	4–6	1.6–3.3	Light breeze	0.2	0.3	**2**	Smooth (wavelets)
3	9	4.3	7–10	3.4–5.4	Gentle breeze	0.6	1.0	**3**	Slight
4	13	6.7	11–16	5.5–7.9	Moderate breeze	1.0	1.5	**3–4**	Slight–Moderate
5	19	9.3	17–21	8.0–10.7	Fresh breeze	2.0	2.5	**4**	Moderate
6	24	12.3	22–27	10.8–13.8	Strong breeze	3.0	4.0	**5**	Rough
7	30	15.5	28–33	13.9–17.1	Near gale	4.0	5.5	**5–6**	Rough–Very rough
8	37	18.9	34–40	17.2–20.7	Gale	5.5	7.5	**6–7**	Very rough–High
9	44	22.6	41–47	20.8–24.4	Severe gale	7.0	10.0	**7**	High
10	52	26.4	48–55	24.5–28.4	Storm	9.0	12.5	**8**	Very High
11	60	30.5	56–63	28.5–32.6	Violent storm	11.5	16.0	**8**	Very High
12	-	-	64+	32.7+	Hurricane	14+	-	**9**	Phenomenal

- These values refer to well-developed wind waves of the open sea. The lag effect between the wind getting up and the sea increasing should be borne in mind. Source: http://www.metoffice.gov.uk/weather/marine/guide/beaufortscale.html , [89]

A.3 Polar lows in Barents Sea 2000 to 2010

Table A.3, List of polar lows in Barents Sea from 2000 to 2010 [52]

Date	**Time**	**Latitude**	**Longitude**	**Remark** (As given in report by DNMI)	**Minimum air pressure, hPA**	**Maximum wind speed, knots**
12.12.99	1340	72°N	18°E		989	45
22.01.00	0250	72,5°N	29°E	Old Erik	990	42
24.03.00	1230	72°N	21°E	Most beautiful	997	35 - 40
01.01.01	1500	75°N	22°E			
01.11.01	0200	71°N	19°E	The Torsvåg case, cirrus outflow	992	50
09.11.01	1700	74°N	25°E			
31.12.01	0400	73°N	38°E	Dual		
12.01.02	1200	73°N	21°E		979	35
22.01.02	1100	75°N	28°E	Dual system	985	50
23.01.02	1200	71°N	17°E	Multiple	978	35
19.02.02	1300	74°N	34°E	Most beautiful	968	55
22.02.02	0000	74°N	33°E	Dual		
20.05.02	1436	73,3°N	15,5°E	Dual system	1010	35
31.12.02	1100	73°N	38°E	Multiple		
17.01.03	0000	73,5°N	25,5°E	Slow moving	985	35
11.03.03	0000	72°N	16,5°E		979	45
24.10.03	0600	71,5°N	18°E	Reversed shear	990	45
08.12.03	1320	71°N	31°E	Reversed, secondary	985	44
17.12.03	1300	72°N	38°E		988	45
27.12.03	1200	73°N	18°E			38
07.03.05	0700	72°N	18°E	The Brummer case		35
02.04.05	0900	75°N	24,5°E	Secondary, strong reversed	994	70
26.04.05	1700	74°N	25°E	Cirrus shield		
23.11.05	1500	74°N	18°E	Double-system, comma in SW		44
29.10.06	1200	72°N	16°E	Primary, good models	992	38 – 54
22.12.06	12-18	71,5°N	17°E	Secondary, baroclinic, poor mod.	979	48 – 61
26.12.06	03-18	72,5°N	18-22°E	Secondary, inst.Occ., reversed	977	49 – 63
13.02.07	0600	71,5°N	23°E	Small PL	1004	40
11.12.07	1930	71°N	31°E			35
29.02.08	1030	74°N	24°E	Dual	950	40
18.03.08	1500	73,5°N	28,5°E	Dual, reversed		35
17.11.08	0700	75°N	25°E		990	35
30.12.08	1200	72°N	34°E	Marginal	995	40
07.01.09	0300	72°N	28°E	Multiple		50
25.02.09	2100	71,5°N	22°E			
27.02.09	1800	72,5°N	32,5°E	Neutral,	1000	30

				baroclinic		
02.04.09	0900	73°N	35,5°E	Baroclinic, reversed	1008	35
05.04.09	0700	73°N	25°E	Cirrus waves on top	2008	30
12.03.10	1200	72°N	19°E	Multiple	991	35
14.03.10	1200	73°N	16°E	No observations	996	
19.03.10	1200	74,5°N	18°E	Dual	994	35
24.03.10	1800	72°N	18°E	Comma, later PL	1012	
27.03.10	0100	72,5°N	19,5°E	Baroclinic, reversed	1005	35
31.05.10	1800	70,5°N	19,5°E	One fatality, baroclinic, neautral	1008	40

A.4 Ice accretion on aircraft, statistics for route Hammerfest to Bjørnøya

Table A.4 below shows the percentage of time per month that icing can be expected for each of the severity classes: no icing, light icing, moderate icing and severe icing.

Table A.4, Icing statistics for route Bjørnøya – Hammerfest at height 267m (876ft) [53]

Icing statistics.
Bjørnøya - Hammerfest
Model level 37. Average height 267m

Month:	No icing	Light	Moderate	Severe
January	49.68	49.38	0.94	0.00
February	45.01	53.69	1.30	0.00
March	51.02	47.31	1.67	0.00
April	58.58	38.72	2.69	0.00
May	69.65	26.75	3.60	0.00
June	81.28	16.89	1.83	0.00
July	96.40	2.96	0.65	0.00
August	96.32	3.09	0.59	0.00
September	92.28	7.31	0.42	0.00
October	78.55	20.62	0.83	0.00
November	65.75	32.64	1.61	0.00
December	51.67	47.15	1.18	0.00

A.5 Overview of exploration activity 1980 to 2011

The table A.5 below presents an overview of exploration activity in the Norwegian sector of the Barents Sea. The data is collected from the Norwegian Petroleum Directorate fact sheets [92] issued after completion of each well. The rigs that have been identified as having drilled in the Barents Sea are listed in the table.

Table A.5, Overview of rig activity in the Norwegian sector of the Barents Sea [92]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Rig
1980						30	31	31	30	12			Treasure Seeker
						16	31	31	30	10			Ross Rig
1981				15	31	30	31	31	11				Treasure Seeker
				14	31	30	31	31	10				Ross Rig
1982				10	31	30	31	31	26				Treasure Scout
				15	31	30	31	31	30	8			Nordraug
1983			15	1,5	31	30	31	31	9				Treasure Scout
				24	31	30	31	21					West Vanguard
					11	30	31	21	12				Dyvi Delta
						19	31	11					Treasure Seeker
1984		10	31	30	31	30	31	31	30	20			Treasure Scout
			13	30	31	30	31	31	30	27			West Vanguard
						3	31	31	25				Byford Dolphin
								11	8				Zapata Ugland
1985	2	28	31	30	31	30	31	31	28				West Vanguard
		26	31	30	31	30	31	31	30	29			Treasure Scout
			18	30	31	21						24	Borgny Dolphin
										21	13		Zapata Ugland
1986			18	30	31	30	21						Borgny Dolphin
			13	30	31	30	31	23					Zapata Ugland
					6	30	31	12					Ross Isle
1987					2	30	31	31	30	31	30	31	Ross Rig
						7	31	31	30	31	24	31	Polar Pioneer
1988	31	25											Polar Pioneer
	31	28	31	30	31	30	31	31	30	31	30	31	Ross Rig
1989	31	28	28			27	31	31	30	31	30	31	Ross Rig
1990	31	28	31	30	7								Ross Rig
							11	31	5				Byford Dolphin
1991	4	23											Polar Pioneer
								20	30	31	25	31	Arcade Frontier
1992	13												Arcade Frontier
							10	31	30	31	11		Polar Pioneer
										26	30	26	Ross Rig
1993								22	30	31	30	31	Ross Rig
1994	31	26											Ross Rig
1995													
1996													
1997													
1998													
1999													
2000							7	31	30	31	30	31	Transocean Arctic

2001	31	28	9										Transocean Arctic
									18	19			West Alpha
2002													
2003													
2004													
2005	11	28	31	30	13					7	30	31	Eirik Raude
2006	26	28	24										Eirik Raude
								21	30	31	30	31	Polar Pioneer
2007	31	28	7			16	22				16	10	Polar Pioneer
2008	24	29	31	30	31	30	31	31	30	31	30	31	Polar Pioneer
2009	14												Polar Pioneer
2010										13	30	31	Polar Pioneer
2011	22	18	31	30	3								Polar Pioneer
				1	31	30	31	31	25				West Phoenix
					15	30	9						Transocean Leader
									12	28	29	25	Aker Barents
Total	333	381	393	440	553	709	793	813	669	530	418	426	

Figure A.5 illustrates the average number of drilling days per months for three periods. The average for the periods only takes into account the years with activity. Activity was originally carried out during the summer in the period 1980 to 1986. Since then there has been a shift towards winter drilling to reduce the consequences to breeding during the spring and summer months.

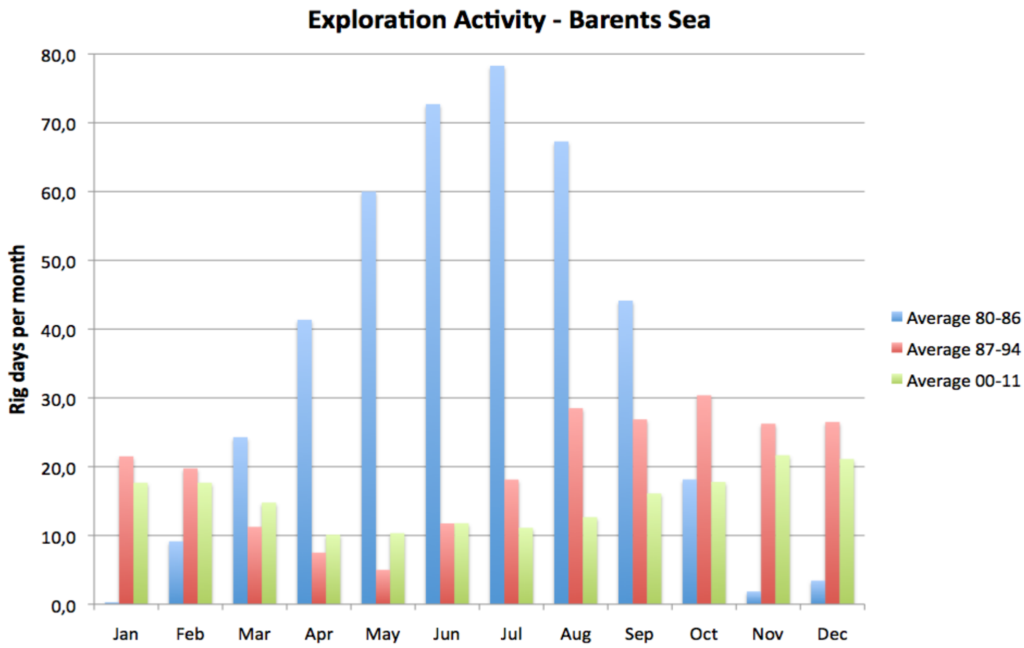


Figure A.5, Average number of rig days per month for the main activity periods

A.6 22nd licence round

The map in figure A.6.1 below shows the interest for blocks, i.e. those that have been nominated as potential exploration prospects in the 22nd round. Grey indicates that a licence has been awarded in a previous round. Light red indicates that only one company has nominated the block while dark red indicates that two or more companies have expressed interest.

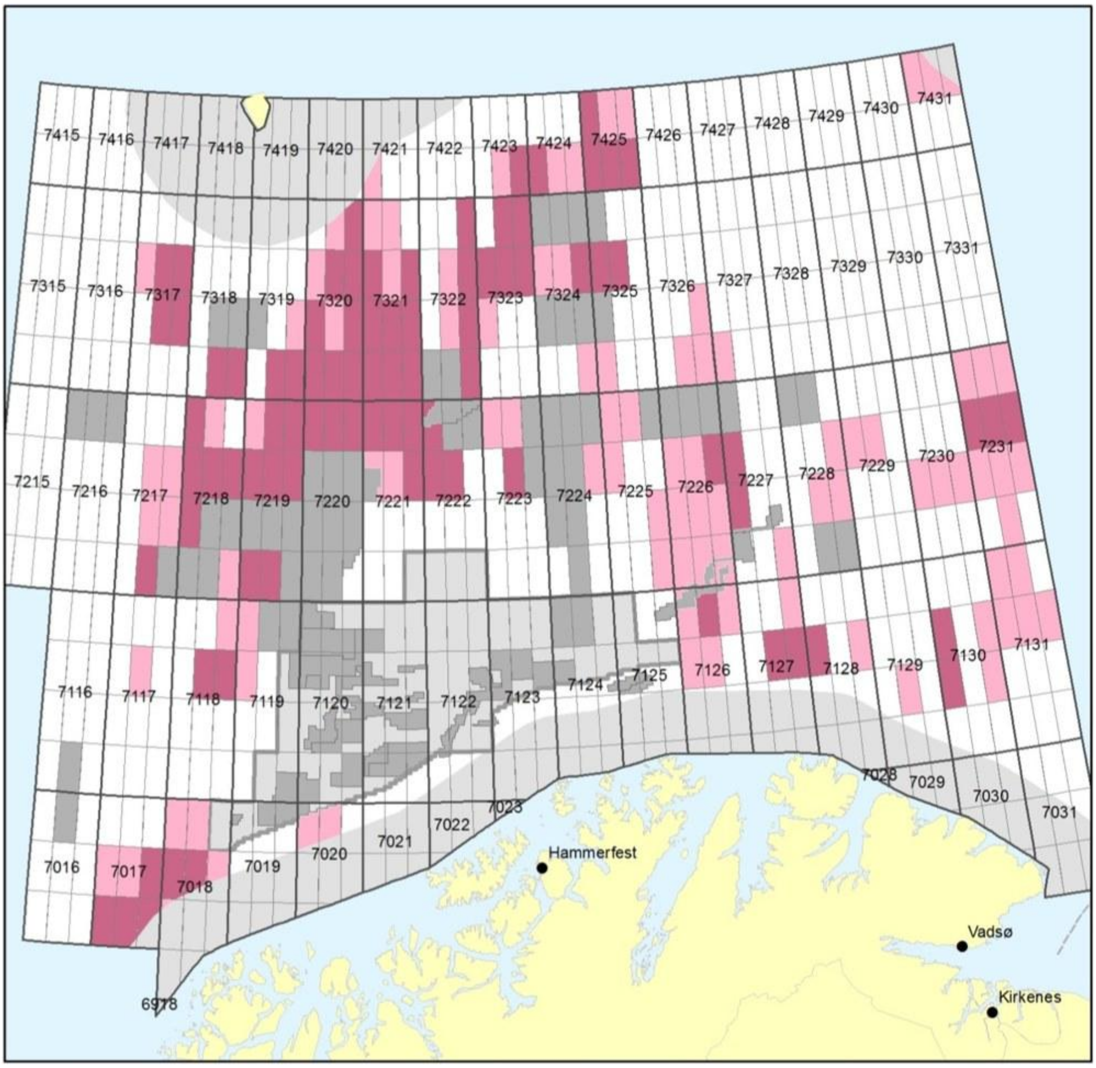


Figure A.6.1, Map of the nominated blocks in the Norwegian part of the Barents Sea [87]

Continued on next page.

The map in figure A.6.2 below shows the blocks that the Oil and Energy Department have decided to include in the 22nd round. Grey indicates that a licence has been awarded in a previous round. Light red indicates the blocks that are included in the 22nd round.

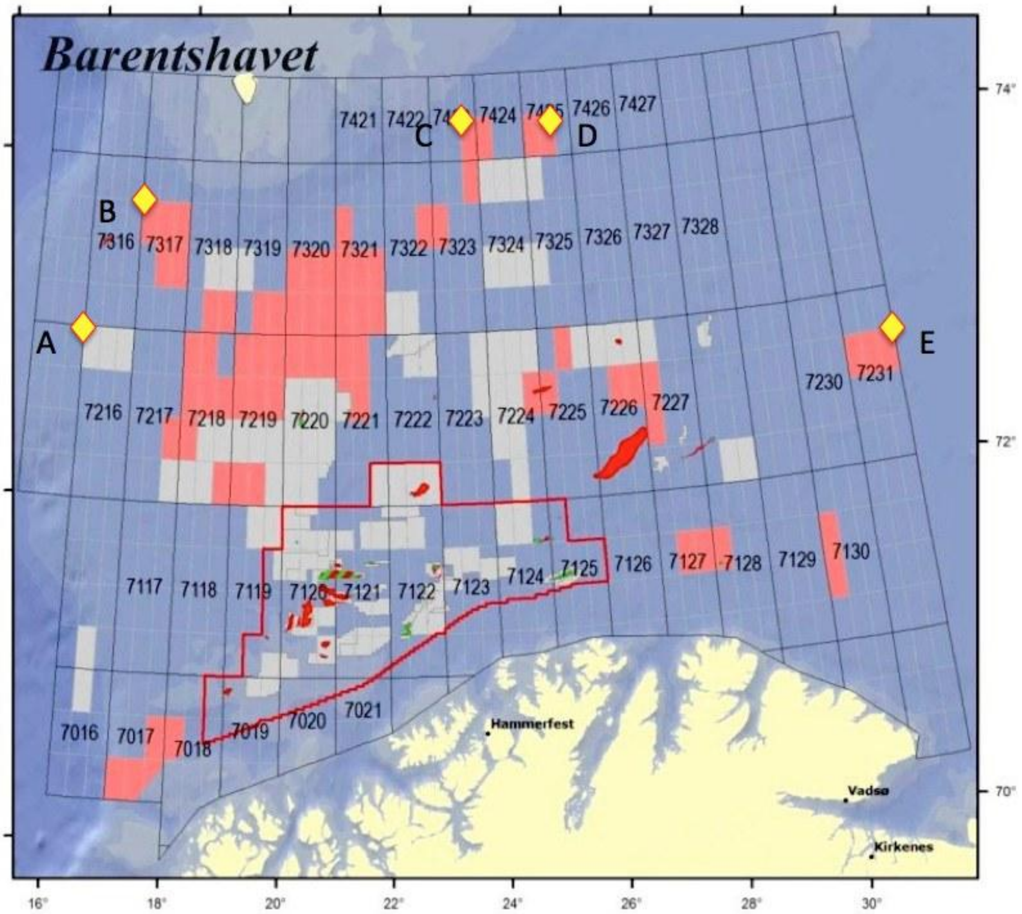


Figure A.6.2, Map of the blocks in the Norwegian part of the Barents Sea [88]

The yellow diamonds marked A to E on the map in figure A.6.2, indicate positions that are 200 NM or more from Hammerfest as shown in table A.4 below. The detailed distances are presented in the table.

Table A.6, Distance between Hammerfest and position marked by yellow diamond

	A	B	C	D	E
Position	73°N, 16°E	73,75°N, 17°E	74,25°N, 23,33°E	74,25°N, 25,67°E	72,75°N, 32°E
Distance	200 NM	221 NM	215 NM	217 NM	200 NM

A.7 Network – facility evacuation

An attempt is made to illustrate the interaction between the many elements involved in the evacuation of a facility as analysed with bow tie diagrams in section 6.3. The network may be difficult to understand but with some explanation, it is a goal that it will enhance appreciation of the context and demonstrate the complexity of the situation. This type of network could be used to build Bayesian Belief Networks and perform an analysis similar to the work done by Norrington et. al. [44]. The network could be further developed and expanded in order to analyse critical issues and provide a basis for performing ALARP evaluations and cost benefit analysis aiding decisions on investments to improve safety.

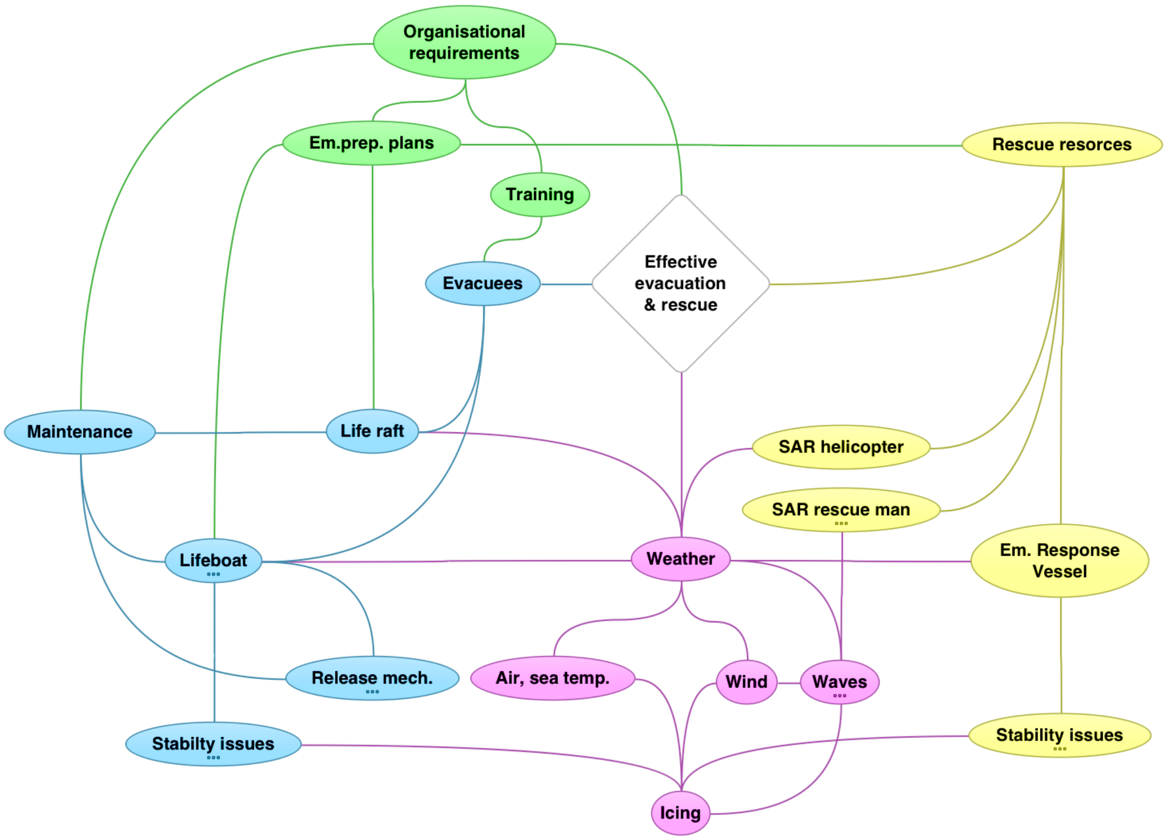


Figure A.7.1 Network diagram illustrating evacuation and rescue

Figure A.7.1 illustrates the interaction between elements that can influence successful evacuation and rescue. It includes elements that influence the ability to evacuate, the effects of weather, the provision of rescue means and issues that an organisation needs to address in order to be prepared. The network is an example of a selection of issues and is not intended to be an exhaustive description of all issues.

The white diamond in the centre of the network shows the objective “Effective evacuation and rescue”. The whole network may be simplified by grouping the issues into 4 groups of issues that affect the outcome:

- organisational measures (green)
- status of the evacuees and the evacuation means (blue)
- rescue resources (yellow)
- weather (magenta)

The status of the evacuees is highly dependent on the functioning of the evacuation means and it has therefore been chosen to deal with these issues as one group.

Organisational measures (green)

Organisational measures ensure that risk and emergency analysis has been performed and that an emergency preparedness plan has been developed. The emergency preparedness plan dictates the requirements for rescue resources and the evacuation equipment that must be provided for those who may need to evacuate the facility. The organisation will also set the requirements for maintenance of the elements in the evacuation system, for example the lifeboats, release mechanisms and life rafts. The organisation will also stipulate requirements for training of the personnel so that the evacuees possess the necessary competence to use the evacuations means that are provided.

Status of the evacuees (blue)

The status of the evacuees depends on how they have evacuated from the facility, the weather at the time of evacuation and the training that they have received. The evacuees’ use of the lifeboats or life rafts depends on issues like the maintenance of the equipment, the functioning of the release mechanisms and launching equipment and the competence of the evacuees. The weather may have a large impact on the status of the evacuees and may necessitate a prolonged stay onboard the lifeboat while waiting for conditions that permit helicopter pick up or safe transfer of persons to the ERV. During this time, ice accretion may occur threatening stability of the lifeboat and eventually the safety of the occupants.

Rescue resources (yellow)

The type of rescue resources available will depend on the provisions made by the organisation and the emergency preparedness plans. Normally an ERV and SAR helicopter will be made available. The rescue resources are dependent on an acceptable weather window allowing a successful rescue operation. For helicopter rescue of persons in the sea, the rescue man is a single critical resource. The rescue man is particularly vulnerable to the influence of the weather, especially waves.

Weather (magenta)

The weather can play an important role in the outcome of an evacuation and rescue situation. The weather is a combination of many factors like air and sea temperature, wind and waves. The weather will influence the status of the evacuees. They may become seasick or suffer the effects of hypothermia, they may have to ride off a storm and they may experience icing on their lifeboat. Ice accretion on the lifeboats or ERV is dependent on the air and sea temperature, the wind and the waves. Also the waves may make it difficult for a rescue man to hoist persons from the lifeboats.

Use of networks, event trees and bow tie diagrams

Due to the complexity of the situations being analysed, it may be beneficial to supplement the chosen analysis method with complementing methods to enhance the understanding and visualisation of the issues. The selection of the methods is for the organisation and persons performing the work to decide. In this thesis it has been found useful to supplement the event trees and bow ties with networks. Due to the size of the document, it has been chosen only to include one network as an example in the appendix.

A.8 Calculations of helicopter ground speed taking into account the effect of wind

Calculations of helicopter ground speed

Calculated values	Value	Units	Value	Value	Value
Av:angle WS to GS	180	deg	180,000001	170,000001	160,000001
Av:convert deg to radians	3,14159	rad	3,14159	2,96706	2,79253
sin(Aw)=sin(Av)*WS/TAS	0,00000		0,00000	0,06946	0,13681
Aw (arcsin of previous result)	0,00000	rad	0,00000	0,06952	0,13724
Aw:wind corr angle	0,00000	deg	0,00000	3,98293	7,86318
Ac:angle WS to TAS	0,00000	deg	0,00000	6,01707	12,13682
Ac:convert deg to radians	0,00000	rad	0,00000	0,10502	0,21183
GS:ground speed(G)	**60,00**	**knots**	**60,00**	**60,37**	**61,47**

Known variables	Value	Units	Value	Value	Value
Heading A to B (C:course)	0,0000001	deg	0,0000011	0,0000011	0,0000011
TAS:true air speed(V)	100	knots	100	100	100
W:wind speed(WS)	50	knots	50	50	50
Wind direction (Wd)	0	deg	0	10	20

Calculated values	Value	Units	Value	Value	Value
Av:angle WS to GS	180	deg	180,000001	170,000001	160,000001
Av:convert deg to radians	3,14159	rad	3,14159	2,96706	2,79253
sin(Aw)=sin(Av)*WS/TAS	0,00000		0,00000	0,08682	0,17101
Aw (arcsin of previous result)	0,00000	rad	0,00000	0,08693	0,17185
Aw:wind corr angle	0,00000	deg	0,00000	4,98092	9,84655
Ac:angle WS to TAS	0,00000	deg	0,00000	5,01907	10,15345
Ac:convert deg to radians	0,00000	rad	0,00000	0,08760	0,17721
GS:ground speed(G)	**50,00**	**knots**	**50,00**	**50,38**	**51,54**

Known variables	Value	Units	Value	Value	Value
Heading A to B (C:course)	0,0000001	deg	0,0000011	0,0000011	0,0000011
TAS:true air speed(V)	100	knots	100	100	100
W:wind speed(WS)	60	knots	60	60	60
Wind direction (Wd)	0	deg	0	10	20

Calculated values	Value	Units	Value	Value	Value
Av:angle WS to GS	180	deg	180,000001	170,000001	160,000001
Av:convert deg to radians	3,14159	rad	3,14159	2,96706	2,79253
sin(Aw)=sin(Av)*WS/TAS	0,00000		0,00000	0,10419	0,20521
Aw (arcsin of previous result)	0,00000	rad	0,00000	0,10438	0,20668
Aw:wind corr angle	0,00000	deg	0,00000	5,98044	11,84191
Ac:angle WS to TAS	0,00000	deg	0,00000	4,01956	8,15808
Ac:convert deg to radians	0,00000	rad	0,00000	0,07015	0,14239
GS:ground speed(G)	**40,00**	**knots**	**40,00**	**40,37**	**41,49**

Value	Value	Value	Value	Value	Value	Value
150,000001	140,000001	130,000001	120,000001	110,000001	100,000001	90,0000011
2,61799	2,44346	2,26893	2,09440	1,91986	1,74533	1,57080
0,20000	0,25712	0,30642	0,34641	0,37588	0,39392	0,40000
0,20136	0,26004	0,31143	0,35374	0,38534	0,40490	0,41152
11,53696	14,89895	17,84348	20,26790	22,07853	23,19883	23,57818
18,46304	25,10105	32,15652	39,73210	47,92147	56,80117	66,42182
0,32224	0,43810	0,56124	0,69346	0,83639	0,99137	1,15928
63,34	**66,00**	**69,48**	**73,81**	**78,99**	**84,97**	**91,65**

Value	Value	Value	Value	Value	Value	Value
0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011
100	100	100	100	100	100	100
50	50	50	50	50	50	50
30	40	50	60	70	80	90

Value	Value	Value	Value	Value	Value	Value
150,000001	140,000001	130,000001	120,000001	110,000001	100,000001	90,0000011
2,61799	2,44346	2,26893	2,09440	1,91986	1,74533	1,57080
0,25000	0,32139	0,38302	0,43301	0,46985	0,49240	0,50000
0,25268	0,32720	0,39307	0,44783	0,48912	0,51485	0,52360
14,47751	18,74724	22,52101	25,65891	28,02432	29,49870	30,00000
15,52249	21,25276	27,47899	34,34109	41,97568	50,50129	60,00000
0,27092	0,37093	0,47960	0,59937	0,73261	0,88141	1,04720
53,52	**56,39**	**60,23**	**65,14**	**71,17**	**78,35**	**86,60**

Value	Value	Value	Value	Value	Value	Value
0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011
100	100	100	100	100	100	100
60	60	60	60	60	60	60
30	40	50	60	70	80	90

Value	Value	Value	Value	Value	Value	Value
150,000001	140,000001	130,000001	120,000001	110,000001	100,000001	90,0000011
2,61799	2,44346	2,26893	2,09440	1,91986	1,74533	1,57080
0,30000	0,38567	0,45963	0,51962	0,56382	0,59088	0,60000
0,30469	0,39594	0,47757	0,54640	0,59900	0,63215	0,64350
17,45760	22,68550	27,36302	31,30645	34,32008	36,21981	36,86990
12,54240	17,31450	22,63698	28,69355	35,67992	43,78019	53,13010
0,21891	0,30220	0,39509	0,50080	0,62273	0,76411	0,92730
43,43	**46,30**	**50,24**	**55,44**	**62,07**	**70,26**	**80,00**

Value	Value	Value	Value	Value	Value	Value
80,0000011	70,0000011	60,0000011	50,0000011	40,0000011	30,0000011	20,0000011
1,39626	1,22173	1,04720	0,87266	0,69813	0,52360	0,34907
0,39392	0,37588	0,34641	0,30642	0,25712	0,20000	0,13681
0,40490	0,38534	0,35374	0,31143	0,26004	0,20136	0,13724
23,19883	22,07853	20,26790	17,84348	14,89895	11,53696	7,86318
76,80117	87,92147	99,73210	112,15652	125,10105	138,46304	152,13681
1,34043	1,53452	1,74065	1,95750	2,18343	2,41664	2,65529
98,86	**106,35**	**113,81**	**120,90**	**127,28**	**132,62**	**136,65**

Value	Value	Value	Value	Value	Value	Value
0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011
100	100	100	100	100	100	100
50	50	50	50	50	50	50
100	110	120	130	140	150	160

Value	Value	Value	Value	Value	Value	Value
80,0000011	70,0000011	60,0000011	50,0000011	40,0000011	30,0000011	20,0000011
1,39626	1,22173	1,04720	0,87266	0,69813	0,52360	0,34907
0,49240	0,46985	0,43301	0,38302	0,32139	0,25000	0,17101
0,51485	0,48912	0,44783	0,39307	0,32720	0,25268	0,17185
29,49870	28,02432	25,65891	22,52101	18,74724	14,47751	9,84655
70,50129	81,97568	94,34109	107,47899	121,25276	135,52249	150,15345
1,23048	1,43075	1,64656	1,87586	2,11626	2,36531	2,62067
95,72	**105,38**	**115,14**	**124,51**	**133,00**	**140,13**	**145,51**

Value	Value	Value	Value	Value	Value	Value
0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011
100	100	100	100	100	100	100
60	60	60	60	60	60	60
100	110	120	130	140	150	160

Value	Value	Value	Value	Value	Value	Value
80,0000011	70,0000011	60,0000011	50,0000011	40,0000011	30,0000011	20,0000011
1,39626	1,22173	1,04720	0,87266	0,69813	0,52360	0,34907
0,59088	0,56382	0,51962	0,45963	0,38567	0,30000	0,20521
0,63215	0,59900	0,54640	0,47757	0,39594	0,30469	0,20668
36,21981	34,32008	31,30645	27,36302	22,68550	17,45760	11,84192
63,78019	75,67992	88,69355	102,63698	117,31450	132,54240	148,15808
1,11317	1,32086	1,54799	1,79135	2,04752	2,31330	2,58585
91,09	**103,11**	**115,44**	**127,38**	**138,23**	**147,36**	**154,25**

Value	Value	Value	Value	Value	Value	Value
10,0000011	1,1E-06	-9,9999989	-19,9999989	-29,9999989	-39,9999989	-49,9999989
0,17453	0,00000	-0,17453	-0,34907	-0,52360	-0,69813	-0,87266
0,06946	0,00000	-0,06946	-0,13681	-0,20000	-0,25712	-0,30642
0,06952	0,00000	-0,06952	-0,13724	-0,20136	-0,26004	-0,31143
3,98293	0,00000	-3,98293	-7,86318	-11,53696	-14,89895	-17,84348
166,01707	180,00000	193,98293	207,86318	221,53696	234,89895	247,84348
2,89754	3,14159	3,38564	3,62790	3,86655	4,09976	4,32568
139,15	**140,00**	**139,15**	**136,65**	**132,62**	**127,28**	**120,90**

Value	Value	Value	Value	Value	Value	Value
0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011
100	100	100	100	100	100	100
50	50	50	50	50	50	50
170	180	190	200	210	220	230

Value	Value	Value	Value	Value	Value	Value
10,0000011	1,1E-06	-9,9999989	-19,9999989	-29,9999989	-39,9999989	-49,9999989
0,17453	0,00000	-0,17453	-0,34907	-0,52360	-0,69813	-0,87266
0,08682	0,00000	-0,08682	-0,17101	-0,25000	-0,32139	-0,38302
0,08693	0,00000	-0,08693	-0,17185	-0,25268	-0,32720	-0,39307
4,98093	0,00000	-4,98092	-9,84655	-14,47751	-18,74724	-22,52101
165,01907	180,00000	194,98092	209,84655	224,47751	238,74724	252,52101
2,88013	3,14159	3,40306	3,66251	3,91787	4,16693	4,40732
148,86	**150,00**	**148,86**	**145,51**	**140,13**	**133,00**	**124,51**

Value	Value	Value	Value	Value	Value	Value
0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011
100	100	100	100	100	100	100
60	60	60	60	60	60	60
170	180	190	200	210	220	230

Value	Value	Value	Value	Value	Value	Value
10,0000011	1,1E-06	-9,9999989	-19,9999989	-29,9999989	-39,9999989	-49,9999989
0,17453	0,00000	-0,17453	-0,34907	-0,52360	-0,69813	-0,87266
0,10419	0,00000	-0,10419	-0,20521	-0,30000	-0,38567	-0,45963
0,10438	0,00000	-0,10438	-0,20668	-0,30469	-0,39594	-0,47757
5,98044	0,00000	-5,98044	-11,84191	-17,45760	-22,68550	-27,36302
164,01956	180,00000	195,98044	211,84191	227,45760	242,68550	257,36302
2,86268	3,14159	3,42050	3,69734	3,96988	4,23566	4,49183
158,54	**160,00**	**158,54**	**154,25**	**147,36**	**138,23**	**127,38**

Value	Value	Value	Value	Value	Value	Value
-59,9999989	-69,9999989	-79,9999989	-89,9999989	-99,9999989	-109,999999	-119,999999
-1,04720	-1,22173	-1,39626	-1,57080	-1,74533	-1,91986	-2,09440
-0,34641	-0,37588	-0,39392	-0,40000	-0,39392	-0,37588	-0,34641
-0,35374	-0,38534	-0,40490	-0,41152	-0,40490	-0,38534	-0,35374
-20,26790	-22,07853	-23,19883	-23,57818	-23,19883	-22,07853	-20,26790
260,26790	272,07853	283,19883	293,57818	303,19883	312,07853	320,26790
4,54253	4,74867	4,94275	5,12391	5,29182	5,44680	5,58973
113,81	**106,35**	**98,86**	**91,65**	**84,97**	**78,99**	**73,81**

Value	Value	Value	Value	Value	Value	Value
0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011
100	100	100	100	100	100	100
50	50	50	50	50	50	50
240	250	260	270	280	290	300

Value	Value	Value	Value	Value	Value	Value
-59,9999989	-69,9999989	-79,9999989	-89,9999989	-99,9999989	-109,999999	-119,999999
-1,04720	-1,22173	-1,39626	-1,57080	-1,74533	-1,91986	-2,09440
-0,43301	-0,46985	-0,49240	-0,50000	-0,49240	-0,46985	-0,43301
-0,44783	-0,48912	-0,51485	-0,52360	-0,51485	-0,48912	-0,44783
-25,65891	-28,02432	-29,49870	-30,00000	-29,49870	-28,02432	-25,65891
265,65890	278,02432	289,49870	300,00000	309,49870	318,02432	325,65891
4,63662	4,85244	5,05271	5,23599	5,40177	5,55057	5,68382
115,14	**105,38**	**95,72**	**86,60**	**78,35**	**71,17**	**65,14**

Value	Value	Value	Value	Value	Value	Value
0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011
100	100	100	100	100	100	100
60	60	60	60	60	60	60
240	250	260	270	280	290	300

Value	Value	Value	Value	Value	Value	Value
-59,9999989	-69,9999989	-79,9999989	-89,9999989	-99,9999989	-109,999999	-119,999999
-1,04720	-1,22173	-1,39626	-1,57080	-1,74533	-1,91986	-2,09440
-0,51962	-0,56382	-0,59088	-0,60000	-0,59088	-0,56382	-0,51962
-0,54640	-0,59900	-0,63215	-0,64350	-0,63215	-0,59900	-0,54640
-31,30645	-34,32008	-36,21981	-36,86990	-36,21981	-34,32008	-31,30645
271,30644	284,32008	296,21981	306,86990	316,21981	324,32008	331,30645
4,73519	4,96232	5,17001	5,35589	5,51908	5,66045	5,78239
115,44	**103,11**	**91,09**	**80,00**	**70,26**	**62,07**	**55,44**

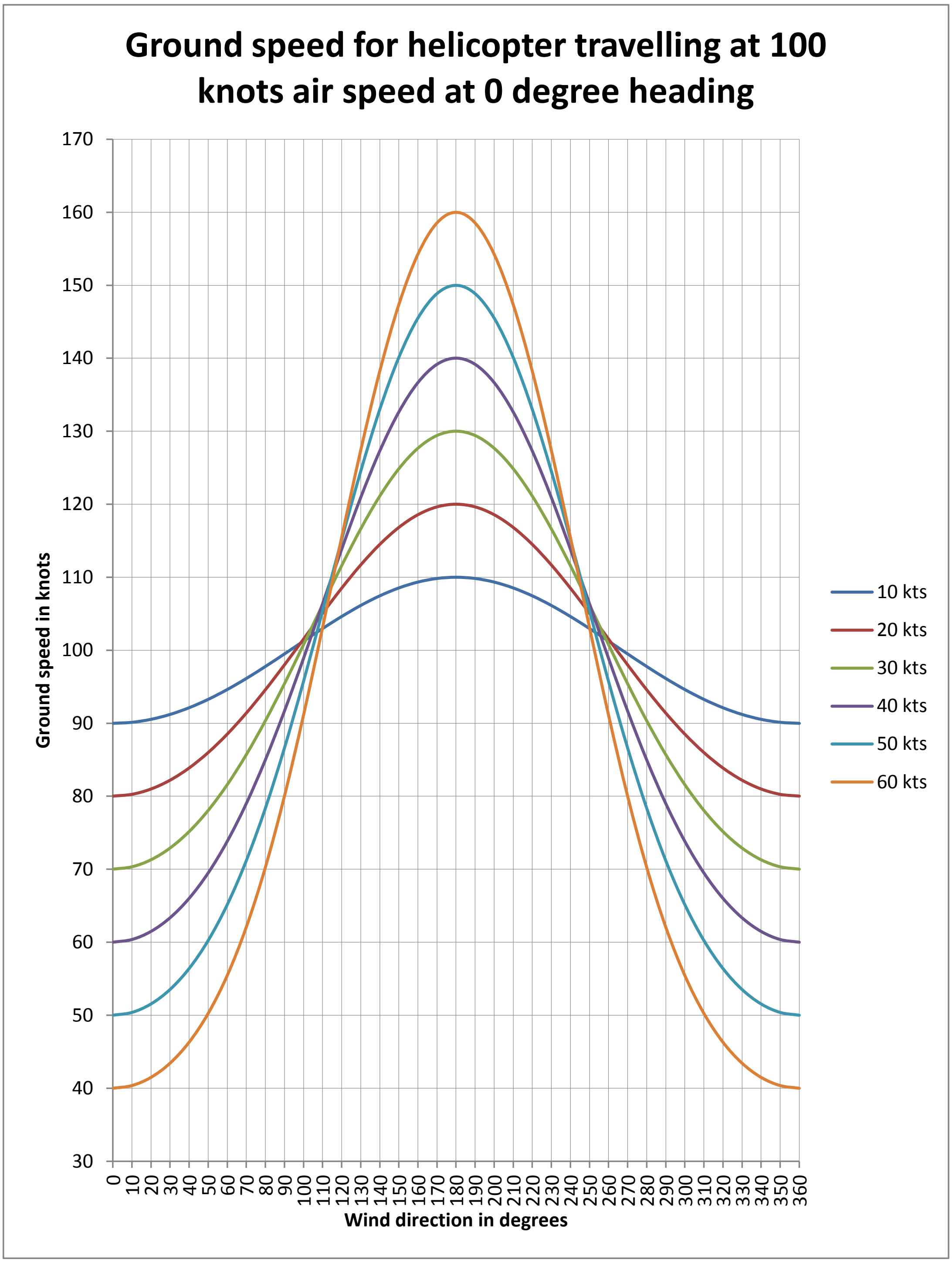
Value	Value	Value	Value	Value	Value
-129,999999	-139,999999	-149,999999	-159,999999	-169,999999	-179,999999
-2,26893	-2,44346	-2,61799	-2,79253	-2,96706	-3,14159
-0,30642	-0,25712	-0,20000	-0,13681	-0,06946	0,00000
-0,31143	-0,26004	-0,20136	-0,13724	-0,06952	0,00000
-17,84348	-14,89895	-11,53696	-7,86318	-3,98293	0,00000
327,84348	334,89895	341,53696	347,86318	353,98293	360,00000
5,72195	5,84509	5,96094	6,07136	6,17817	6,28319
69,48	**66,00**	**63,34**	**61,47**	**60,37**	**60,00**

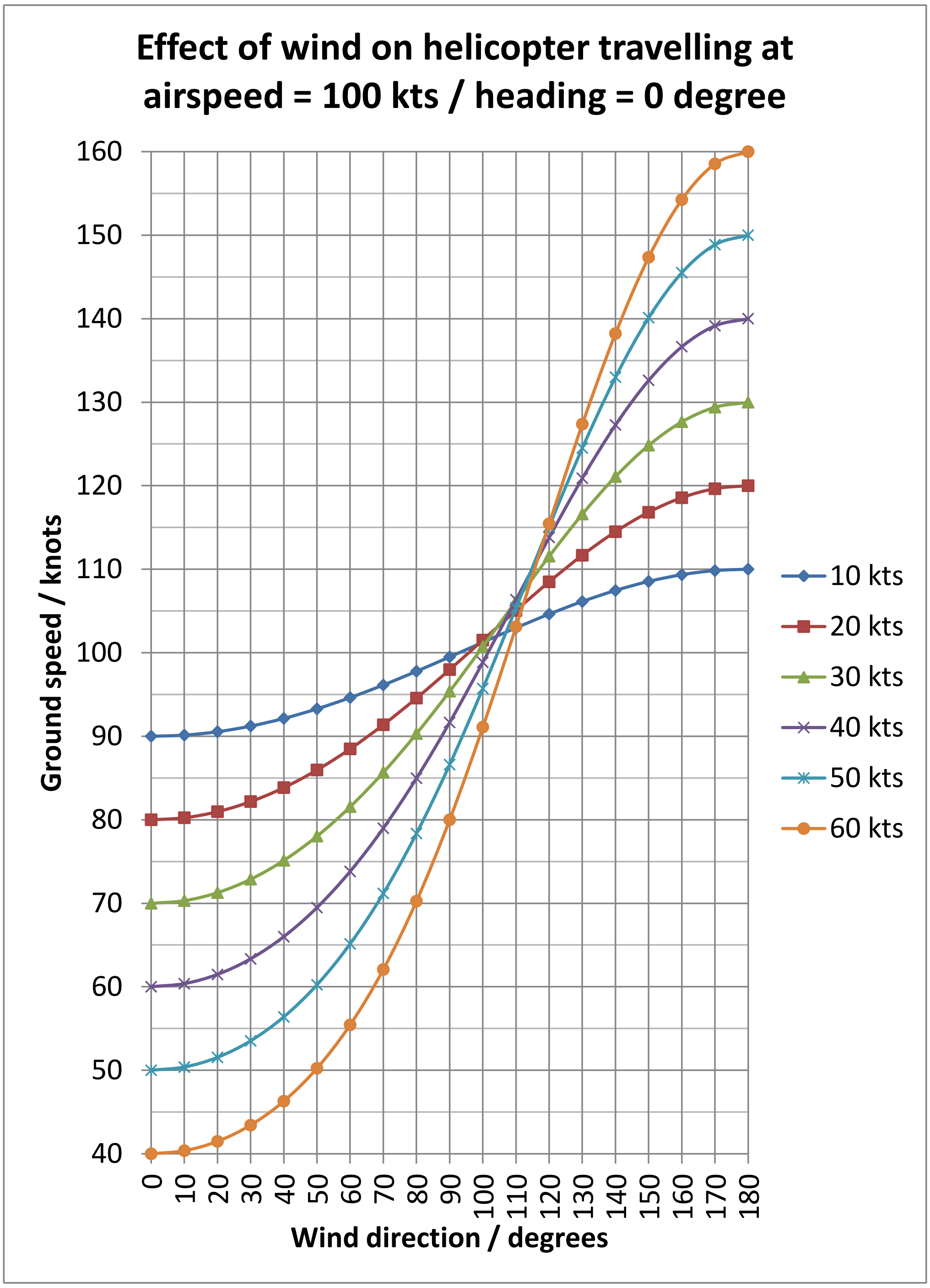
Value	Value	Value	Value	Value	Value
0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011
100	100	100	100	100	100
50	50	50	50	50	50
310	320	330	340	350	360

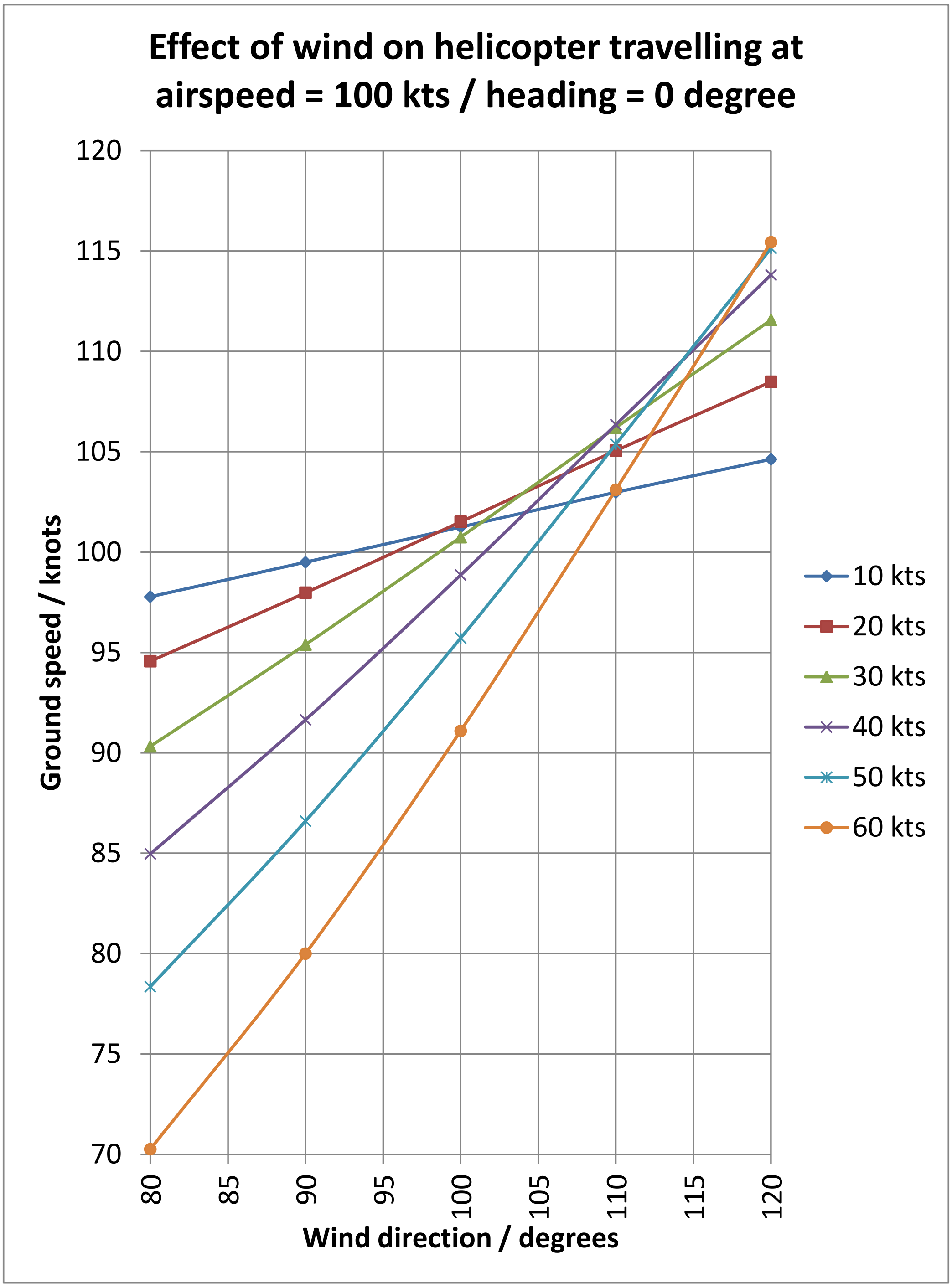
Value	Value	Value	Value	Value	Value
-129,999999	-139,999999	-149,999999	-159,999999	-169,999999	-179,999999
-2,26893	-2,44346	-2,61799	-2,79253	-2,96706	-3,14159
-0,38302	-0,32139	-0,25000	-0,17101	-0,08682	0,00000
-0,39307	-0,32720	-0,25268	-0,17185	-0,08693	0,00000
-22,52101	-18,74724	-14,47751	-9,84655	-4,98093	0,00000
332,52101	338,74724	344,47751	349,84655	354,98092	360,00000
5,80359	5,91225	6,01227	6,10597	6,19559	6,28319
60,23	**56,39**	**53,52**	**51,54**	**50,38**	**50,00**

Value	Value	Value	Value	Value	Value
0,0000011	0,0000011	0,0000011	0,0000011	0,0000011	0,0000011
100	100	100	100	100	100
60	60	60	60	60	60
310	320	330	340	350	360

Value	Value	Value	Value	Value	Value
-129,999999	-139,999999	-149,999999	-159,999999	-169,999999	-179,999999
-2,26893	-2,44346	-2,61799	-2,79253	-2,96706	-3,14159
-0,45963	-0,38567	-0,30000	-0,20521	-0,10419	0,00000
-0,47757	-0,39594	-0,30469	-0,20668	-0,10438	0,00000
-27,36302	-22,68550	-17,45760	-11,84192	-5,98044	0,00000
337,36302	342,68550	347,45760	351,84191	355,98044	360,00000
5,88810	5,98099	6,06428	6,14080	6,21303	6,28319
50,24	**46,30**	**43,43**	**41,49**	**40,37**	**40,00**


Ground speed for helicopter travelling at 100 knots air speed at 0 degree heading
Ground speed in knots
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360
Wind direction in degrees
10 kts
20 kts
30 kts
40 kts
50 kts
60 kts


Effect of wind on helicopter travelling at airspeed = 100 kts / heading = 0 degree
Ground speed / knots
160
150
140
130
120
110
100
90
80
70
60
50
40
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Wind direction / degrees
10 kts
20 kts
30 kts
40 kts
50 kts
60 kts


Effect of wind on helicopter travelling at airspeed = 100 kts / heading = 0 degree
Ground speed / knots
120
115
110
105
100
95
90
85
80
75
70
80
85
90
95
100
105
110
115
120
Wind direction / degrees
10 kts
20 kts
30 kts
40 kts
50 kts
60 kts

A.9 Calculation of helicopter round trip between Berlevåg and 74,5°N/37°E

Summary of caculation results

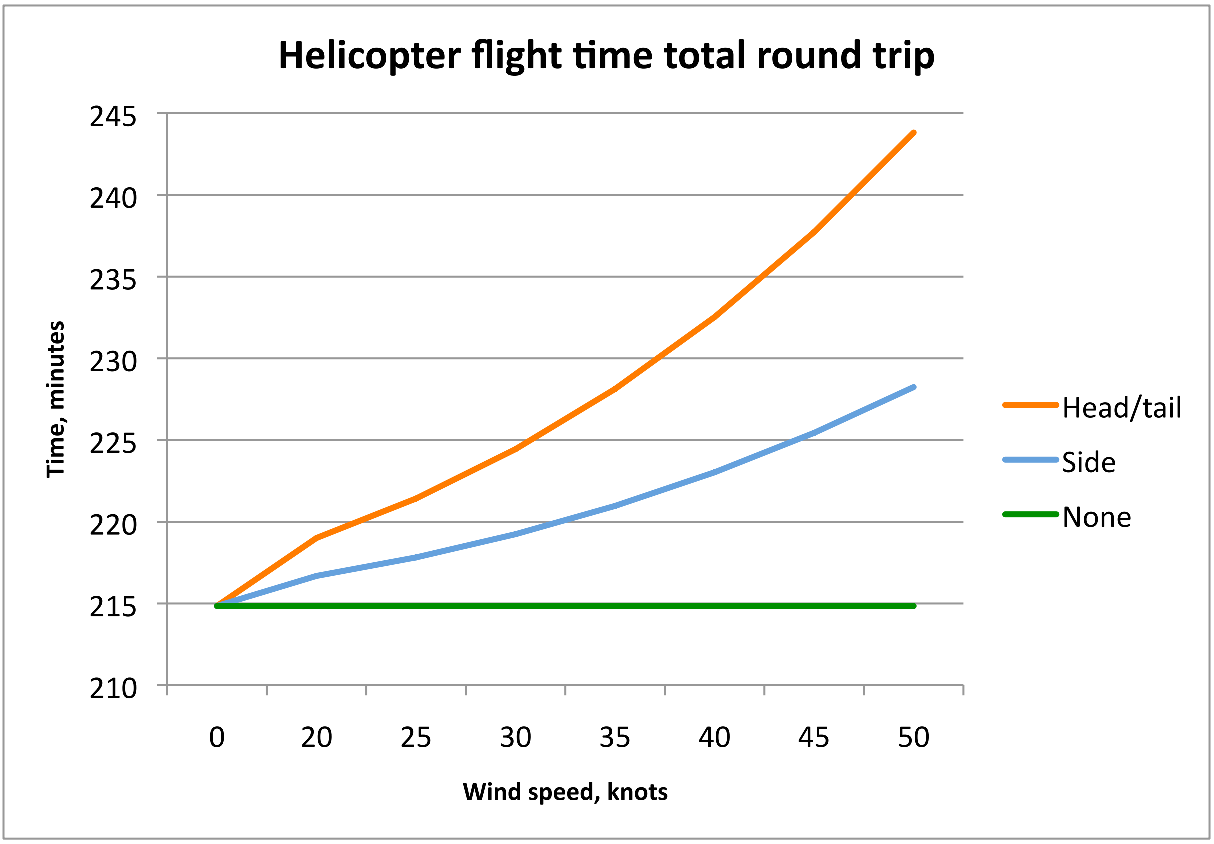
Wind speed	0	20	25	30	35	40	45	50	knots
Leg 1 T	55,6	64,5	67,2	70,1	73,3	76,8	80,6	84,9	minutes
Leg 2 T	51,8	60,1	62,6	65,3	68,3	71,5	75,1	79,1	minutes
Leg 3 T	51,8	45,5	44,2	42,9	41,7	40,6	39,5	38,5	minutes
Leg 4 T	55,6	48,9	47,4	46,1	44,8	43,6	42,4	41,4	minutes
Time	214,8	219,0	221,4	224,4	228,1	232,5	237,7	243,8	minutes

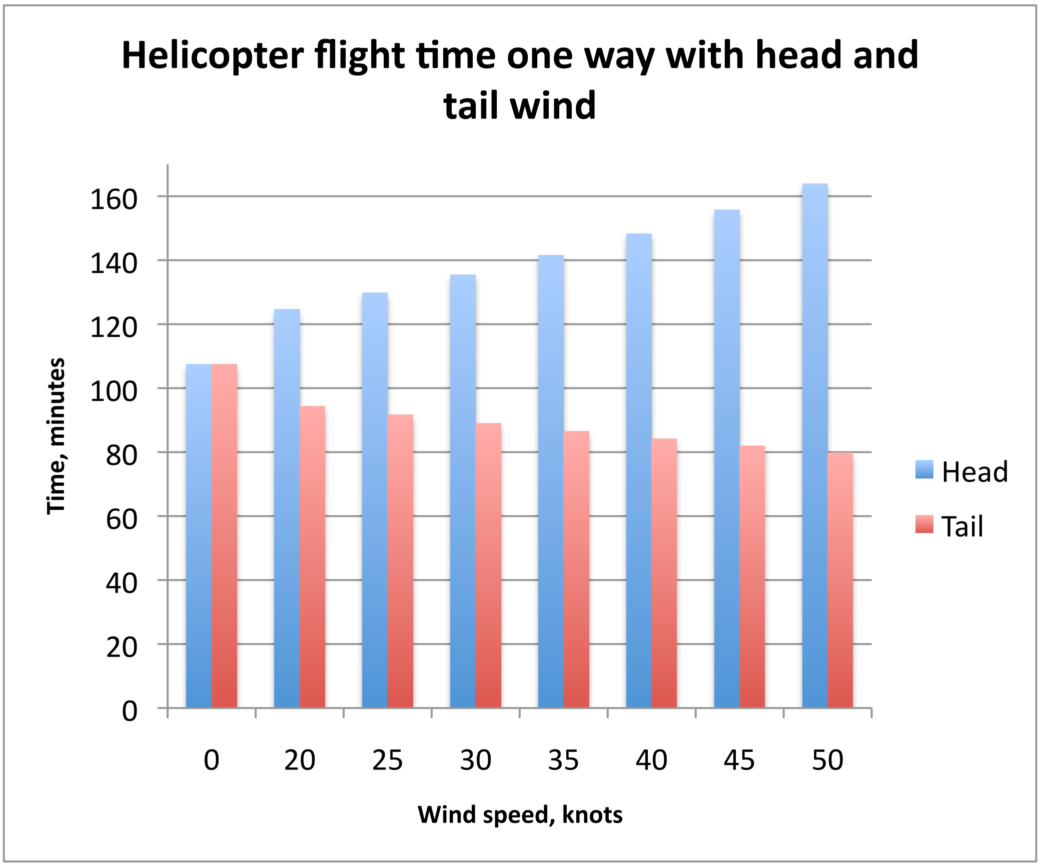
Wind speed	0	20	25	30	35	40	45	50	knots
Head	107	125	130	135	142	148	156	164	minutes
Tail	107	94	92	89	87	84	82	80	minutes

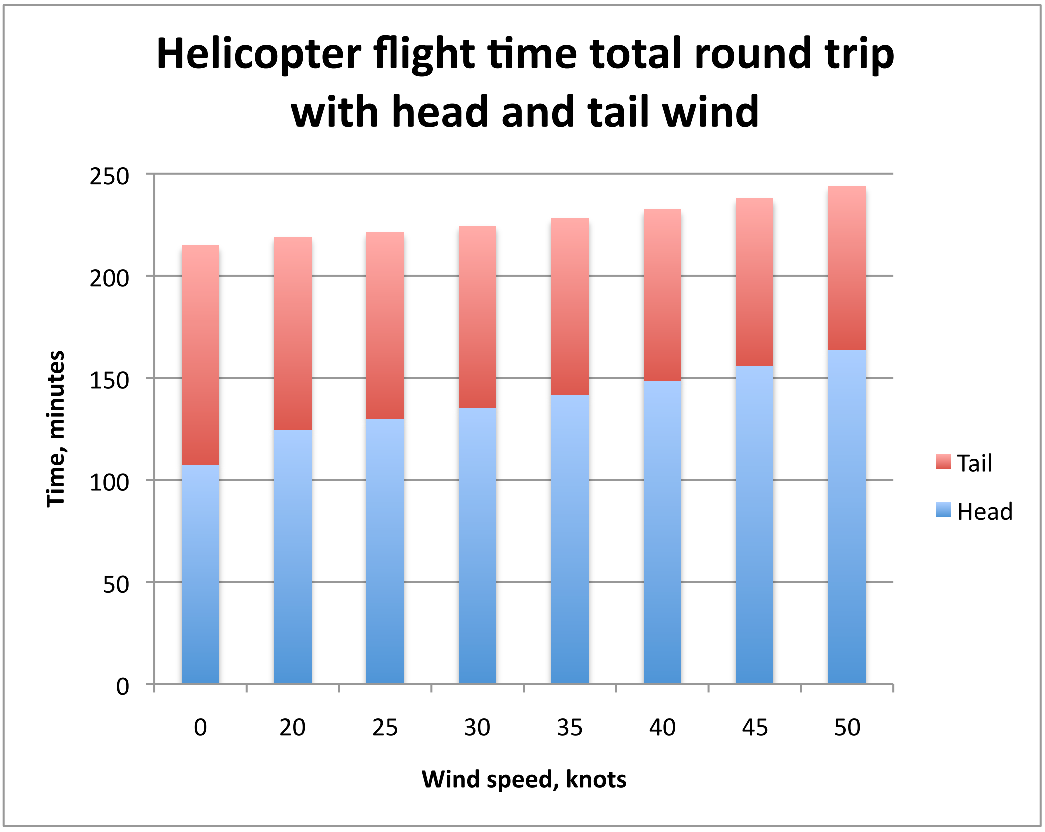
Wind speed	0	20	25	30	35	40	45	50	knots
Time	214,8	219,0	221,4	224,4	228,1	232,5	237,7	243,8	minutes
Delta time		4,2	6,6	9,6	13,3	17,7	22,9	29,0	minutes
			2,4	3,0	3,7	4,4	5,2	6,1	

Wind speed	0	20	25	30	35	40	45	50	knots
Head/tail	215	219	221	224	228	233	238	244	minutes
Side	215	217	218	219	221	223	225	228	minutes
None	215	215	215	215	215	215	215	215	minutes

Side wind situation calculated by adding 90 degrees to wind direction and recalculating




Helicopter flight time one way with head and tail wind
Time, minutes
160
140
120
100
80
60
40
20
0
0
20
25
30
35
40
45
50
Wind speed, knots
Head
Tail


Helicopter flight time total round trip with head and tail wind
Time, minutes
250
200
150
100
50
0
0
20
25
30
35
40
45
50
Wind speed, knots
Tail
Head

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

BVG - 7450370		
Cruising speed	145	
OUT	1000	
Leg 1		
Lat1/Long1	70,87	29,03
Lat2/Long2	72,79	32,75
Wind speed	20,00	
Wind directiection	33,00	
Initial heading	29,40	
Average heading for leg	31,20	
Time to fly	64,51	
Leg 2		
Lat2/Long2	72,79	32,75
Lat3/Long3	74,50	37,00
Wind speed	20,00	
Wind directiection	33,00	
Initial heading	32,93	
Average heading for leg	34,80	
Time to fly	60,09	
IN		
Leg 3		
Lat3/Long3	74,50	37,00
Lat2/Long2	72,79	32,75
Wind speed	20,00	
Wind directiection	33,00	
Initial heading	-142,99	
Average heading for leg	214,80	
Time to fly	45,53	
Leg 4		
Lat2/Long2	72,79	32,75
Lat1/Long1	70,87	29,03
Wind speed	20,00	
Wind directiection	33,00	
Initial heading	-147,08	
Average heading for leg	211,20	
Time to fly	48,87	

Round trip	WIND	mins	hours	NO WIND	Δ time
Leg 1	64,51			55,61	8,89
Leg 2	60,09	124,60	2,077	51,81	8,29
Leg 3	45,53			51,81	-6,28
Leg 4	48,87	94,41	1,573	55,61	-6,74
TOTAL	219,01	219,01	3,65	214,85	4,16

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 1				
Name				dec	radians
BVG	Lat1			70,8708	1,2369288
	Long1			29,0348	0,5067529
NR Border north	Lat2			72,788729	1,270403
	Long2			32,751556	0,5716225
Radius km	6371			y	0,0340559
Radius nm	3438			x	0,0191812
Lat1	1,2369288				
Long1	0,50675286				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	0,5129413
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**29,39**

Leg 1

Known variables	**Value**	**Units**		
Heading A to B (C:course)	31,20	deg		
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	20,00	knots		
Wind direction (Wd)	33,00	deg		

(No wind)

Calculated values	**Value**	**Units**	No wind	
Av:angle WS to GS	178,20000	deg		
Av:convert deg to radians	3,11018	rad		
sin(Aw)=sin(Av)*WS/TAS	0,00433			
Aw (arcsin of previous res	0,00433	rad		
Aw:wind corr angle	0,24824	deg		
Ac:angle WS to TAS	1,55176	deg		
Ac:convert deg to radians	0,02708	rad		
GS:ground speed(G)	**125,01**	**knots**	145,00	
Flying time outbound	64,50835	min	55,61444	8,89

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 2				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			74,50	1,3002703
	Long2			37,00	0,6457718
Radius km	6371			y	0,0305643
Radius nm	3438			x	0,0197974
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,30027029				
Long2	0,64577182				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	0,5747772
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**32,93**

Leg 2

Known variables	**Value**	**Units**		
Heading A to B (C:course)	34,80	deg	No wind	
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	20	knots		
Wind direction (Wd)	33	deg		

Calculated values	**Value**	**Units**		
Av:angle WS to GS	181,80000	deg		
Av:convert deg to radians	3,17301	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00433			
Aw (arcsin of previous res	-0,00433	rad		
Aw:wind corr angle	-0,24824	deg		
Ac:angle WS to TAS	-1,55176	deg		
Ac:convert deg to radians	-0,02708	rad		
GS:ground speed(G)	**125,01**	**knots**	145,00	
Flying time outbound	60,09420	min	51,80887	8,29

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 3				
Name				dec	radians
BVG	Lat1			74,50	1,3002703
	Long1			37,00	0,6457718
NR Border north	Lat2			72,79	1,270403
	Long2			32,75	0,5716225
Radius km	6371			y	-0,029079
Radius nm	3438			x	-0,02192
Lat1	1,30027029				
Long1	0,64577182				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	-2,495656
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**-142,99**

Leg 3

Known variables	**Value**	**Units**		
Heading A to B (C:course)	214,80	deg	No wind	
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	20	knots		
Wind direction (Wd)	33	deg		

Calculated values	**Value**	**Units**		
Av:angle WS to GS	361,80000	deg		
Av:convert deg to radians	6,31460	rad		
sin(Aw)=sin(Av)*WS/TAS	0,00433			
Aw (arcsin of previous res	0,00433	rad		
Aw:wind corr angle	0,24824	deg		
Ac:angle WS to TAS	-182,04824	deg		
Ac:convert deg to radians	-3,17734	rad		
GS:ground speed(G)	**164,99**	**knots**	145,00	
Flying time outbound	45,53211	min	51,80887	-6,28

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 4					
Name				dec		radians
BVG	Lat1				72,79	1,270403
	Long1				32,75	0,5716225
NR Border north	Lat2				70,87	1,2369288
	Long2				29,03	0,5067529
Radius km	6371			y		-0,03281
Radius nm	3438			x		-0,021243
Lat1	1,27040298					
Long1	0,57162248					
Lat2	1,2369288					
Long2	0,50675286					
		Error 0,:	+ 0.3%			
Distance km	249,046076	0,7471	249,8	bearing rad		-2,567006
Distance nm	**134,40**	0,4032	134,8	**bearing de**		**-147,08**

Leg 4

	Value	Units			
Heading A to B (C:course)	-147,08	deg		No wind	
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	20	knots			
Wind direction (Wd)	33	deg			

Calculated values	**Value**	**Units**		
Av:angle WS to GS	-0,07860	deg		
Av:convert deg to radians	-0,00137	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00019			
Aw (arcsin of previous res	-0,00019	rad		
Aw:wind corr angle	-0,01084	deg		
Ac:angle WS to TAS	180,08944	deg		
Ac:convert deg to radians	3,14315	rad		
GS:ground speed(G)	**165,00**	**knots**	145,00	
Flying time outbound	48,87330	min	55,61444	-6,74

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

BVG - 7450370					25 %
Cruising speed	145				
OUT	1000				
Leg 1					
Lat1/Long1	70,87	29,03			
Lat2/Long2	72,79	32,75			
Wind speed	25,00				
Wind directiection	33,00				
Initial heading	29,40				
Average heading for leg	31,20				
Time to fly	67,20				
Leg 2					
Lat2/Long2	72,79	32,75			
Lat3/Long3	74,50	37,00			
Wind speed	25,00				
Wind directiection	33,00				
Initial heading	32,93				
Average heading for leg	34,80				
Time to fly	62,60				
IN					
Leg 3					
Lat3/Long3	74,50	37,00			
Lat2/Long2	72,79	32,75			
Wind speed	25,00				
Wind directiection	33,00				
Initial heading	-142,99				
Average heading for leg	214,80				
Time to fly	44,19				
Leg 4					
Lat2/Long2	72,79	32,75			
Lat1/Long1	70,87	29,03			
Wind speed	25,00				
Wind directiection	33,00				
Initial heading	-147,08				
Average heading for leg	211,20				
Time to fly	47,44				
Round trip	WIND	mins	hours	NO WIND	
Leg 1	67,20			55,61	11,58
Leg 2	62,60	129,79	2,163	51,81	10,79
Leg 3	44,19			51,81	-7,62
Leg 4	47,44	91,63	1,527	55,61	-8,18
TOTAL	221,42	221,42	3,69	214,85	6,58

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 1				
Name				dec	radians
BVG	Lat1			70,8708	1,2369288
	Long1			29,0348	0,5067529
NR Border north	Lat2			72,788729	1,270403
	Long2			32,751556	0,5716225
Radius km	6371			y	0,0340559
Radius nm	3438			x	0,0191812
Lat1	1,2369288				
Long1	0,50675286				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	0,5129413
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**29,39**

Leg 1

Known variables	Value	Units			
Heading A to B (C:course)	31,20	deg		No wind	
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	25,00	knots			
Wind direction (Wd)	33,00	deg			

Calculated values	Value	Units			
Av:angle WS to GS	178,20000	deg			
Av:convert deg to radians	3,11018	rad			
sin(Aw)=sin(Av)*WS/TAS	0,00542				
Aw (arcsin of previous res	0,00542	rad			
Aw:wind corr angle	0,31030	deg			
Ac:angle WS to TAS	1,48970	deg			
Ac:convert deg to radians	0,02600	rad			
GS:ground speed(G)	**120,01**	**knots**		145,00	
Flying time outbound	67,19506	min		55,61444	11,58

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 2				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			74,50	1,3002703
	Long2			37,00	0,6457718
Radius km	6371			y	0,0305643
Radius nm	3438			x	0,0197974
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,30027029				
Long2	0,64577182				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	0,5747772
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**32,93**

Leg 2

Known variables	Value	Units		
Heading A to B (C:course)	34,80	deg	No wind	
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	25	knots		
Wind direction (Wd)	33	deg		

Calculated values	Value	Units		
Av:angle WS to GS	181,80000	deg		
Av:convert deg to radians	3,17301	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00542			
Aw (arcsin of previous res	-0,00542	rad		
Aw:wind corr angle	-0,31030	deg		
Ac:angle WS to TAS	-1,48970	deg		
Ac:convert deg to radians	-0,02600	rad		
GS:ground speed(G)	**120,01**	**knots**	145,00	
Flying time outbound	62,59706	min	51,80887	10,79

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 3					
Name				dec		radians
BVG	Lat1				74,50	1,3002703
	Long1				37,00	0,6457718
NR Border north	Lat2				72,79	1,270403
	Long2				32,75	0,5716225
Radius km	6371			y		-0,029079
Radius nm	3438			x		-0,02192
Lat1	1,30027029					
Long1	0,64577182					
Lat2	1,27040298					
Long2	0,57162248					
		Error 0,:	+ 0.3%			
Distance km	232,004443	0,696	232,7	bearing rad		-2,495656
Distance nm	**125,20**	0,3756	125,6	**bearing de**		**-142,99**

Leg 3

Known variables	**Value**	**Units**			
Heading A to B (C:course)	214,80	deg			
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	25	knots			
Wind direction (Wd)	33	deg			

No wind

Calculated values	**Value**	**Units**		
Av:angle WS to GS	361,80000	deg		
Av:convert deg to radians	6,31460	rad		
sin(Aw)=sin(Av)*WS/TAS	0,00542			
Aw (arcsin of previous res	0,00542	rad		
Aw:wind corr angle	0,31030	deg		
Ac:angle WS to TAS	-182,11030	deg		
Ac:convert deg to radians	-3,17842	rad		
GS:ground speed(G)	**169,99**	**knots**	145,00	
Flying time outbound	44,19368	min	51,80887	-7,62

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 4				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			70,87	1,2369288
	Long2			29,03	0,5067529
Radius km	6371			y	-0,03281
Radius nm	3438			x	-0,021243
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,2369288				
Long2	0,50675286				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	-2,567006
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**-147,08**

Leg 4

	Value	Units		
Heading A to B (C:course)	-147,08	deg	No wind	
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	25	knots		
Wind direction (Wd)	33	deg		
Calculated values	**Value**	**Units**		
Av:angle WS to GS	-0,07860	deg		
Av:convert deg to radians	-0,00137	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00024			
Aw (arcsin of previous res	-0,00024	rad		
Aw:wind corr angle	-0,01355	deg		
Ac:angle WS to TAS	180,09215	deg		
Ac:convert deg to radians	3,14320	rad		
GS:ground speed(G)	**170,00**	**knots**	145,00	
Flying time outbound	47,43585	min	55,61444	-8,18

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

BVG - 7450370						50 %
Cruising speed		145				
OUT		1000				
Leg 1						
Lat1/Long1		70,87	29,03			
Lat2/Long2		72,79	32,75			
Wind speed		30,00				
Wind directiection		33,00				
Initial heading		29,40				
Average heading for leg		31,20				
Time to fly		70,12				
Leg 2						
Lat2/Long2		72,79	32,75			
Lat3/Long3		74,50	37,00			
Wind speed		30,00				
Wind directiection		33,00				
Initial heading		32,93				
Average heading for leg		34,80				
Time to fly		65,32				
IN						
Leg 3						
Lat3/Long3		74,50	37,00			
Lat2/Long2		72,79	32,75			
Wind speed		30,00				
Wind directiection		33,00				
Initial heading		-142,99				
Average heading for leg		214,80				
Time to fly		42,93				
Leg 4						
Lat2/Long2		72,79	32,75			
Lat1/Long1		70,87	29,03			
Wind speed		30,00				
Wind directiection		33,00				
Initial heading		-147,08				
Average heading for leg		211,20				
Time to fly		46,08				
Round trip	WIND		mins	hours	NO WIND	Δ time
Leg 1		70,12			55,61	14,50
Leg 2		65,32	135,43	2,257	51,81	13,51
Leg 3		42,93			51,81	-8,88
Leg 4		46,08	89,01	1,484	55,61	-9,53
TOTAL		224,45	224,45	3,74	214,85	9,60

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 1					
Name				dec		radians
BVG	Lat1				70,8708	1,2369288
	Long1				29,0348	0,5067529
NR Border north	Lat2				72,788729	1,270403
	Long2				32,751556	0,5716225
Radius km	6371			y		0,0340559
Radius nm	3438			x		0,0191812
Lat1	1,2369288					
Long1	0,50675286					
Lat2	1,27040298					
Long2	0,57162248					
		Error 0,:	+ 0.3%			
Distance km	249,046076	0,7471	249,8	bearing rad		0,5129413
Distance nm	**134,40**	0,4032	134,8	**bearing de**		**29,39**

Leg 1

Known variables	**Value**	**Units**			
Heading A to B (C:course)	31,20	deg	No wind		
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	30,00	knots			
Wind direction (Wd)	33,00	deg			

Calculated values	**Value**	**Units**			
Av:angle WS to GS	178,20000	deg			
Av:convert deg to radians	3,11018	rad			
sin(Aw)=sin(Av)*WS/TAS	0,00650				
Aw (arcsin of previous res	0,00650	rad			
Aw:wind corr angle	0,37236	deg			
Ac:angle WS to TAS	1,42764	deg			
Ac:convert deg to radians	0,02492	rad			
GS:ground speed(G)	**115,01**	**knots**		145,00	
Flying time outbound	70,11539	min		55,61444	14,50

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 2				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			74,50	1,3002703
	Long2			37,00	0,6457718
Radius km	6371			y	0,0305643
Radius nm	3438			x	0,0197974
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,30027029				
Long2	0,64577182				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	0,5747772
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**32,93**

Leg 2

Known variables	**Value**	**Units**			
Heading A to B (C:course)	34,80	deg			
TAS:true air speed(V)	145	knots		No wind	
W:wind speed(WS)	30	knots			
Wind direction (Wd)	33	deg			

Calculated values	**Value**	**Units**		
Av:angle WS to GS	181,80000	deg		
Av:convert deg to radians	3,17301	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00650			
Aw (arcsin of previous res	-0,00650	rad		
Aw:wind corr angle	-0,37236	deg		
Ac:angle WS to TAS	-1,42764	deg		
Ac:convert deg to radians	-0,02492	rad		
GS:ground speed(G)	**115,01**	**knots**	145,00	
Flying time outbound	65,31756	min	51,80887	13,51

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 3				
Name				dec	radians
BVG	Lat1			74,50	1,3002703
	Long1			37,00	0,6457718
NR Border north	Lat2			72,79	1,270403
	Long2			32,75	0,5716225
Radius km	6371			y	-0,029079
Radius nm	3438			x	-0,02192
Lat1	1,30027029				
Long1	0,64577182				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	-2,495656
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**-142,99**

Leg 3

Known variables	**Value**	**Units**		
Heading A to B (C:course)	214,80	deg	No wind	
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	30	knots		
Wind direction (Wd)	33	deg		

Calculated values	**Value**	**Units**		
Av:angle WS to GS	361,80000	deg		
Av:convert deg to radians	6,31460	rad		
sin(Aw)=sin(Av)*WS/TAS	0,00650			
Aw (arcsin of previous res	0,00650	rad		
Aw:wind corr angle	0,37236	deg		
Ac:angle WS to TAS	-182,17236	deg		
Ac:convert deg to radians	-3,17951	rad		
GS:ground speed(G)	**174,98**	**knots**	145,00	
Flying time outbound	42,93173	min	51,80887	-8,88

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 4				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			70,87	1,2369288
	Long2			29,03	0,5067529
Radius km	6371			x	-0,03281
Radius nm	3438			y	-0,021243
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,2369288				
Long2	0,50675286				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	-2,567006
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**-147,08**

Leg 4

	Value	Units			
Heading A to B (C:course)	-147,08	deg	No wind		
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	30	knots			
Wind direction (Wd)	33	deg			

Calculated values	**Value**	**Units**		
Av:angle WS to GS	-0,07860	deg		
Av:convert deg to radians	-0,00137	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00028			
Aw (arcsin of previous res	-0,00028	rad		
Aw:wind corr angle	-0,01626	deg		
Ac:angle WS to TAS	180,09486	deg		
Ac:convert deg to radians	3,14325	rad		
GS:ground speed(G)	**175,00**	**knots**	145,00	
Flying time outbound	46,08054	min	55,61444	-9,53

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

BVG - 7450370						75 %
Cruising speed	145					
OUT	1000					
Leg 1						
Lat1/Long1	70,87	29,03				
Lat2/Long2	72,79	32,75				
Wind speed	35,00					
Wind directiection	33,00					
Initial heading	29,40					
Average heading for leg	31,20					
Time to fly	73,30					
Leg 2						
Lat2/Long2	72,79	32,75				
Lat3/Long3	74,50	37,00				
Wind speed	35,00					
Wind directiection	33,00					
Initial heading	32,93					
Average heading for leg	34,80					
Time to fly	68,29					
IN						
Leg 3						
Lat3/Long3	74,50	37,00				
Lat2/Long2	72,79	32,75				
Wind speed	35,00					
Wind directiection	33,00					
Initial heading	-142,99					
Average heading for leg	214,80					
Time to fly	41,74					
Leg 4						
Lat2/Long2	72,79	32,75				
Lat1/Long1	70,87	29,03				
Wind speed	35,00					
Wind directiection	33,00					
Initial heading	-147,08					
Average heading for leg	211,20					
Time to fly	44,80					
Round trip	WIND	mins	hours	NO WIND		Δ time
Leg 1	73,30			55,61		17,69
Leg 2	68,29	141,59	2,36	51,81		16,48
Leg 3	41,74			51,81		-10,07
Leg 4	44,80	86,54	1,442	55,61		-10,81
TOTAL	228,13	228,13	3,80	214,85		13,28

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 1				
Name				dec	radians
BVG	Lat1			70,8708	1,2369288
	Long1			29,0348	0,5067529
NR Border north	Lat2			72,788729	1,270403
	Long2			32,751556	0,5716225
Radius km	6371			y	0,0340559
Radius nm	3438			x	0,0191812
Lat1	1,2369288				
Long1	0,50675286				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	0,5129413
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**29,39**

Leg 1

Known variables	**Value**	**Units**		
Heading A to B (C:course)	31,20	deg	No wind	
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	35,00	knots		
Wind direction (Wd)	33,00	deg		

Calculated values	**Value**	**Units**		
Av:angle WS to GS	178,20000	deg		
Av:convert deg to radians	3,11018	rad		
sin(Aw)=sin(Av)*WS/TAS	0,00758			
Aw (arcsin of previous res	0,00758	rad		
Aw:wind corr angle	0,43442	deg		
Ac:angle WS to TAS	1,36558	deg		
Ac:convert deg to radians	0,02383	rad		
GS:ground speed(G)	**110,01**	**knots**	145,00	
Flying time outbound	73,30121	min	55,61444	17,69

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 2				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			74,50	1,3002703
	Long2			37,00	0,6457718
Radius km	6371			y	0,0305643
Radius nm	3438			x	0,0197974
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,30027029				
Long2	0,64577182				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	0,5747772
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**32,93**

Leg 2

Known variables	Value	Units			
Heading A to B (C:course)	34,80	deg			
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	35	knots			
Wind direction (Wd)	33	deg			

No wind

Calculated values	Value	Units		
Av:angle WS to GS	181,80000	deg		
Av:convert deg to radians	3,17301	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00758			
Aw (arcsin of previous res	-0,00758	rad		
Aw:wind corr angle	-0,43442	deg		
Ac:angle WS to TAS	-1,36558	deg		
Ac:convert deg to radians	-0,02383	rad		
GS:ground speed(G)	**110,01**	**knots**	145,00	
Flying time outbound	68,28538	min	51,80887	16,48

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 3				
Name				dec	radians
BVG	Lat1			74,50	1,3002703
	Long1			37,00	0,6457718
NR Border north	Lat2			72,79	1,270403
	Long2			32,75	0,5716225
Radius km	6371			y	-0,029079
Radius nm	3438			x	-0,02192
Lat1	1,30027029				
Long1	0,64577182				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	-2,495656
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**-142,99**

Leg 3

Known variables	Value	Units		
Heading A to B (C:course)	214,80	deg	No wind	
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	35	knots		
Wind direction (Wd)	33	deg		

Calculated values	Value	Units		
Av:angle WS to GS	361,80000	deg		
Av:convert deg to radians	6,31460	rad		
sin(Aw)=sin(Av)*WS/TAS	0,00758			
Aw (arcsin of previous res	0,00758	rad		
Aw:wind corr angle	0,43442	deg		
Ac:angle WS to TAS	-182,23442	deg		
Ac:convert deg to radians	-3,18059	rad		
GS:ground speed(G)	**179,98**	**knots**	145,00	
Flying time outbound	41,73990	min	51,80887	-10,07

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 4				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			70,87	1,2369288
	Long2			29,03	0,5067529
Radius km	6371			x	-0,03281
Radius nm	3438			y	-0,021243
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,2369288				
Long2	0,50675286				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	-2,567006
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**-147,08**

Leg 4

	Value	Units			
Heading A to B (C:course)	-147,08	deg			
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	35	knots			
Wind direction (Wd)	33	deg			

No wind

Calculated values	**Value**	**Units**		
Av:angle WS to GS	-0,07860	deg		
Av:convert deg to radians	-0,00137	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00033			
Aw (arcsin of previous res	-0,00033	rad		
Aw:wind corr angle	-0,01897	deg		
Ac:angle WS to TAS	180,09757	deg		
Ac:convert deg to radians	3,14330	rad		
GS:ground speed(G)	**180,00**	**knots**	145,00	
Flying time outbound	44,80053	min	55,61444	-10,81

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

BVG - 7450370						100 %
Cruising speed	145					
OUT	1000					
Leg 1						
Lat1/Long1	70,87	29,03				
Lat2/Long2	72,79	32,75				
Wind speed	40,00					
Wind directiection	33,00					
Initial heading	29,40					
Average heading for leg	31,20					
Time to fly	76,79					
Leg 2						
Lat2/Long2	72,79	32,75				
Lat3/Long3	74,50	37,00				
Wind speed	40,00					
Wind directiection	33,00					
Initial heading	32,93					
Average heading for leg	34,80					
Time to fly	71,54					
IN						
Leg 3						
Lat3/Long3	74,50	37,00				
Lat2/Long2	72,79	32,75				
Wind speed	40,00					
Wind directiection	33,00					
Initial heading	-142,99					
Average heading for leg	214,80					
Time to fly	40,61					
Leg 4						
Lat2/Long2	72,79	32,75				
Lat1/Long1	70,87	29,03				
Wind speed	40,00					
Wind directiection	33,00					
Initial heading	-147,08					
Average heading for leg	211,20					
Time to fly	43,59					
Round trip	WIND	mins	hours	NO WIND		
Leg 1	76,79				55,61	21,18
Leg 2	71,54	148,33	2,472		51,81	19,73
Leg 3	40,61				51,81	-11,20
Leg 4	43,59	84,20	1,403		55,61	-12,02
TOTAL	232,53	232,53	3,88		214,85	17,68

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 1				
Name				dec	radians
BVG	Lat1			70,8708	1,2369288
	Long1			29,0348	0,5067529
NR Border north	Lat2			72,788729	1,270403
	Long2			32,751556	0,5716225
Radius km	6371			y	0,0340559
Radius nm	3438			x	0,0191812
Lat1	1,2369288				
Long1	0,50675286				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	0,5129413
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**29,39**

Leg 1

Known variables	**Value**	**Units**		No wind	
Heading A to B (C:course)	31,20	deg			
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	40,00	knots			
Wind direction (Wd)	33,00	deg			

Calculated values	**Value**	**Units**			
Av:angle WS to GS	178,20000	deg			
Av:convert deg to radians	3,11018	rad			
sin(Aw)=sin(Av)*WS/TAS	0,00867				
Aw (arcsin of previous res	0,00867	rad			
Aw:wind corr angle	0,49648	deg			
Ac:angle WS to TAS	1,30352	deg			
Ac:convert deg to radians	0,02275	rad			
GS:ground speed(G)	**105,01**	**knots**		145,00	
Flying time outbound	76,79043	min		55,61444	21,18

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 2				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			74,50	1,3002703
	Long2			37,00	0,6457718
Radius km	6371			y	0,0305643
Radius nm	3438			x	0,0197974
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,30027029				
Long2	0,64577182				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	0,5747772
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**32,93**

Leg 2

Known variables	Value	Units			
Heading A to B (C:course)	34,80	deg		No wind	
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	40	knots			
Wind direction (Wd)	33	deg			

Calculated values	Value	Units		
Av:angle WS to GS	181,80000	deg		
Av:convert deg to radians	3,17301	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00867			
Aw (arcsin of previous res	-0,00867	rad		
Aw:wind corr angle	-0,49648	deg		
Ac:angle WS to TAS	-1,30352	deg		
Ac:convert deg to radians	-0,02275	rad		
GS:ground speed(G)	**105,01**	**knots**	145,00	
Flying time outbound	71,53585	min	51,80887	19,73

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 3				
Name				dec	radians
BVG	Lat1			74,50	1,3002703
	Long1			37,00	0,6457718
NR Border north	Lat2			72,79	1,270403
	Long2			32,75	0,5716225
Radius km	6371			y	-0,029079
Radius nm	3438			x	-0,02192
Lat1	1,30027029				
Long1	0,64577182				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	-2,495656
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**-142,99**

Leg 3

Known variables	Value	Units		
Heading A to B (C:course)	214,80	deg	No wind	
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	40	knots		
Wind direction (Wd)	33	deg		

Calculated values	Value	Units		
Av:angle WS to GS	361,80000	deg		
Av:convert deg to radians	6,31460	rad		
sin(Aw)=sin(Av)*WS/TAS	0,00867			
Aw (arcsin of previous res	0,00867	rad		
Aw:wind corr angle	0,49648	deg		
Ac:angle WS to TAS	-182,29648	deg		
Ac:convert deg to radians	-3,18167	rad		
GS:ground speed(G)	**184,97**	**knots**	145,00	
Flying time outbound	40,61248	min	51,80887	-11,20

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 4				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			70,87	1,2369288
	Long2			29,03	0,5067529
Radius km	6371			x	-0,03281
Radius nm	3438			y	-0,021243
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,2369288				
Long2	0,50675286				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	-2,567006
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**-147,08**

Leg 4

	Value	Units			
Heading A to B (C:course)	-147,08	deg			
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	40	knots			
Wind direction (Wd)	33	deg			

No wind

Calculated values	**Value**	**Units**		
Av:angle WS to GS	-0,07860	deg		
Av:convert deg to radians	-0,00137	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00038			
Aw (arcsin of previous res	-0,00038	rad		
Aw:wind corr angle	-0,02168	deg		
Ac:angle WS to TAS	180,10028	deg		
Ac:convert deg to radians	3,14334	rad		
GS:ground speed(G)	**185,00**	**knots**	145,00	
Flying time outbound	43,58970	min	55,61444	-12,02

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

BVG - 7450370					125 %
Cruising speed	145				
OUT	1000				
Leg 1					
Lat1/Long1	70,87	29,03			
Lat2/Long2	72,79	32,75			
Wind speed	45,00				
Wind directiection	33,00				
Initial heading	29,40				
Average heading for leg	31,20				
Time to fly	80,63				
Leg 2					
Lat2/Long2	72,79	32,75			
Lat3/Long3	74,50	37,00			
Wind speed	45,00				
Wind directiection	33,00				
Initial heading	32,93				
Average heading for leg	34,80				
Time to fly	75,11				
IN					
Leg 3					
Lat3/Long3	74,50	37,00			
Lat2/Long2	72,79	32,75			
Wind speed	45,00				
Wind directiection	33,00				
Initial heading	-142,99				
Average heading for leg	214,80				
Time to fly	39,54				
Leg 4					
Lat2/Long2	72,79	32,75			
Lat1/Long1	70,87	29,03			
Wind speed	45,00				
Wind directiection	33,00				
Initial heading	-147,08				
Average heading for leg	211,20				
Time to fly	42,44				

Round trip	WIND	mins	hours	NO WIND	Δ time
Leg 1	80,63			55,61	25,01
Leg 2	75,11	155,74	2,596	51,81	23,30
Leg 3	39,54			51,81	-12,26
Leg 4	42,44	81,99	1,366	55,61	-13,17
TOTAL	237,73	237,73	3,96	214,85	22,88

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 1				
Name				dec	radians
BVG	Lat1			70,8708	1,2369288
	Long1			29,0348	0,5067529
NR Border north	Lat2			72,788729	1,270403
	Long2			32,751556	0,5716225
Radius km	6371			y	0,0340559
Radius nm	3438			x	0,0191812
Lat1	1,2369288				
Long1	0,50675286				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	0,5129413
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**29,39**

Leg 1

Known variables	**Value**	**Units**			
Heading A to B (C:course)	31,20	deg		No wind	
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	45,00	knots			
Wind direction (Wd)	33,00	deg			

Calculated values	**Value**	**Units**		
Av:angle WS to GS	178,20000	deg		
Av:convert deg to radians	3,11018	rad		
sin(Aw)=sin(Av)*WS/TAS	0,00975			
Aw (arcsin of previous res	0,00975	rad		
Aw:wind corr angle	0,55854	deg		
Ac:angle WS to TAS	1,24146	deg		
Ac:convert deg to radians	0,02167	rad		
GS:ground speed(G)	**100,02**	**knots**	145,00	
Flying time outbound	80,62858	min	55,61444	25,01

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 2					
Name				dec		radians
BVG	Lat1				72,79	1,270403
	Long1				32,75	0,5716225
NR Border north	Lat2				74,50	1,3002703
	Long2				37,00	0,6457718
Radius km	6371			y		0,0305643
Radius nm	3438			x		0,0197974
Lat1	1,27040298					
Long1	0,57162248					
Lat2	1,30027029					
Long2	0,64577182					
		Error 0,:	+ 0.3%			
Distance km	232,004443	0,696	232,7	bearing rad		0,5747772
Distance nm	**125,20**	0,3756	125,6	**bearing de**		**32,93**

Leg 2

Known variables	**Value**	**Units**			
Heading A to B (C:course)	34,80	deg			
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	45	knots			
Wind direction (Wd)	33	deg			

No wind

Calculated values	**Value**	**Units**		
Av:angle WS to GS	181,80000	deg		
Av:convert deg to radians	3,17301	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00975			
Aw (arcsin of previous res	-0,00975	rad		
Aw:wind corr angle	-0,55854	deg		
Ac:angle WS to TAS	-1,24146	deg		
Ac:convert deg to radians	-0,02167	rad		
GS:ground speed(G)	**100,02**	**knots**	145,00	
Flying time outbound	75,11136	min	51,80887	23,30

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 3					
Name				dec		radians
BVG	Lat1				74,50	1,3002703
	Long1				37,00	0,6457718
NR Border north	Lat2				72,79	1,270403
	Long2				32,75	0,5716225
Radius km	6371			y		-0,029079
Radius nm	3438			x		-0,02192
Lat1	1,30027029					
Long1	0,64577182					
Lat2	1,27040298					
Long2	0,57162248					
		Error 0,:	+ 0.3%			
Distance km	232,004443	0,696	232,7	bearing rad		-2,495656
Distance nm	**125,20**	0,3756	125,6	**bearing de**		**-142,99**

Leg 3

Known variables	**Value**	**Units**		
Heading A to B (C:course)	214,80	deg	No wind	
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	45	knots		
Wind direction (Wd)	33	deg		

Calculated values	**Value**	**Units**		
Av:angle WS to GS	361,80000	deg		
Av:convert deg to radians	6,31460	rad		
sin(Aw)=sin(Av)*WS/TAS	0,00975			
Aw (arcsin of previous res	0,00975	rad		
Aw:wind corr angle	0,55854	deg		
Ac:angle WS to TAS	-182,35854	deg		
Ac:convert deg to radians	-3,18276	rad		
GS:ground speed(G)	**189,97**	**knots**	145,00	
Flying time outbound	39,54440	min	51,80887	-12,26

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 4				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			70,87	1,2369288
	Long2			29,03	0,5067529
Radius km	6371			y	-0,03281
Radius nm	3438			x	-0,021243
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,2369288				
Long2	0,50675286				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	-2,567006
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**-147,08**

Leg 4

	Value	Units			
Heading A to B (C:course)	-147,08	deg		No wind	
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	45	knots			
Wind direction (Wd)	33	deg			

Calculated values	**Value**	**Units**		
Av:angle WS to GS	-0,07860	deg		
Av:convert deg to radians	-0,00137	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00043			
Aw (arcsin of previous res	-0,00043	rad		
Aw:wind corr angle	-0,02439	deg		
Ac:angle WS to TAS	180,10299	deg		
Ac:convert deg to radians	3,14339	rad		
GS:ground speed(G)	**190,00**	**knots**	145,00	
Flying time outbound	42,44261	min	55,61444	-13,17

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

BVG - 7450370						150 %
Cruising speed	145					
OUT	1000					
Leg 1						
Lat1/Long1	70,87	29,03				
Lat2/Long2	72,79	32,75				
Wind speed	50,00					
Wind directiection	33,00					
Initial heading	29,40					
Average heading for leg	31,20					
Time to fly	84,87					
Leg 2						
Lat2/Long2	72,79	32,75				
Lat3/Long3	74,50	37,00				
Wind speed	50,00					
Wind directiection	33,00					
Initial heading	32,93					
Average heading for leg	34,80					
Time to fly	79,06					
IN						
Leg 3						
Lat3/Long3	74,50	37,00				
Lat2/Long2	72,79	32,75				
Wind speed	50,00					
Wind directiection	33,00					
Initial heading	-142,99					
Average heading for leg	214,80					
Time to fly	38,53					
Leg 4						
Lat2/Long2	72,79	32,75				
Lat1/Long1	70,87	29,03				
Wind speed	50,00					
Wind directiection	33,00					
Initial heading	-147,08					
Average heading for leg	211,20					
Time to fly	41,35					

Round trip	WIND	mins	hours	NO WIND	Δ time
Leg 1	84,87			55,61	29,26
Leg 2	79,06	163,93	2,732	51,81	27,25
Leg 3	38,53			51,81	-13,28
Leg 4	41,35	79,89	1,331	55,61	-14,26
TOTAL	243,82	243,82	4,06	214,85	28,97

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 1				
Name				dec	radians
BVG	Lat1			70,8708	1,2369288
	Long1			29,0348	0,5067529
NR Border north	Lat2			72,788729	1,270403
	Long2			32,751556	0,5716225
Radius km	6371			y	0,0340559
Radius nm	3438			x	0,0191812
Lat1	1,2369288				
Long1	0,50675286				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	0,5129413
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**29,39**

Leg 1

Known variables	**Value**	**Units**		No wind	
Heading A to B (C:course)	31,20	deg			
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	50,00	knots			
Wind direction (Wd)	33,00	deg			

Calculated values	**Value**	**Units**			
Av:angle WS to GS	178,20000	deg			
Av:convert deg to radians	3,11018	rad			
sin(Aw)=sin(Av)*WS/TAS	0,01083				
Aw (arcsin of previous res	0,01083	rad			
Aw:wind corr angle	0,62060	deg			
Ac:angle WS to TAS	1,17940	deg			
Ac:convert deg to radians	0,02058	rad			
GS:ground speed(G)	**95,02**	**knots**		145,00	
Flying time outbound	84,87075	min		55,61444	29,26

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 2				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			74,50	1,3002703
	Long2			37,00	0,6457718
Radius km	6371			y	0,0305643
Radius nm	3438			x	0,0197974
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,30027029				
Long2	0,64577182				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	0,5747772
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**32,93**

Leg 2

Known variables	Value	Units			
Heading A to B (C:course)	34,80	deg			
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	50	knots		No wind	
Wind direction (Wd)	33	deg			

Calculated values	Value	Units		
Av:angle WS to GS	181,80000	deg		
Av:convert deg to radians	3,17301	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,01083			
Aw (arcsin of previous res	-0,01083	rad		
Aw:wind corr angle	-0,62060	deg		
Ac:angle WS to TAS	-1,17940	deg		
Ac:convert deg to radians	-0,02058	rad		
GS:ground speed(G)	**95,02**	**knots**	145,00	
Flying time outbound	79,06324	min	51,80887	27,25

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 3				
Name				dec	radians
BVG	Lat1			74,50	1,3002703
	Long1			37,00	0,6457718
NR Border north	Lat2			72,79	1,270403
	Long2			32,75	0,5716225
Radius km	6371			y	-0,029079
Radius nm	3438			x	-0,02192
Lat1	1,30027029				
Long1	0,64577182				
Lat2	1,27040298				
Long2	0,57162248				
		Error 0,:	+ 0.3%		
Distance km	232,004443	0,696	232,7	bearing rad	-2,495656
Distance nm	**125,20**	0,3756	125,6	**bearing de**	**-142,99**

Leg 3

Known variables	**Value**	**Units**			
Heading A to B (C:course)	214,80	deg	No wind		
TAS:true air speed(V)	145	knots			
W:wind speed(WS)	50	knots			
Wind direction (Wd)	33	deg			

Calculated values	**Value**	**Units**		
Av:angle WS to GS	361,80000	deg		
Av:convert deg to radians	6,31460	rad		
sin(Aw)=sin(Av)*WS/TAS	0,01083			
Aw (arcsin of previous res	0,01083	rad		
Aw:wind corr angle	0,62060	deg		
Ac:angle WS to TAS	-182,42060	deg		
Ac:convert deg to radians	-3,18384	rad		
GS:ground speed(G)	**194,97**	**knots**	145,00	
Flying time outbound	38,53110	min	51,80887	-13,28

Calculations of head/tail wind situation for all four legs of the round trip
Berlevåg to 74,5°N/37°E

Haversine formula	Leg 4				
Name				dec	radians
BVG	Lat1			72,79	1,270403
	Long1			32,75	0,5716225
NR Border north	Lat2			70,87	1,2369288
	Long2			29,03	0,5067529
Radius km	6371			y	-0,03281
Radius nm	3438			x	-0,021243
Lat1	1,27040298				
Long1	0,57162248				
Lat2	1,2369288				
Long2	0,50675286				
		Error 0,:	+ 0.3%		
Distance km	249,046076	0,7471	249,8	bearing rad	-2,567006
Distance nm	**134,40**	0,4032	134,8	**bearing de**	**-147,08**

Leg 4

	Value	**Units**		
			No wind	
Heading A to B (C:course)	-147,08	deg		
TAS:true air speed(V)	145	knots		
W:wind speed(WS)	50	knots		
Wind direction (Wd)	33	deg		

Calculated values	**Value**	**Units**		
Av:angle WS to GS	-0,07860	deg		
Av:convert deg to radians	-0,00137	rad		
sin(Aw)=sin(Av)*WS/TAS	-0,00047			
Aw (arcsin of previous res	-0,00047	rad		
Aw:wind corr angle	-0,02710	deg		
Ac:angle WS to TAS	180,10570	deg		
Ac:convert deg to radians	3,14344	rad		
GS:ground speed(G)	**195,00**	**knots**	145,00	
Flying time outbound	41,35434	min	55,61444	-14,26