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Operations and Maintenance of Oil and Gas platforms under Arctic conditions

Master thesis

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Abstract

In the Master thesis presented here, operations and maintenance challenges for offshore oil & gas (O&G) industry in Arctic regions shall be discussed.

As oil prices remain on a high level Arctic oil and gas becomes more interesting. The higher price level allows for development of fields in this challenging remote environment. Understanding the environmental conditions is the key for successful projects. As there is still a lack of experience with equipment in these regions, maintenance of offshore oil and gas platforms will face many challenges. The cold and harsh climate, the remoteness, the poorly developed infrastructure and many other factors require new designs with optimal performance for these conditions.

In the first part of this thesis, a general overview of the Arctic development shall be given. This part is followed by a discussion about challenges that developments will face in the Arctic will be discussed. Here especially the cold weather influence, remoteness and other factors are discussed in depth. In the third main part, maintenance of equipment shall be discussed under an Arctic perspective. Emphasis will be put on the selection of an appropriate maintenance strategy, the design for human factors/ ergonomics and the design for performance and availability. In the last part, the Goliat offshore platform will be presented as an industry example. Some of the winterization measures will be discussed.

Keywords: Operations, Maintenance, Arctic, Cold Climate, Goliat offshore platform

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List of abbreviations

CBM	Condition Based Maintenance
FPSO	Floating Production Storage and Offloading
GPS	Global Positioning System
JRCC	Joint Rescue Coordination Center
MTTF	Mean Time To Failure
MTBF	Mean Time Between Failure
O&G	Oil & Gas
RAMS	Reliability, Availability, Maintainability, Supportability

Prologue and acknowledgments

This thesis is submitted for the fulfillment of the Master degree in Offshore Technology with specialization in Industrial Asset Management at the University of Stavanger.

"For the oil and gas industry, the Arctic is without doubt the next frontier." states the Scandinavian Oil and Gas magazine (2012, p. 5). It is a fact that with the rising demand for energy in the world, developments in the Arctic regions are increasingly important. It is assumed that up to 30% of the world's undiscovered natural gas and 13% of world's undiscovered oil (Ole Anders, 2011) can be found in this region. With the recent increase in the oil price, Arctic energy resources have become economically more interesting. This has lead to a bigger interest in the Arctic region. The obvious reasons that these energy sources haven't been explored yet are due to the environmental factors. Harsh climate with very cold temperatures and sea ice, fast changing weather situations, the remote location, a sensitive ecosystem and high cost are major factors that need to be considered during activities in this region.

I would like to express my sincere gratitude to Professor Tore Markeset from the University of Stavanger for supervising my Thesis. I appreciated very much his thoughts and comments as well as his personal support whenever questions arouse.

Further, I would like to thank Ove Tobias Gudmestad, Professor at the University of Stavanger. Mr. Gudmestad has supported me by allowing me to use some of his course material regarding the Arctic. I further had the chance to visit his course Arctic technology at the University of Stavanger. This has helped me to understand the complexity and importance of the subject.

I would like to thank Mr. Per Inge Leiros and Mr. Ole Rekdal from Eni Norge, for supporting me with a chapter about the offshore project Goliat in the Norwegian Barents Sea.

Finally, I would like to thank Megan Rolerkite for her assistance with proof reading and checking of consistency in the text.

1 Introduction

In the following section a short introduction to the problem will be given. Further the goals and delimitations of the thesis will be described.

1.1 Problem statement

The remote location of the Arctic development and the special environment creates major challenges for the Arctic oil and gas industry/ development. Especially maintenance and operational tasks will need proper planning so they can be performed in the most efficient and safest way.

Operations in the Arctic are creating enormous challenges for the oil and gas industry. In Norway, this environment can be found in the Barents Sea. The following figure separates the Barents Sea into different zones with and without surface icing.

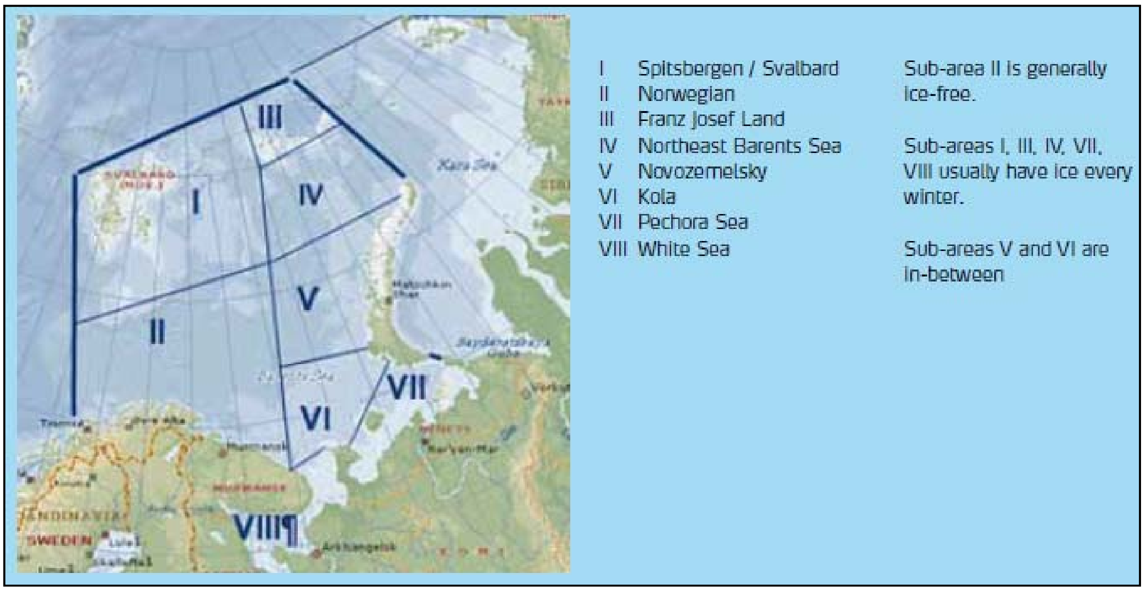

Figure 1: Different environmental regions in the Norwegian Barents Sea (modified, original by Det Norske Veritas (2010))

New methods and old methods have to be evaluated to face these challenges. The harsh environment creates the need for special logistic and maintenance strategies that can overcome the problems.

Further, the nature has to be considered. This region is very sensitive, and special measures must be taken to protect it successfully.

The following three main questions shall be discussed in the thesis:

- What is the theoretical background of oil and gas in cold regions?
- What are critical factors concerning the operation and maintenance in Arctic environment?
- How to implement reliability and maintenance in the Arctic environment?

1.2 Goal of the thesis

The goal is to present methods how to approach the platforms operation and maintenance activities in the Barents Sea. Main activities include literature research and discussions regarding how oil and gas platforms can be operated and maintained under Arctic conditions.

As a result this paper can be used for further studies concerning Arctic environments.

1.2.1 Sub goals

In the following the sub goals of the thesis shall be stated. The sub goals shall be individually discussed and researched in the chapters of this thesis.

- Describe the relevant basics
- Discuss some ongoing projects in the industry that are relevant
- Discuss the impact of the environment such as temperature, ice and icing and other
- Discuss challenges reading communication and navigation in the Arctic
- Discuss use of different materials in the Arctic environment
- Discussion of operation requirements with emphasis on the Arctic environment
- Discuss what considerations must be taken related to the logistics
- Introduction of the concept of reliability and maintenance
- Discussion of different maintenance strategies
- Define requirements for the design emphasizing on human factors/ ergonomics
- Define methods to achieve high production assurance
- Describe an industry example of a winterized platform

1.3 Delimitations

The following report will focus on operations and maintenance of offshore installations in Arctic regions. In specific the Norwegian Barents Sea and challenges related to this region shall be discussed. The difference of the Norwegian Barents Sea to other regions is that there is much less sea ice due to the impact of the warm Gulf Stream currents. Thus, the impact of sea ice on e.g. logistics of the offshore platform will not be discussed in depth.

2 Theoretical background

In the following section the background for the thesis shall be described. Short descriptions of current offshore oil and gas development in cold environments will be given. In the following the definition of the “Arctic” and “cold climate regions” are stated. Finally the terms “operations” and “maintenance” are shortly defined.

2.1 Oil and gas development in cold environments

First oil and gas reserves in cold climates have been discovered about a century ago. One of them was the Norman Wells in northern Canada 1920 (ExxonMobil, 2013). Most of the current developments in the Arctic are dependent of a high oil and gas price to make the financial investments worthwhile. This is e.g. due to the higher costs involved with transportation of the crude but also because of the harsh and difficult environment.

2.1.1 Current projects

Ongoing projects such as production and exploration in cold regions can be found in many different areas. Russia, the USA and Canada have been the biggest players in recent years (Lloyd’s Maritime Academy Seminar, 2009). Norway is currently entering this run for the arctic resources. There is a big importance on current projects. According to Budzik (2009) these fields have the capability to create a spinoff development for other smaller known fields in the region. These fields are becoming financially interesting as bigger fields are developed and produced.

Current projects for exploration and production are:

- Canada/ Alaska Beaufort Sea
- Alaska Chukchi Sea
- Russia
    - Barents Sea (Stockman)
    - Kara Sea (Yamal)
    - Chukchi Sea
    - Sakhalin Island
- Norway
    - Western Barents Sea with Snohvit, Goliat and Johan Castberg (former called Skrugard-Havis)

The Norwegian reserves in the North Sea have decreased, so new projects have been started in the Norwegian Barents Sea.

In the following a short overview will be given of selected projects to present the current status of the development with the regional focus being put on the Norwegian Barents Sea. Figure 2 on page 12 gives an overview of the location of the fields Snøhvit, Johan Castberg and Goliat. In the following Snøhvit and Johan Castberg will be presented. The filed Goliat will be discussed in chapter 5 on page 53 in more detail.

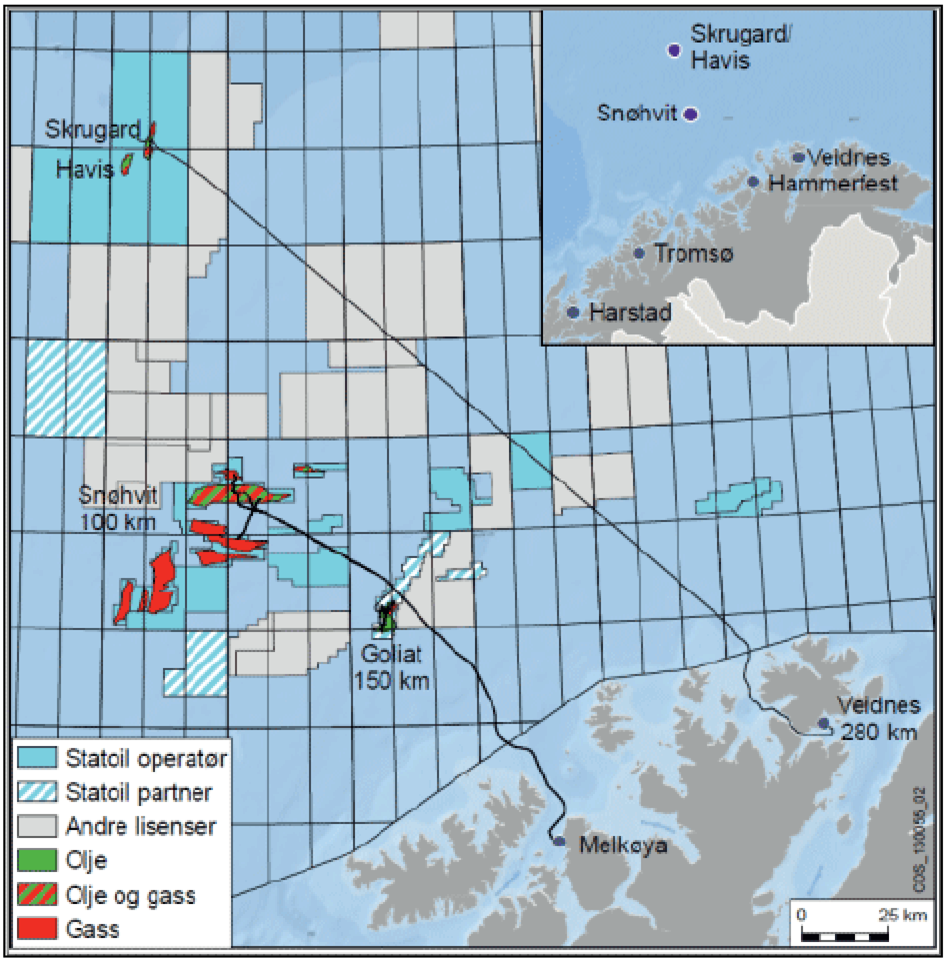

Figure 2: Overview of fields, pipelines and onshore treatment facilities in the Barents Sea (Statoil, 2013)

2.1.1.1 Snøhvit

The following section is based on information from Statoil (2012), Net Resources International (2012) and the conference paper by Engebretsen et al.(2002).

The Snøhvit project is the first realized gas offshore development in the Barents Sea. The reserves are estimated to be 190 billion cubic meters of natural gas and 18 million cubic meters of condensate. The major shareholders are Statoil, Petoro, Total E&P Norge and GDF Suez E&P.

One major difference compared to many other projects in the world is that this field has been realized with only subsea installations at a depth of 300 m. Therefore subsea templates have been installed. The product (gas) is transported via a 143 km long pipeline towards the shore. There the gas is liquefied in an LNG plant on the Island Melkøya. This is the very first LNG plant in Europe and the world's most northern plant of its kind. The liquefied gas is exported by LNG carriers to Europe and the USA. To reduce the impact on the environment, produced CO2 is spereated in the plant at Melkøya and then reinjected. This will improve the CO2 balance.

This is the first offshore project and a major investment in the region Finnmark. The impact on the city ,Hammerfest, has been intense. The LNG plan has created many jobs and has in general a very big impact on local economy and population (Engebretsen, et al., 2002).

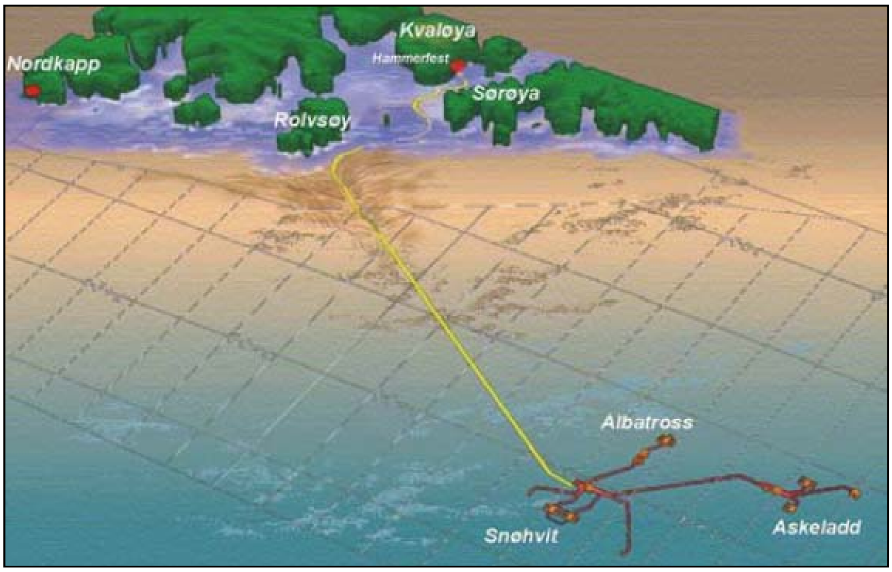

Figure 3: The Snøhvit project (Engebretsen, et al., 2002)

2.1.1.2 Johan Castberg (Skrugard-Havis)

The following section is based on information's from Statoil (2012), Statoil (2013) and an article from the online page of Offshore (2013).

Johan Castberg is a new discovery in the middle of the Norwegian Barents Sea. The field has just recently been renamed from Skrugard-Havis to Johan Castberg. Statoil, Eni Norge As and Petoro AS are together involved in the discovery which has an estimated volume of 200 to 300 million barrels of oil equivalents. The filed lies 100 km north of the Snøhvit-field.

It is planned that production will start in 2018. The field will be developed with a semi-submersible platform. Using a 280 km long pipeline the oil will be sent to a terminal at Veidnes in northern Norway. There the oil will be stored in caves that will be built into the rock. Tankers will be loaded with the oil from the storage caves in the safety of the harbor. The oil can then be shipped to the marked. This type of storage allows overcoming periods in which production must be stopped to various reasons such as maintenance and bad weather. Further the storage possibility gives room for undiscovered offshore fields in the region by using the same infrastructure and storage capacity.

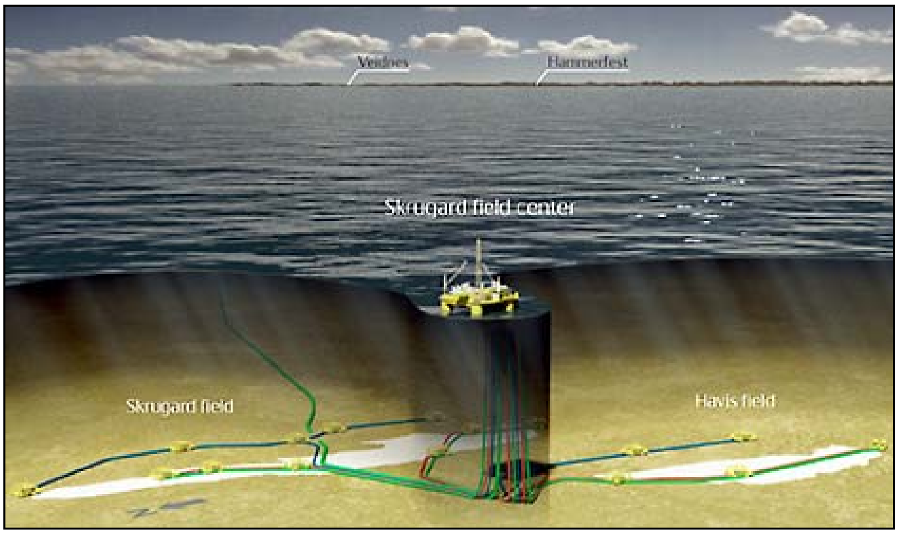

Figure 4: Concept for development of the Johan Castberg field (Statoil, 2013)

2.1.2 Expected reserves of the Arctic

The Arctic has a large energy potential. According to Budzik (2009, p. 3) large new discoveries are crucial for the future development of the Arctic region. Once larger fields have been developed it becomes economically interesting to develop smaller fields which are in the vicinity of the larger findings. The reason is that often infrastructure that is necessary to develop a field is simply too expensive, making the smaller fields uneconomical. For example Budzik (2009, p. 9) states that onshore projects on the Alaska North Slope can have a 1.5 to 2.0 higher capital cost then similar projects in Texas.

Most of the known fields (approximately 61 large fields are known in October 2009 (Budzik, 2009, p. 4)) are located in Russia. An extensive analysis of the “Energy potential of the Russian Arctic Seas” can be found in the book of Piskarev & Shkatov (2012). They point out that the Barents and Kara Sea seems to be especially promising (2012, pp. 55 - 56).

In the following different graphs will be presented to highlight the energy potential of the Arctic Ocean and the distribution of the predicted resources.

Figure 5: Different potential basins (Belonin & Grigorenko, 2007)

As it can be seen in Figure 5 the highest potential basins are:

- Norwegian Barents Sea
- Barents- Kara Sea
- The South Kara Sea
- The North Alaska Slope

The biggest extend of high potential basins lies in the Russian sector.

The following two maps will give an overview of estimated oil and gas reserves above the Arctic Circle.

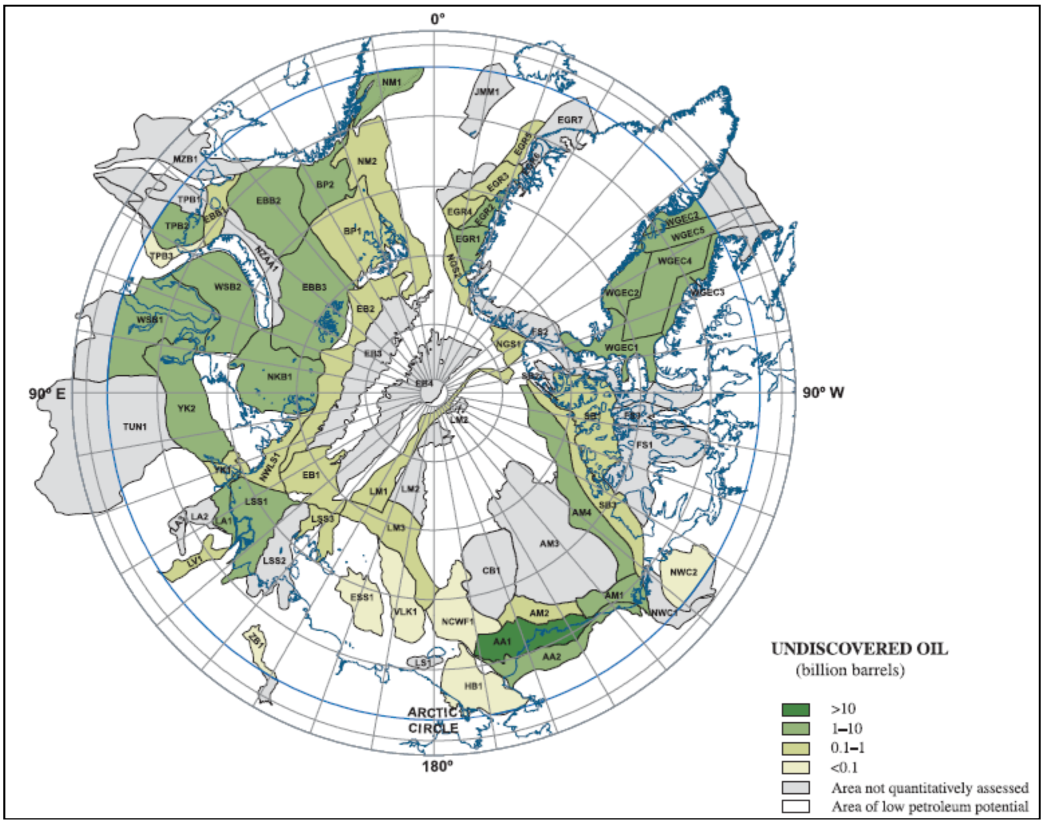

Figure 6: Undiscovered Oil reserves in Arctic regions (Gautier, 2009)

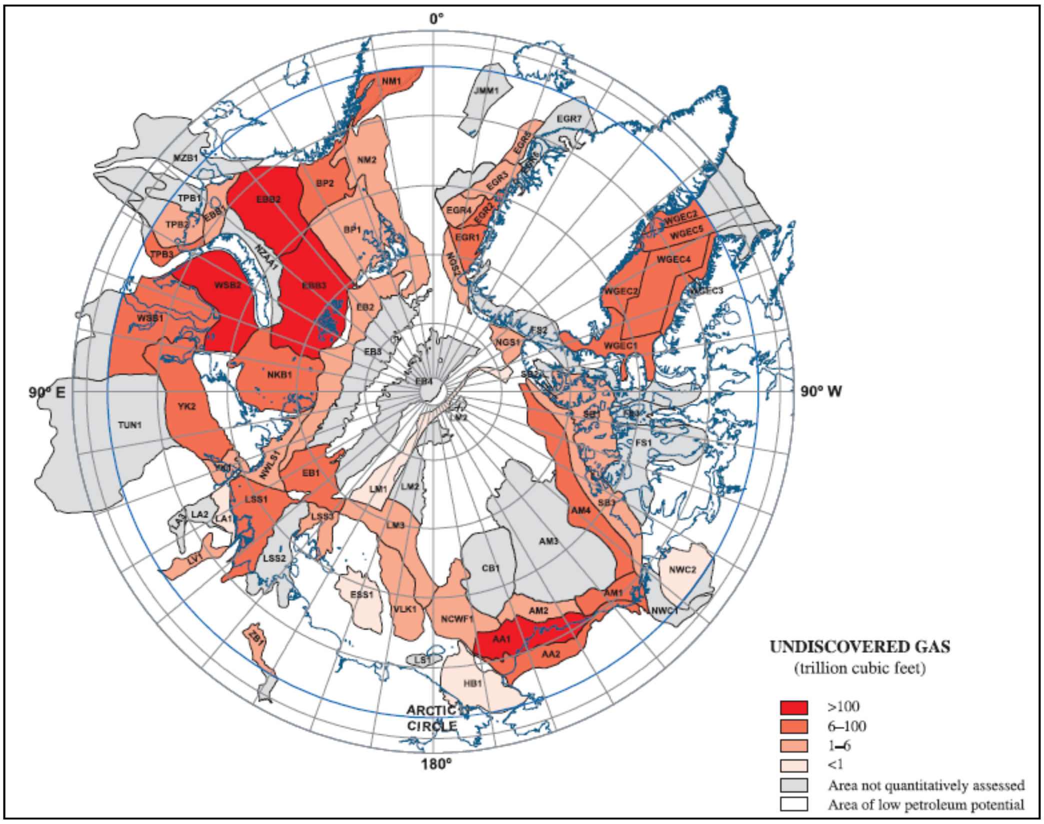

Figure 7: Undiscovered Gas reserves in Arctic regions (Gautier, 2009)

In both figures Norway can be found between 90°E and 0°. According to Gautier (Gautier, 2009) the potential for large gas reserves is higher than for large oil reserves in the Norwegian Barents. As exploration is still in the beginning in the Arctic, positive and/or negative corrections of the estimates are probable.

2.2 Arctic location and cold climate

2.2.1 Arctic

The following section is based on information's provided by the report of Budzik (2009).

The Arctic has been defined as the area north of the Arctic Circle. The Arctic Circle defines the line where sunlight or darkness can be present for 24 or more hours. This line is at 66.56° north latitude. This area represents approximately 6% of the entire earth surface.

As it can be seen in Figure 8 the Arctic is mainly covered by water. Only one-third is covered by land.

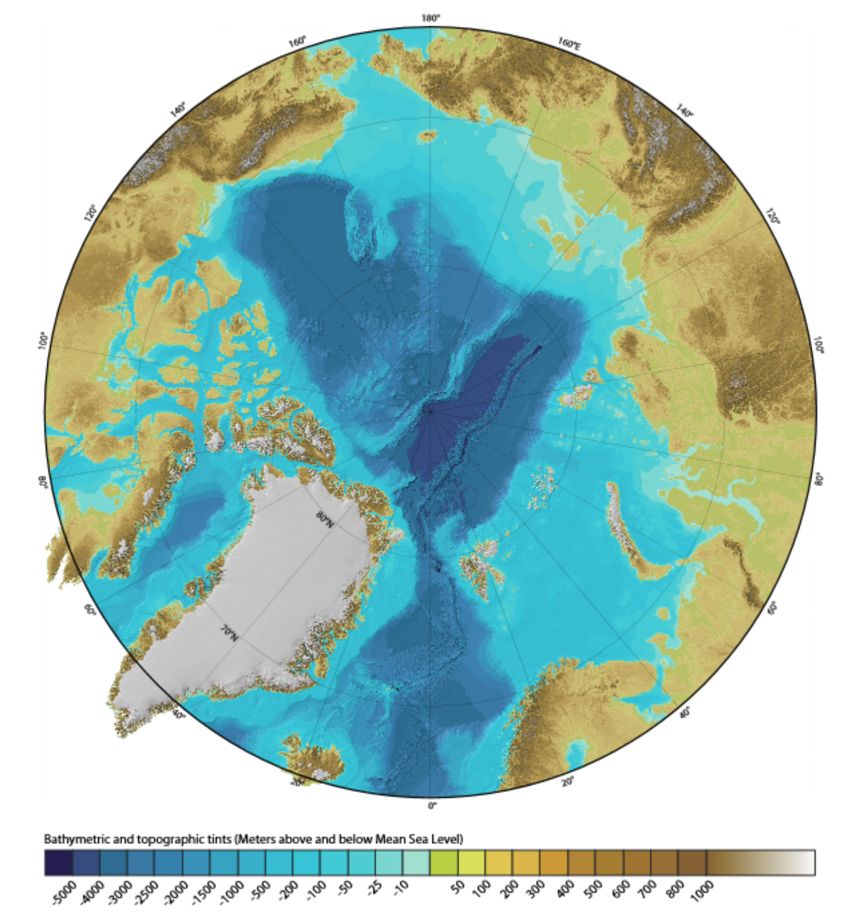

Figure 8: Arctic Ocean (National Geophysical Data Center, 2012)

According to Budzik (2009) the Arctic could hold up to 22% of all conventional oil and gas reserves on the planet.

A distinguishing characteristic of the Arctic is the permanent pack ice as shown in the next figure.

Figure 9: Arctic with approximate permanent pack ice (LLOYD'S, 2005, p. 14)

The ices surrounding the pack ice varies by season. Due to global warming ice is melting in this region. The impact of this development is still under research.

There are eight countries bordering the Arctic. These countries are (see also Figure 9):

- Russia
- United States of America
- Canada
- Greenland which belongs to Denmark
- Norway
- Iceland

- Finland and Sweden who do not have jurisdictional claims in the Arctic Ocean

As mentioned previously the Arctic experiences long periods without sunlight. This leads to a very cold climate with the main temperatures often being below freezing point. Further this allows the buildup of the permanent pack ice in the center of the Arctic Ocean. Due to the climate, there is only a small amount of vegetation and other living organisms onshore. This is one of the reasons why settlements are rather limited. Because of the development of the energy potential of the Arctic, the human population in the Arctic will increase (Budzik, 2009).

Although Antarctica is believed to be energy rich as well, the Antarctic Treaty prohibits any activity in the region (The Secretariat of the Antarctic Treaty, 2011).

2.2.2 Cold climate

Arctic environments can not only be found above the Arctic circles but also in other geographic regions. There are different criteria on how to define cold climate regions. Freitag & McFadden (1997, p. 2) point out that each scientific discipline usually develops the most suitable definition. This can be e.g. the tree growing line, the average below 10°C line (10°C isotherm) or regions with permafrost in the ground. A distinguishing factor for the Arctic is the lack of sunlight for more than a 24 hours period.

The northern Caspian Sea is a good example for a cold climate region. Many factors in this region are the same as in Arctic environments during the winter months. Very low temperatures and wind chill effects can be observed. Even sea ice is possible and often observed on the northern Caspian Sea. In this case the environment can be described as “cold climate”.

2.3 Operations and maintenance

In the following sections the terms operations and maintenance shall be shortly described. At a later stage of this thesis operations and maintenance will be discussed more in depth.

2.3.1 Operations

Operations are actions required to control, and if necessary correct system functions to achieve optimal performance. This in turn will lead to the lowest running cost (Investopedia US, 2013). On offshore platforms many different operations are necessary to achieve optimal performance.

Typical activities that can be considered part of operations include (Driscoll & Kucik, 2011, p. 69):

- The operation of the system to satisfy the user needs
- Reduce risk by monitoring and measuring system parameters
- Identify improvement potential
- Sustain the level of performance using maintenance

These actions are necessary since the surrounding environment of the systems often constantly changes. Operations are thus necessary to adapt to the changes. Operations in Arctic environments will be further discussed at a later stage in this Thesis.

2.3.2 Maintenance

“Due to cost and technological considerations, it is difficult to design a system that doesn’t degrade or fail.” (Kayrbekova, et al., 2011, p. 122). After a system starts operations, its performance usually will gradually starts to degrade (Driscoll & Kucik, 2011, p. 65). Therefore systems need maintenance to achieve their optimal performance over long periods of time.

Maintenance is further necessary to compensate for unreliability (Markeset, 2012), the probability that a component will fail during use. Maintenance is thus an action that will improve the state of a system or component of a system. It can therefore be stated that maintenance is a part of the operations. There are different types of maintenance which will be further discussed in depth at a later stage in this thesis.

3 Critical factors for operation and maintenance in the Barents Sea

Arctic projects will have high demands on the design of systems. Further, there is a need for good organizational bases. In the following chapter critical factors that arise due to the Arctic conditions will be discussed.

The main source of information is the book “Introduction to Cold Region Engineering” by Freitag & McFadden (1997).

3.1 Overview

The following table will name the main critical factors and their sub factors that apply for operations and maintenance in Arctic regions.

Table 1: Critical factors overview

Factor	Sub factors
Environment	• Temperature • Snow • Ice and icing • Wind • Polar lows • Weather forecast • Visibility • Sensitive environment
Communication and Navigation	• Communication means • Navigation means
Materials and lubrication oils	• Materials • Lubrication oils
Operations	• Human factors • Winterization
Logistics	• Remoteness • Infrastructure • Inbound and outbound logistics • Storage of spare parts and supplies

The listed factors in Table 1 will be discussed in the following chapters. The used information source will be noted at the beginning of each chapter.

3.2 Environmental challenges

In the following chapter challenges related to the environment will be discussed. Especially the cold temperatures and the unstable weather conditions create a very demanding environment.

3.2.1 Temperature

The maximum average air temperatures in the Arctic is +4,4 °C (range +2,0 to +7,0) while the minimum average air temperature is -7,7°C (range -6,0 to -9,0°C) (Jacobsen & Gudmestad, 2012). However, the coldest temperatures can reach up to -30°C or -40°C (Larsen, 2007).

The temperature of the Arctic is a key challenge. The Arctic is a region where very cold temperatures can be reached. Most of the oil and gas projects have taken place in rather moderate temperatures such as the North Sea. Most of the designs of systems and the organization of operations have been adapted to these temperatures. Thus the Temperature of the environment is important as it effects how well particular operations can be performed in the Barents Sea. Humans, systems and materials are strongly affected by cold temperatures.

The effects of the cold in the different circumstances will be discussed in the following chapters.

3.2.2 Snow

Snow forms when water vapor condenses and freezes on very small particles. These particles occur as dust in high altitudes. Often snow clouds form clouds. After snow has formed it will fall to the ground where it either stays or melts away.

If snow has fallen and stays on the ground it will form ice grains that grow due to freezing of water vapor to their surface (Freitag & McFadden, 1997, p. 503). Thus over time the density of the fallen snow increases. Additional snow might fall and pile up on top, further increasing the density due to the load.

Snow can have impact on offshore facilities. However the biggest impact can be seen for onshore facilities. Snow can make maintenance tasks difficult as it blocks access to equipment (Larsen, 2007, p. 13). Further, snowdrift can create very large pileups of snow with considerably high weight. Thus supporting structures must be able to carry the weight of snow if piled up. Snow pileup is very important when onshore facilities are planned. If not considered properly high loads can result due to snow pileup. Therefore snow removal could be required (Ryerson, 2008, p. 12). Freitag & McFadden (1997, p. 508) suggest that the snow conditions at a possible site should be monitored at least for one winter before the site is selected. This process should also include possible land transportation routes as snow might block these. For further information reference is made to Freitag & McFadden (1997).

Especially small openings must be protected so that snow cannot enter. If this is not done properly, snow will pile up inside the volume with the opening. Since the snow might melt or freeze in the opening, further problems can occur (e.g. electrical short circuit due to melting water).

Other negative impacts of snow are that if falling heavily it can block the vision of aircraft pilots, crane operators or ship captains (Freitag & McFadden, 1997, p. 505). The phenomenon is called “whiteout” and creates an all white vision (Gerwick, 2007, p.

755). Good weather forecasts and technical systems are necessary to overcome the challenge of low visibility in snow.

3.2.3 Ice and icing

Ice is created when water temperatures fall below the freezing point. The freezing point for fresh water is 0.0°C while sea water is freezing at about -1.9°C depending on its salt content (National Oceanic and Atmospheric Administration, 2013). Ice is a challenge in many ways for offshore installations and supply operations.

3.2.3.1 Sea ice and icebergs

Sea ice is one of the most distinguishing features of the Arctic. The Arctic Ocean in its center is covered by a permanent pack ice layer. The diameter of this ice layer is approximately 1500 km and has an average thickness of four meters (Gerwick, 2007, p. 752). At the outer edge of the pack ice icebergs can be found.

The pack ice is surrounded by seasonal changing ice features. Most of the current potential offshore fields are in the shear zone where seasonally different sea ice states govern (Gerwick, 2007, p. 754). The following table lists these states according to their period

Table 2: Seasonal ice development in Arctic waters (Gerwick, 2007, p. 754)

Time period	Conditions
November – May	Winter ice conditions with very thick and large ice rafts containing multi and first year ice. The movement of the ice is rather slow and directed by wind and currents.
May – July	Spring breakup of the ice. As the first year ice melts the movement of the ice becomes more dynamic.
July – September	Only multiyear ice rafts and icebergs might occur. As the sea is free of ice high waves and strong storms can occur.
September – November	Slowly ice is developing. Multiyear ice, ice rafts and Iceberg will eventually freeze together.

Main effects of the sea ice are very high loads on vessels and fixed structures. To prevent problems with sea ice and icebergs active ice management can be necessary. Ice management can include towing of icebergs, use of an icebreaker and other measures such as e.g. use of ice detection, ice forecasting and ice tracking (International Standard Organisation ISO, 2010, pp. 109 - 110).

This thesis is not covering sea ice and icebergs in depth. Therefore reference is made to “Engineering Aspects to Arctic Offshore Developments” by Gudmestad, et al (2007) and “Actions from ice on Arctic Offshore and Costal Structures” by Løset et al. (2006).

3.2.3.2 Icing

When a ship hits waves or when water splash is carried by wind, it can accumulate on the surface of structures. Temperatures must be freezing for this to occur. When icing on structures occurs large additional loads will be created that can be a challenge for the stability of vessels or the load bearing system. Further falling ice can pose a threat to personnel on board. In Figure 10 the result of strong icing is shown.

Figure 10: Icing on a vessel (Gudmestad, 2012)

As it can be seen in the above figure a large ice crust has accumulated. The effect on the accessibility of equipment is obvious. The effect of icing on a vessel is further illustrated in the next figure. The same principle can be applied to other structure in or close to open waters.

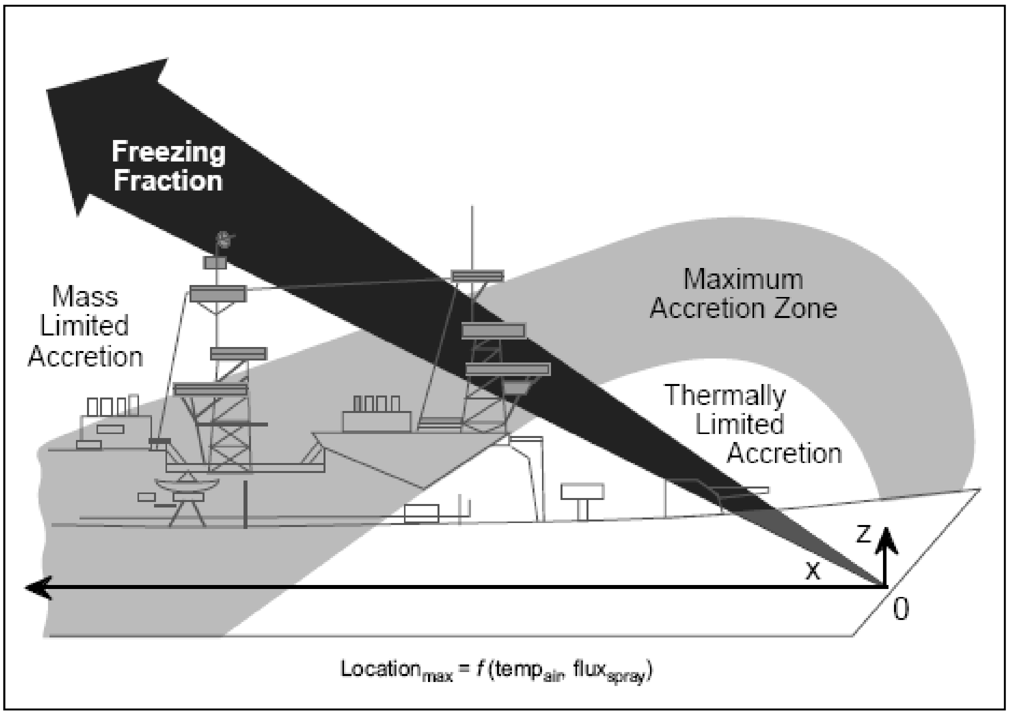

Figure 11: Vessel icing process (Ryerson & Gow, 2000, p. 2)

The water splash needs to be in the air for a certain time period to cool down sufficiently. Due to this fact, icing will occur mainly in the area behind the bow. Equipment such as antennas and masts should especially be protected against icing. The effect of vessel icing can also be seen on land. If splash is generated because of waves hitting the shoreline, icing on onshore structures can occur.

For vessels the loads from icing can have tremendous effects on the floating stability. Due to the high topside weight the center of gravity will rise and the vessel will become instable and capsize. Further the local stresses can rise above the design criterion which in turn leads to damage of the structure (Gerwick, 2007, p. 755).

The following table gives an overview of how sea spray icing is calculated. Further the table gives a prediction what increase of the ice strength can be expected.

Table 3: Prediction of vessel sea spray icing (after Overland (1990)

$$PPR = \frac{V_a(T_f - T_a)}{1 + 0.3(T_w - T_f)}$$

PPR = Icing Predictor (m^oCs^{-1})
V_a = Wind Speed ($m\ s^{-1}$)
T_f = Freezing point of seawater (usually -1.7 °C or -1.8 °C)
T_a = Air Temperature (°C)
T_w = Sea Temperature (°C)

PPR	< 0	0 – 22.4	22.4 – 53.3	53.3 – 83.0	> 83.0
Class	None	Light	Moderate	Heavy	Extreme
Rate (cm/h)	0	< 0.7	0.7 – 2.0	2.0 – 4.0	> 4.0

Icing will make maintenance tasks very difficult. Openings might not be accessible and must be cleaned from the ice with wooden baseball bats. Optionally, heating of critical openings or equipment that will not withstand the impact of the baseball bat might be necessary to ensure access.

3.2.4 Wind

Wind should be considered as a challenge by considering two major aspects.

The first point is the environment that wind is creating. The strongest winds occur in cold regions (Freitag & McFadden, 1997, p. 30). These high wind speeds make operations difficult because e.g. waves are created. Crane handling of different equipment can be impossible if the wind speed is too high or when the generated waves are too large. This effect is currently increased as the sea ice cover is melting the fetch length for the wind becomes larger. This will most probably result in even bigger waves and should be considered in the planning of supply operations for offshore platforms. Wind is also the major factor for sea spray icing on structures with higher waves and strong winds increasing sea spray icing (see section 3.2.3 Ice and icing).

The second important aspect of wind and cold is the wind chill effect. The heat loss of an exposed surface will increase if wind blows. On the one hand this can be desirable if cooling is necessary. On the other hand it can be highly undesirable if e.g. the working conditions are considered. The next table shows a wind chill chart.

Table 4: Wind chill chart (Canadian Centre for Occupational Health & Safety, 2008)

WIND CHILL CHART

		Ambient Temperature (∞C)								
		4	-1	-7	-12	-18	-23	-29	-34	-40
Wind km/h	Velocity mph	Equivalent Chill Temperature (∞C)								
Calm 0	0	4	-1	-7	-12	-18	-23	-29	-34	-40
8	5	3	-3	-9	-14	-21	-26	-32	-38	-44
16	10	-2	-9	-16	-23	-30	-35	-43	-50	-57
24	15	-6	-13	-20	-28	-36	-43	-50	-58	-65
32	20	-8	-16	-23	-32	-39	-47	-55	-63	-71
40	25	-9	-18	-26	-34	-42	-51	-59	-67	-76
48	30	-16	-19	-22	-36	-44	-53	-62	-70	-78
56	35	-11	-20	-29	-37	-46	-55	-63	-72	-81
64	40	-12	-21	-29	-38	-47	-56	-65	-73	-82

Adapted from: Threshold Limit Values (TLV™) and Biological Exposure Indeces (BEI™) booklet; published by ACGIH, Cincinnati, Ohio

Little danger in less than one hour exposure of dry skin

Maximum danger of false sense of security

DANGER – Exposed flesh freezes within one minute

GREAT DANGER – Flesh may freeze within 30 seconds

As it can be seen in Table 4 the wind together with low temperature creates an equivalent cooler temperature. Thus e.g. human skin will cool considerably faster. This can create dangerous working environments if the working force is not properly protected.

3.2.5 Polar Low

According to Larsen (2007) a major challenge is rapidly changing weather and temperature. These occur due to polar low pressure systems. These systems are developing over the North Pole and then usually travel e.g. towards the coast of Norway (Gudmestad, 2011).

A polar low is small and often limited to a certain area. It is formed when cold, dry air masses that have been formed over the pack ice in the Arctic move out to the sea (Zahn & Storch, 2010). The diameter of theses weather systems ranges from in between 100 to 500 km. Once a polar low has developed it can last from 6 hours to 48 hours. These phenomena are rare but create a very intense weather situation. Very heavy snowfall with strong winds and low temperatures are characteristic for this situation.

Polar Low's are hard to predict and develop rapidly. Therefore weather forecasts are very important. Due to the intense weather situation, polar lows have a very negative effect on marine operations.

3.2.6 Weather forecast

According to Gudmestad (Gudmestad & Markeset, 2013) a major challenge is forecasting the weather as polar lows are not predictable. Weather forecasts in the Arctic environment are of critical importance. For many tasks a weather window with sufficient length is important (Gudmestad, et al., 1999, p. 85).

Weather forecasts are based on numerical models (United States Arctic Research Commission, 2009, p. 162). These models need input from e.g. drifting buoys and satellite images. There are several reasons that there is a lack of data for these models. Remoteness, low shipping traffic and a small number of buoys are making weather forecasting a very difficult task for Arctic regions (United States Arctic Research Commission, 2009, p. 163).

Sea ice information should also be included in the weather forecast. Due to global warming the sea ice cover will be reduced. However, sea ice will still form during winter months (United States Arctic Research Commission, 2009, p. 160). It is therefore important that extend and location of sea ice is monitored. Especially ice management is dependent on sea ice information.

3.2.7 Visibility

Visibility is an important factor to carry out efficient and safe operations. The main challenge from low visibility is that tasks can only be performed slowly and that safety issues might arise. Collision of e.g. vessels is more probable in bad lighting conditions.

Visibility can be influenced by different factors which are as follows:

- Darkness and poor light conditions
- Fog
- Whiteout due to snowfall

Darkness and poor lighting conditions are a result of the lack of sun during the winter month. The effects of lack of natural sunlight are:

- Loss of efficiency if no additional light is available
- Negative impact on the mental state of the workforce (Freitag & McFadden, 1997, p. 30).

Lighting on offshore structures must be sufficient to support all activities on and in the surrounding of a platform. The negative impact of the mental state of the workforce must be studied. Lack of e.g. vitamin D must be compensated with diet.

Fog is condensed water vapor and is often formed in Arctic environments when cold dry air over ice features is moving over the warmer free water surface (Freitag & McFadden, 1997, p. 12). There are statistically 76 days with visibility below 1 km due to fog in the Barents (Gudmestad & Karunakaran, 2012, p. 5). Thus it is important that e.g. supply vessels have sufficient technical equipment to navigate in fog. It is also probable that waiting on weather is necessary more often.

The effect of a Whiteout is a loss of contrast due to heavy snowfall. This effect is further described in section 3.2.2.

3.2.8 Sensitive environment

The Arctic environment is a very big and important topic. It is therefore important to notice that the following section will only give a brief introduction into this field.

The Arctic environment reacts very sensitively to any kind of change. The impact of pollution in the Arctic on Arctic species shall therefore be discussed in the following sections.

3.2.8.1 Pollution sources and types

All marine activities can pose a threat to the sensitive Arctic environment. Offshore oil and gas activities create various possibilities how harmful substances can enter the environment. These pollutions could create very large challenges.

The key sources of pollution due to accidents and normal operations are:

- The offshore platforms
- Ship and helicopter activities
- Pipelines to transport the final product

The following chart shall give a basic overview of different specific pollution types for the above mentioned pollution sources. This table is partially based on the chapter “Environmental Considerations and Impacts“ from the report of the United States Arctic Research Commission (2009, p. 138).

Table 5: Sources and types of pollution

Pollution source	**Type of pollution (normal and accidental)**
Oil and gas platforms	• Accidental release of oil due to a blowout • Accidental release of chemicals • Pollution of air due to machinery • Noise pollution of the sea during drilling operations and production • Local footprint of the structure
Pipelines	• Accidental release of oil or gas products • Accidental release of chemicals • Local footprint of the structure
Helicopter	• Air pollution • Noise pollution • Release of liquids after accident
Tanker ships	• Spill of oil or LNG • Spill of chemicals • Noise pollution • Introduction of new species
Icebreakers	• Impact on ice structures and thus wildlife • Release of harmful chemicals • Release of radioactive material in case of accident
Supply vessels	• Air pollution • Noise pollution • Accidental release of substances
Oil and gas exploration vessels	• Noise pollution of the sea during drilling operations • Pollution due to seismic activities • Air pollution

As it can be seen in the above table Arctic activities will lead to various pollutions. These pollutions can be summarized in the following major pollution types (United States Arctic Research Commission, 2009, p. 134):

- Release of substances due to emission to air/ water
- Accidental release of oil or other hazardous cargo
- Disturbance of wildlife due to e.g. sound or light
- Introduction of invasive species

Due to the uniqueness of the Arctic it is very important to reduce the above mentioned types of pollutions. Neglecting of the responsibility regarding the pollution could result in prohibition of certain arctic activities. It is therefore very important to conduct all Arctic activities in a manner that produces the least amount of pollution.

3.2.8.2 Arctic species under the impact of pollution

Arctic species have adapted to the difficult climatically conditions by e.g. being able to pass long periods without nutrition. Further adaption to the cold climate is defining these species. The food chain of the Arctic is very complex and interconnected. Various species such as fish, seabirds, seals, and whales live in the Arctic. The fish industry is a major food source for humans living in the coastal regions and a major economic factor for the Arctic.

A key definition of many Arctic mammals (especially whales) and birds is that they migrate in and out of the Arctic region in a course of a year (United States Arctic Research Commission, 2009, p. 134). The breeding season is in the Arctic while for the cold and dark winter time the animals migrate south. If the animals are disturbed while they are in the Arctic, it can have negative impacts on their behavior and thus on their reproduction. This is a challenge as many activities concerning the Arctic will have to be performed during the summer as the weather conditions are much better.

Considering the Barents Sea mammals can be found in the southeast during wintertime (United States Arctic Research Commission, 2009, p. 135). During springtime the mammals migrate further north and reproduce. Currently there are only very limited ship and construction activities during this period and the mammals are not influenced.

Arctic bird species often rely on feathers as main insulation (United States Arctic Research Commission, 2009, pp. 134 - 135). This is an important factor relating to oil. In an accidental release of oil e.g. due to a blowout the oil will stick to the feathers. This will result with a high probability in the death of the animal due to the loss of the ability to fly and to withstand the cold temperatures.

In the Svalbard region, but also along the Norwegian shoreline, large bird breading areas exist (Norwegian Directorate for Nature Management, 2011). Here cold less salty melting water from Svalbard and warmer water from the sea are mixing. A very rich and productive maritime ecosystem is created. Therefore the Barents Sea is one of the areas with the most seabirds. Estimates assume that there are up to 20 million seabirds in late summer (Norwegian Directorate for Nature Management, 2011, p. 8).

3.3 Communicational and navigational challenges

Communication and navigation is an important challenge in the arctic environment. The remoteness creates the need for very sophisticated systems. In the following chapter related challenges will be discussed.

3.3.1 Communication

The following section is based on a report by the United States Arctic Research Commission (2009, pp. 164-165).

Communication and Navigational assistance is important because weather, wave and ice information must be broadcasted to vessels. Therefore the “radio facsimile broadcast” via analog signals is used by various radio stations in e.g. the USA and Russia to broadcast information about the weather and marine communication. Digital signals are still only slowly broadcasted in the Arctic. The infrastructure for this signal needs to be further developed. Voice and data transmission with the analog system doesn't reach all regions in the north. In very far northern areas, satellite digital communication systems must be used. These systems offer only limited transfer rates which will put limitations on the amount of data that is possible to be transmitted. Additionally Gerwick (2007, p. 755) points out that due to effect of Aurora Borealis (northern light), electrical magnetic disturbance can occur which can cause problems with communication systems.

Norway has a special situation regarding the communication infrastructure. According to the United States Arctic Research Commission (2009, pp. 164-165) Norway has a very advanced system that guides and informs vessels. This system is necessary as Norway will increase Arctic activities. The system will help to reduce risk.

3.3.2 Navigation

Navigation with cards and technical systems is a very big challenge in the arctic. Satellite navigation via GPS is very well possible in Arctic areas (Gerwick, 2007, p. 756). However, compasses in the far north are useless as the magnetic north pole is too close. Further navigational charts are often currently unavailable or outdated (National Oceanic and Atmospheric Administration, 2013). Often, shoreline and depth of the water is unknown. Additionally currents and tides in Arctic regions are often unknown. This makes ship navigation challenging and poses a thread as vessels might ground and sink. To prevent accidents, nautical charts must be updated.

3.4 Challenges related to materials and lubrication oils

In the following chapter, challenges related to materials and lubrication oils behavior in cold climate will be discussed. As most of the designs that are in use today for e.g. the North Sea didn't consider very cold temperatures, this will be a major challenge to overcome.

3.4.1 Materials

According to Freitag and McFadden (1997, p. 531) materials are characterize by their manner of failure, brittle and ductile.

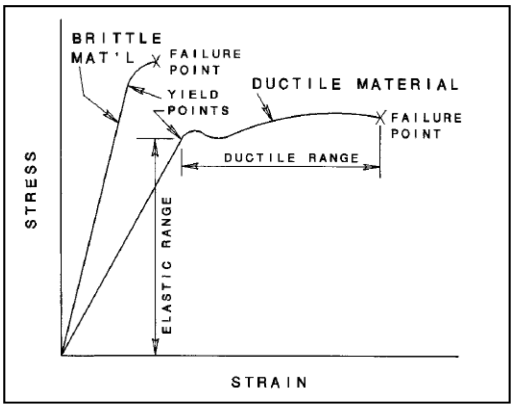

Figure 12: Stress- stain curves for brittle and ductile materials (Freitag & McFadden, 1997, p. 532)

An example of a brittle material is glass. As it can be seen in Figure 12 brittle materials have a sudden break point. This makes these materials difficult to predict as failure happens unexpectedly. Ductile materials, on the other hand, show large permanent deformations before failure. This process of deformation allows monitoring and thus preventive actions before failure. Many materials behave and fracture differently in cold climate.

3.4.1.1 Metals

Metal strength increases with dropping temperatures. With dropping temperature, the yield strength increases until it equals the ductile range. Then, the metal will fail like brittle material (Freitag & McFadden, 1997, p. 532). This means that e.g. iron and steel will become more brittle while aluminum will improve its usability and durability.

In cold regions, machines break down more often. The reason for this is that the metal contracts in the cold. As it has less ductility, it doesn’t cope with the contraction change and fails in a brittle mode. Freitag and McFadden (1997, p. 543) recommend the use of low carbon steels in cold climates.

Special considerations must be taken when welding is performed. Welding in cold areas should include pre- and post heating of the welding area (Freitag & McFadden, 1997, p. 544).

3.4.1.2 Polymers

Polymers, generally called “plastics” change their characteristics in cold temperatures. According to Freitag and McFadden (1997, p. 552) polymers are divided into two groups which are thermoplastics and thermosetting plastics. Thermoplastics can be melted and remodeled. Thermo setting plastics can only be heated and modeled once. Generally, polymers will become more brittle in cold temperatures. Polymers are used in many different ways, e.g. as housing for elements, as insulation or as seals.

Elastomers (amorphous polymers), which are generally called “rubbers” are used as seals. Some elastomers perform well under cold conditions. It is thus very important that the right type is selected so that the sealing function is achieved (see Freitag and McFadden (1997, p. 555)).

Electrical insulation on the other hand is posing according to Freitag and McFadden (1997, p. 556) a hazard as current products are often not suitable for the cold. If the wrong insulation for cold conditions has been selected (e.g. PVC (polyvinylchloride)) the insulations will lose flexibility at temperatures below -30°C and peal of.

The speed of degradation of plastic and rubber components is accelerated if large temperature changes occur. This typically occurs in cold environments as the working temperature of machines is much higher than the surrounding temperature. Freitag and McFadden (1997, p. 556) point out that failed plastic or rubber elements can cause secondary failures such as e.g. blocking of air intakes or loss of containment if rubber seals break. It is therefore important to check these elements and determine what results their failure can have.

3.4.2 Lubrication oils

Lubrication oil has many different functions. These are (Markeset, 2012):

- Reduced friction for startup
- Lubrication to reduce friction and wear
- Protection of metals against rust and corrosion
- Removal of wear particles

- Cooling of engine parts
- Seal combustion pressure

The performance of lubrication oil is strongly affected by temperature. The viscosity especially has an influence on how well lubrication will work in cold environments (Khonsari, 2007). If the viscosity drops below the pour point of the oil, very high startup torque will be required to startup machines. If the torque resistance is too high, the machine might not start or parts might be overstressed, leading to severe damage. If the startup is still achieved, high abrasive wear will result until the lubrication oil has reached a sufficient high temperature to perform well.

A solution is to use lubrication oils with a pour point below the temperatures that can be expected in the temperature environment the machine will be used. Alternatively, special additives can change the behavior of lubrication oils, making them more viscous even in very cold environments. Another possibility is to use winterization with pre heating of systems that use lubrication (Freitag & McFadden, 1997, p. 585).

3.5 Operational challenges

3.5.1 Human factors/ ergonomics

Human factors/ ergonomics are a major challenge for the Arctic development. The human body is strongly influenced by the environment. Especially the cold, dark and remote environment makes it difficult for humans to adapt. High quality engineering is needed to protect the human body from the influence of these factors. Further, it is important to define if there will be a higher demand for personnel in the cold climate during the winter period. The direct effect is, that it makes the developments more expensive as the workforce expects higher wages to compensate for the inconvenient living situations (Budzik, 2009, p. 9).

Cold temperatures will directly influence the performance of a human worker (Larsen, 2007, p. 18). Temperatures below freezing will reduce the efficiency of a worker and also introduce errors (Freitag & McFadden, 1997, p. 4). Warm and dry clothing as well as longer work breaks are necessary to compensate the effects of cold temperatures, wind, rain and others.

It is important to ensure safe working conditions for the crew. Here frostbite and hypothermia (too low body temperature) can be considered as a major challenge (Heller & Zieve, 2012). If skin is exposed to cold temperatures, bad injuries will occur. Therefore warm and dry clothing becomes necessary. The drawback of this layer of clothing is that the human loses some of his ability to perform work efficiently. Larsen (2007) points out that any kind of maintenance becomes difficult when gloves are used. Operations and maintenance tasks have to consider the additional time a worker uses to perform certain tasks. To compensate for the drawbacks of the clothing the machine design needs to specifically include the clothing of the working force. Tools have to be adapted if necessary. The Canadian Centre for Occupational Health & Safety (2008) further suggests that equipment safety can be easily improved by covering metals that could be in contact with skin.

As mentioned previously warm-up periods for workers are necessary. In Table 6 suggestions for a four hour work shift in a combination of different cold temperatures and wind speeds are shown. This table has been developed by the Canadian Centre for Occupational Health & Safety (2008).

Table 6: Work/ Warm-up schedule example (Canadian Centre for Occupational Health & Safety, 2008)

THRESHOLD LIMIT VALUES WORK/WARM-UP SCHEDULE FOR FOUR-HOUR SHIFT*

Air Temperature Sunny Sky		No Noticeable Wind		5 mph Wind		10 mph Wind		15 mph Wind		20 mph Wind	
°C (approx)	°F (approx)	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks
-26° to -28°	-15° to -19°	(Norm breaks) 1		(Norm breaks) 1		75 min.	2	55 min.	3	40 min.	4
-29° to -31°	-20° to -24°	(Norm breaks) 1		75 min.	2	55 min.	3	40 min.	4	30 min.	5
-32° to -34°	-25° to -29°	75 min.	2	55 min.	3	40 min.	4	30 min.	5	Non-emergency work should cease	
-35° to -37°	-30° to -34°	55 min.	3	40 min.	4	30 min.	5	Non-emergency work should cease			
-38° to -39°	-35° to -39°	40 min.	4	30 min.	5	Non-emergency work should cease					
-40° to -42°	-40° to -44°	30 min.	5	Non-emergency work should cease							
-43° to below	-45° & below	Non-emergency work should cease									

Another important fact is that in cold temperatures the metabolism rate of the human body increases. Therefore workers will require approximately 1.5 to 2.0 times more food (Freitag & McFadden, 1997, p. 601).

Human factors and ergonomics are discussed further in the chapter 4.4.

3.5.2 Winterization

Winterization is a key challenge as it can largely improve working conditions on an offshore platform. The following questions regarding winterization must be discussed:

- How can be ensured that production equipment and other equipment can work in the cold
- How can safety equipment be kept functional (e.g. firewater system)
- How can personnel work in the cold

Winterization thus means that equipment must be specifically designed for the cold. This can include heating of machines, surfaces and other. This heating system must also consider production stops where machines stand still over long time periods with liquids that can freeze. It is further a major task of winterization that safety equipment such as the firefighting system, the evacuation means and alarms work in the cold climate.

Due to icing on the outer structure of the facility, falling ice can cause a hazard for the workforce. Therefore, sufficient protection against possible falling ice must be provided. It is also important that deicing of e.g. cranes and other equipment is possible.

Another important factor is to reduce the effect of wind chill by covering working areas (Freitag & McFadden, 1997, pp. 603 - 605). Much care has to be taken to prevent gas from accumulating. Bjerketvedt et al. (1993, p. 12) point out that large mixtures of combustible fuel-air must be avoided in any case. Else confined explosion with very large pressure build up will result. This stands in contradiction of the requirement to create a wind still environment to protect workers against the cold.

Gudmestad & Markeset (2013) point out the criticality for providing sufficient ventilation. The ventilation system must be designed in a way that pressure piling (locally dynamic increase of pressure) cannot occur and that gas is not transported from one area to another (Bjerketvedt, et al., 1993, pp. 124, 141). To avoid very high overpressures, some walls should be designed in a way that they open if an explosion occurs. This will reduce the overpressure (explosion relief panels could be used). Another possibility is to use partially perforated walls or the use of wind panels that are only closed if maintenance is performed. The challenge will be to find the right method for each case with the little experience that has been gained.

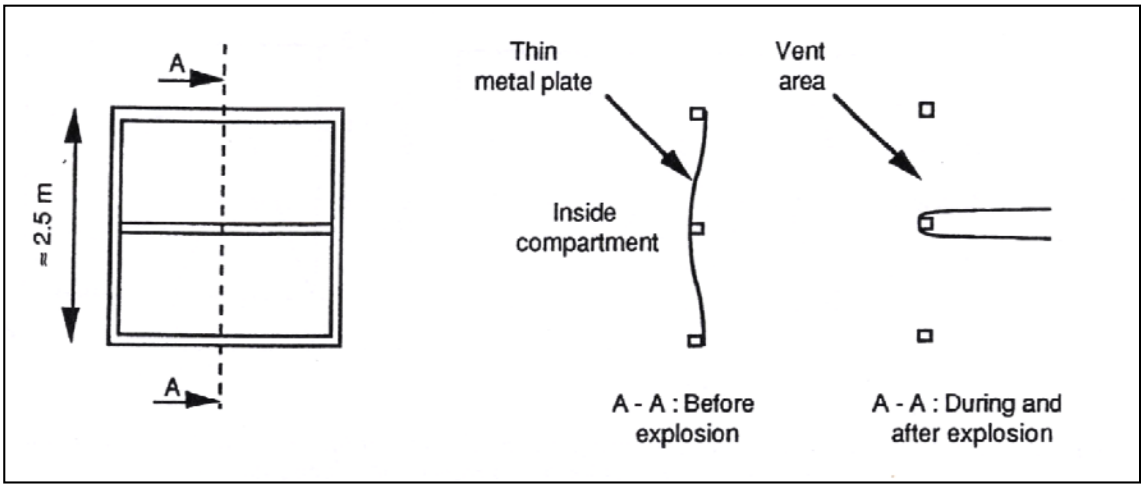

Figure 13: Explosion relief panel (Bjerketvedt, et al., 1993, p. 134)

Bjerketvedt et al. (1993, p. 16) therefore emphasis that gas explosion hazards should be considered in the very first design phase, as changes made later will be costly and result in suboptimal solutions. This is especially the case for Arctic projects as explosion hazards due to protection against the cold are a major problem.

Gudmestad and Karunakaran (2012) make a reference to ISO 19906 (International Standardization Organization, ISO, 2010) where measures for winterization are suggested. Some suggestions are as follows (Gudmestad & Karunakaran, 2012):

- No pockets or dead ends in pipes to avoid damage to freezing water.
- Maintain flow in lines such as fire and cooling water to avoid freezing of static liquid.
- Use insulation to protect against freezing.
- Use of heating to prevent freezing.
- Use of enclosure.
- Use of chemical and mechanical seals on equipment to avoid entrance of exterior substances.
- Use of protecting walls against wind chill effect.
- Use of chemicals to change freezing point of liquids.
- Ensure sufficient ventilation

Winterization is very challenging if sea ice can be expected. In this case it must be defined to which degree a mobile or fixed unit has to be able to resist the ice force. Reinforced designs are necessary to resist the ice loads.

3.6 Logistical challenges

Due to the remoteness of the Arctic, the logistics of platforms are a key challenge. These challenges will be discussed in the following sections from different perspectives.

3.6.1 Remoteness

Remoteness of the Arctic is a distinguishing feature. Remoteness has two major drawbacks.

The first drawback is that it is difficult to support a platform with man and material if it is in a remote area. Discoveries in the Arctic are currently far away from manufacturers and suppliers. This means that developments in this region will have a higher cost with transportation for supplies and manpower being a major cost driver.

Second, the products such as oil, gas and condensate are much further away from the customers. This transportation cost will increase their price and is just as well a major cost driver.

To better express the remoteness, different distances from the Russian harbor Murmansk to other harbors in Europe have been listed as an example in Table 7.

Table 7: Traveling distances from Murmansk to different European harbors (LLOYD'S, 2005, p. 21)

To	Murmansk
London	3150 km
Rotterdam	3015 km
Hamburg	2900 km
Bergen	2052 km
Le Havre	3290 km

With this table it becomes obvious that travel distances from most of the cities in Europe to the Arctic are enormous. The same applies to other Arctic regions. Thus the distance to suppliers can be considered as a major challenge.

Another major drawback of the remoteness is that in case of emergencies and accidents the time to reach the site will be large. The next image shows the current range of JRCC (Joint Rescue coordination Center) Helicopters for the Norwegian Barents Sea.

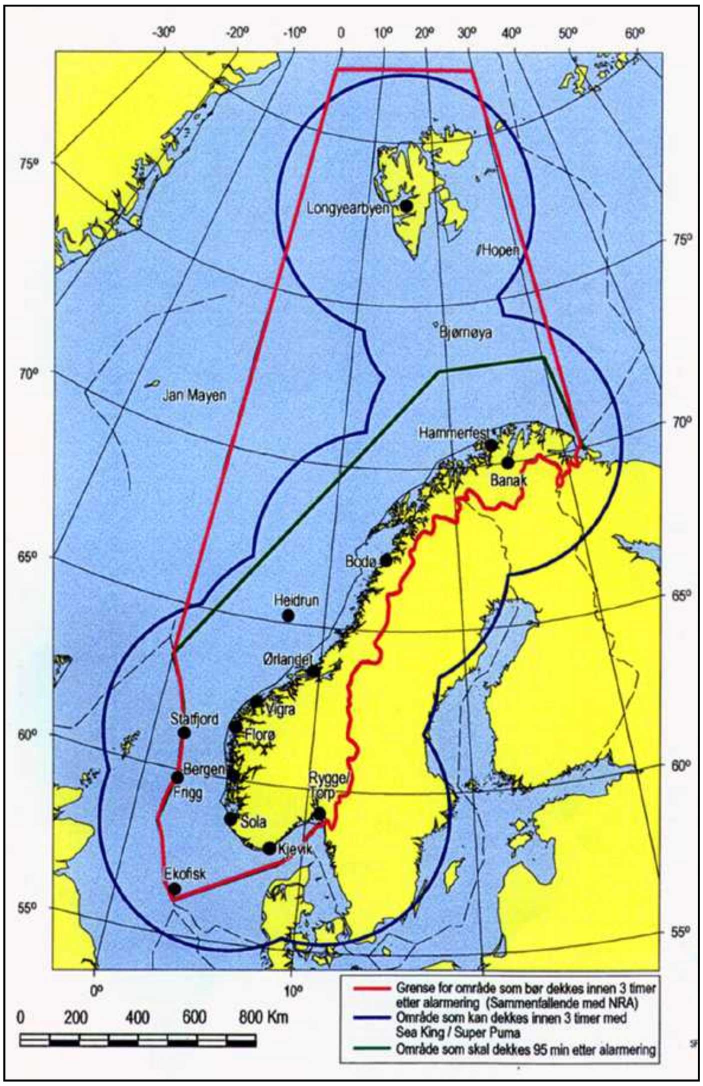

Figure 14: Operational range of rescue helicopters (Gudmestad, 2012)

It becomes clear with this image that in general large Arctic areas cannot be covered by helicopters flying from shore to the offshore location. Stops to refuel might become necessary. Thus emergency response is a particular challenge in Arctic regions (United States Arctic Research Commission, 2009, p. 173). This again also applies to the transport of workforce and spare parts. It might be necessary to use mobile vessels and stationary places, such as islands, with helicopter landing spots for refueling.

3.6.2 Infrastructure

Infrastructure in the Arctic is a challenge as it is often only slightly developed. The main reason for the limited infrastructure is the low population in many regions. However, it is important to note that the population density varies to a large extent. For example Norway has many small settlements, while in Russia very large populations in the Barents region exist (Barentswatch Atlas, 2013). For offshore oil and gas projects, it is important to assess the infrastructure regarding land supply bases. Depending on the region the infrastructure is negatively influenced by the surrounding environment. Icing, snow piling up or the melting of the permafrost can make roads and train tracks impassable.

The next part of this section will highlight some important facts about each transportation measure. Existing and possible transportation means in the Arctic:

- Roads and seasonal ice roads
- Airfields and use of airplanes and helicopters
- Train connections
- Transportation via vessels to ports and deep water ports

Normal roads are hard to build because the ground is often too soft during summer time when the permafrost ground melts to some extent. To efficiently support these roads, piling of the support into the permanent frozen ground is necessary. An alternative are ice roads. Ice roads are seasonal roads (Freitag & McFadden, 1997, p. 518). They form by themselves when the water surface of a rivers or lakes freezes and can be strengthened by spraying water over the frozen surface. These roads must be constantly monitored to avoid breaking of the ice. They are used to supply many communities in Arctic regions and might allow some supply for onshore supply bases.

Another form of transportation is the use of airplanes or helicopters. Therefore airfields are needed. Transportation of goods by airplane is for many remote regions one of the most important and reliable systems available (Christopher, 2008, p. 1). Due to high fuel costs this way of transportation is getting more and more expensive.

Train transportation varies with the region. While Scandinavia and Russia have a quite extensive railroad system, Alaska and Greenland use predominantly air transportation (Freitag & McFadden, 1997, p. 43). Many challenges faced for train transportation are equivalent to road transportation. The major difference is that by train usually larger and heavier loads can be transported.

Finally, transportation by ship is a very good option regarding transportation of supplies and spare parts. Ships can carry very heavy and large loads over long distances. During the summer months, ships are a very good option for transportation in Arctic regions (Freitag & McFadden, 1997, p. 37). Problems occur during the wintertime when large storms are forming and the sea becomes rough (Freitag & McFadden, 1997, p. 37). Additionally, it is possible that sea ice is formed and some ports become inaccessible. Sea ice is a thread to vessels that are not designed for ice pressure on their hull. Cargo ships that are designed for ice might still need assistance from ice breakers during their voyage which will add additional cost. Norwegian ports on the continental shelf have an advantage. Warm water from the Gulfstream keeps ports ice free. Many northern ports in Norway are deep water ports which allow large vessels to access the port. In other regions, cargo must be unloaded offshore and then transported by smaller ships to shore. With the increasing temperatures in the Arctic transportation via ship might become increasingly important. According to Christopher (2008, p. 1) the strong variability of the sea ice conditions will make the Arctic very challenging as traffic conditions could vary greatly.

3.6.3 Inbound and outbound logistics

As mentioned previously, a major challenge is the remoteness of the new developments. Therefore, the outbound and inbound logistics need to be well scheduled. Inbound logistics is concerned with the management of transportation and storage of supply materials to an installation. On the other hand, outbound logistics is focused on the management of the storage and transportation of produced goods and also waste materials (Murray, 2013). To efficiently plan these activities, it will be necessary to gain more data about the weather in Arctic regions. Weather is a key influencing factor for logistic systems on the sea. In the following chapter, inbound and outbound logistics will be discussed in more detail.

3.6.3.1 Inbound logistics

Inbound logistics ensures that support material for the operations is ordered in time. This includes spare parts but also the transportation of the workforce. Delays in this supply chain will result in costly production stops. It is therefore necessary to plan when material is supposed to arrive offshore. Due to the large distances, this process is very difficult in Arctic regions. The planning must include waiting times to cover unexpected events such as heavy storms or sea ice. These waiting times will increase the cost for offshore operations. Monitoring with technical equipment is therefore very important. This can include the tracking of goods via GPS (Global Positioning System) as well as monitoring the weather via satellite to only mention some possibilities. Challenges will occur if waiting periods have been underestimated. Storage closer to the offshore platforms can provide a solution to decrease the risk of inbound logistic delays. It is therefore necessary to assess the onshore storage possibilities.

3.6.3.2 Outbound logistics

A key challenge will also be the organization and management of the outbound logistic systems. The final product should be shipped or transported as fast as possible to the costumer. There are different approaches. In principle the two solutions are:

- Storage of the product offshore at the site
- Transportation to an onshore location

The offshore storage requires offshore offloading of the product. This operation is highly dependent on the weather situation on the sea. Offshore storage is used for the Goliat field (see chapter 5).

The second approach, which is currently applied, is the redirection of the product to an onshore storage facility. From here the product can be loaded easier and transported because harbor structures can be used to protect the loading site. This decreases the risk of unloading problems. However, cost will increase since pipelines are necessary to transport the final product. This approach is used for Snøhvit (see section 2.1.1.1). Depending on the properties of the product this method will not always be an option.

Transportation of waste material is an additional challenge. Additional space on an offshore platform could be necessary to store waste material.

3.6.4 Storage of spare parts and supplies

Spare parts and supplies are necessary to keep an offshore platform operational. If any equipment breaks down, diagnosis has to be made and the broken part has to be replaced. According to Markeset (2008) this process must be well assessed according to the Arctic environment.

Weather conditions are very harsh in the Arctic and offshore facilities will be far away from spare part storage centers. This means that necessary parts might be impossible to fly in by helicopter or offload by ship immediately if waiting on weather becomes necessary. This in turn leads to the importance to store more critical parts on the offshore plant. Increased topside weight will always increase the overall cost of the load bearing system of the offshore structure. Therefore Markeset (2008) suggests that smaller critical parts as well as big and critical parts should be stored offshore. Also storage of different parts on different offshore platforms should be considered. Interorganizational cooperation would therefore be necessary. Markeset (2008) points out that seasonal exchange of stored parts and supplies might be an option.

4 Maintenance and reliability in the Arctic

In the following section, the importance of maintenance and reliability of systems will be discussed. Good practices in maintenance as well as reliable designs will provide a good basis to overcome some of the major challenges in the Arctic.

4.1 Basic concepts of reliability and maintenance

Reliability is a distinguishing feature of equipment. Reliability is commonly expressed by probabilities defining equipments "Mean time to failure" (MTTF) or "Mean time between failures" (MTBF) which represents the uptime of the equipment. Reliability thus expresses the ability of a piece of equipment to perform its function during a certain period of time without failing.

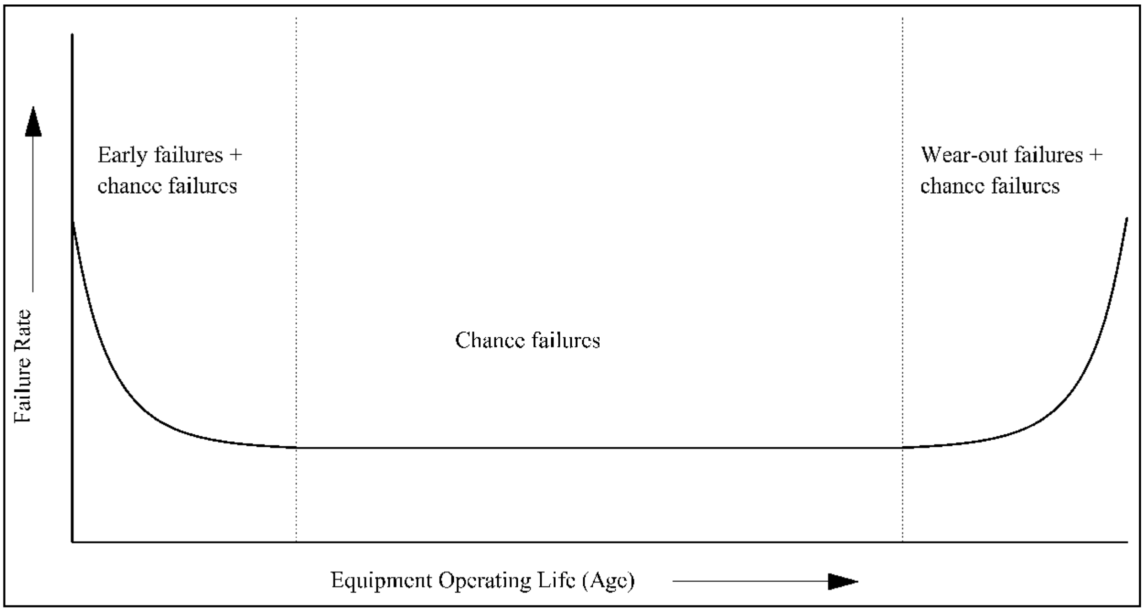

Figure 15: Bathtub curve (original by Ben-Daya et al. (2009, p. 338))

In Figure 15 the Bathtub curve is displayed. This curve shows possible occurrences of failures for equipment like e.g. a motor. The failure rate is highest at the beginning and at the end of the age of a component or system. In the beginning equipment fails more often due to a "run in period" while in the end the equipment fails more often as it has worn out and reach its maximal lifetime.

Maintenance is used to set equipment back into a functional state. Maintenance can be divided in three major branches:

- Improvement maintenance
- Planned maintenance
- Unplanned maintenance

There are different methods such as condition based maintenance (CBM) where the health of equipment is monitored and maintenance is performed before fatal failure occurs. This and the above mentioned branches will be further discussed under "Maintenance strategies" in chapter 4.3 on page 42.

4.2 Balance between design for maintenance and designing reliable systems

“One must recognize that no product can be assumed to have 100% reliability at any point in its life cycle – even in the first minutes of use. However, successful designs should have 100% maintainability.” (Markeset, 2012, p. 202).

To achieve high reliability of a design engineers must analyze the failure rates of equipment and conduct reliability studies. According to their findings they shall used proven methods and available equipment. The Arctic is a challenge for reliability as only little experience and data with currently available equipment has been gathered. Probability distributions available from other regions to define reliability and failure functions might not apply to equipment working in the Arctic environment. This is e.g. due to the impact of cold climate such as changed behavior of materials and lubrications as discussed under chapter 3. However, equipment used under the Arctic environments must be highly reliable because of the remoteness of the offshore plants. If equipment fails, long downtime periods and large cost will result. The challenge of reliability is that it increases the cost of the design and 100% reliability is hardly feasible because complex systems can fail in complex ways. The system reliability cannot be improved, unlimited and unforeseen failures will occur because a design cannot cover all failure causes. In particular the lack of data for the Arctic will introduce new failure causes. Here especially common mode failures are a threat to high reliability systems. Common mode failures occur in complex systems. Multiple systems interact with each other and are dependent on each other. This is making them prone to errors that successively overcome all inbuilt barriers of the highly reliable design. The following overview shows some of the main failure causes for common mode failures.

ENGINEERING				OPERATIONS			
Design		Construction		Procedural		Environmental	
Functional deficiencies	Design realisation	Manufacture	Installation and commissioning	Maintenance and test	Operation	Normal extremes	Energetic events
Logical error	Channel dependency	Inadequate quality control	Inadequate quality control	Imperfect repair	Operator errors	Temperature	Fire
Inadequate measurement	Common operation & protection components	Inadequate standards	Inadequate standards	Imperfect testing	Inadequate procedures	Pressure	Flood
Inadequate control	Operational deficiencies	Inadequate inspection	Inadequate inspection	Imperfect calibration	Inadequate supervision	Humidity	Weather
Inadequate response	Inadequate components	Inadequate testing	Inadequate testing and commissioning	Imperfect procedures	Communication error	Vibration	Earthquake
	Design errors				Inadequate supervision	Acceleration	Explosion
	Design limitations					Stress	Missiles
						Corrosion	Electrical power
						Contamination	Radiation
						Interference	Chemical sources
						Radiation	
						Static charge	

Figure 16: Causes for common mode failures of equipment (Aven, 1993, p. 118)

Kayrbekova et al. (2011, p. 121) suggest that for the beginning the poor statistical data available for Arctic regions should be used as far as possible. This data should then be combined with e.g. data from the North Sea region to estimate the maintenance cost. They further suggest using the Monte Carlo simulation tool as it provides more information about risk and uncertainty. Reference is made to Kayrbekova et al. (2011) as in this PhD Thesis the Monte Carlo simulation has been applied.

Markeset states that "Maintenance is an enabler for improved business performance" (Markeset, 2008, p. 1). Maintenance is necessary as it is extremely difficult to make a system fully reliable. Kayrbekova et al. (2011) point out that unplanned maintenance in northern regions is a major risk to the business. Unplanned maintenance comes at a high cost and has an important influence on the organizations profitability (Ben-Daya, et al., 2009, p. 3). Man work, spare parts transport, spare parts storage and the downtime during the maintenance operation can result in large costs. Finding the right maintenance strategy is a critical element in the risk reduction for maintenance (Kayrbekova, et al., 2011, p. 121). Kayrbekova et al. (2011, p. 121) point out that current uncertainty to define the right maintenance strategy arises due to:

- Insufficient data about working conditions
- Insufficient data about the equipment performance (reliability, maintainability and supportability)
- Cost of the maintenance activity and the spare parts.

These challenges and uncertainties related to maintenance make reliable designs more desirable. Thus assessments should be conducted clarifying for each case if the design should focus on maintenance or reliability. The optimum cost will most probably give the best solution in terms of performance.

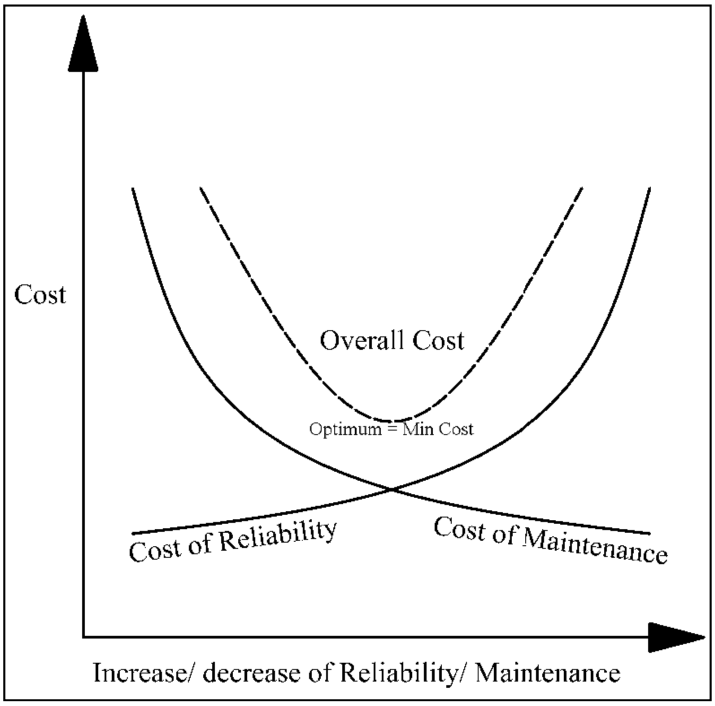

Figure 17: Correlation of cost between reliability and maintenance

As it can be seen in Figure 17 the optimal balance between cost of maintenance and cost of reliability is the minimum overall cost. Cost benefit analysis should consider many aspects to define the optimal solution. The correlation between the cost of a reliable design and a maintainable design are often not linear.

4.3 Maintenance strategies

As mentioned in the previous chapter, maintenance is an important factor in keeping a platform operational. The key to success is the right maintenance strategy for the right equipment.

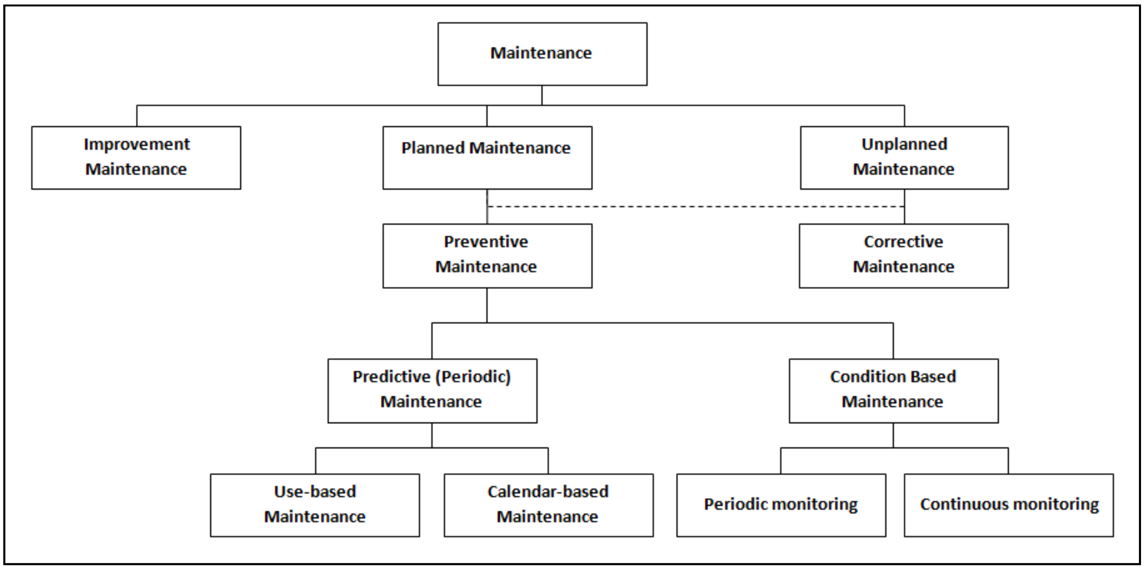

Figure 18: Maintenance overview (modified, original by Markeset (2012, p. 50))

In Figure 18 different types of maintenance is shown. The following section will go into more detail about this figure.

4.3.1 Improvement maintenance/ upgrading

The following section is based on “Design for Petroleum Production Performance in Arctic Locations Considering Maintenance and Support Services” by Markeset (2008).

Improvement maintenance includes redesign, upgrading and modification of equipment. Upgrading is often initiated by the manufacturer. The main benefit of an upgrade is that the performance is improved while the rest of the system will be kept in the original state. This results in lower cost for the improvement. The outcome of the improvement can be:

- Improvement of design to withstand environment
- Increased performance
- Higher safety
- Less pollution of the environment

Improvement maintenance can thus be anything from updating software to installing new filters in turbines.

According to Markeset (2008) the new Arctic development will result in a high percentage of improvement maintenance. The operators will try to design for all possible environmental factors. However, not all aspects can be covered. This is the experience that has been made with some systems already installed. For example the Statoil LNG plant at Melkøya at the Barents Sea frequently has many problems with long downtime and large costs (Pettersen, 2011). Improvement maintenance due to available upgrades for current systems could be used to reduce reactive maintenance.

4.3.2 Proactive or planned maintenance

Proactive or also known as planned maintenance has large benefits if done properly. These benefits are listed below:

- Lower repair costs
- Less downtime
- Reduced risk of accidents

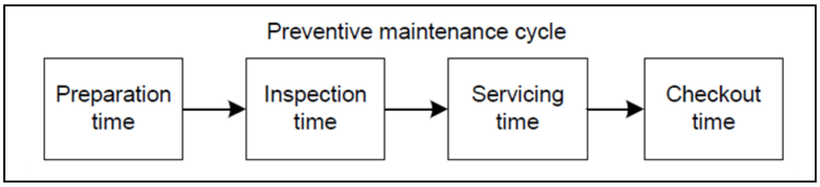

Figure 19: Preventive maintenance cycle (Markeset, 2012, p. 13)

Due to the possibility to “plan a job” preventive maintenance gives the operator time to organize the actual work. This allows negotiating better prices for replacement parts and labor. Planned Maintenance itself can be separated into:

- Preventive maintenance
- Planned corrective maintenance

Preventive maintenance itself can then be further developed into:

- Predictive (Periodic) maintenance
- Condition based maintenance

Predictive or also known as periodic maintenance uses statistical data to define when maintenance should be performed. The actual state of the machinery is not taken into consideration. Thus, there is the possibility to establish incorrect maintenance dates. These can either be too early or too late.

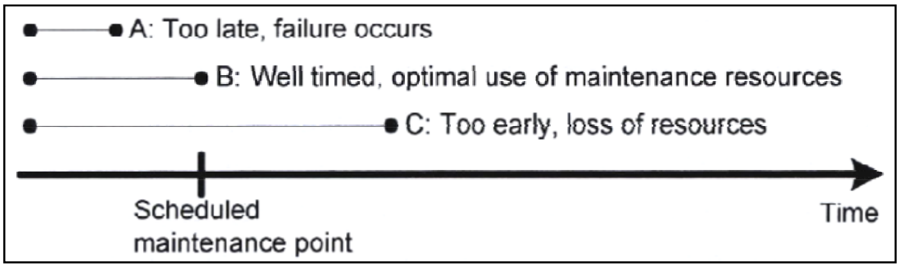

Figure 20: Drawbacks of periodic maintenance (Markeset, 2008, p. 4)

Maintenance performed too early in advance, while parts are still in working condition, can create unnecessary replacement costs. If maintenance is performed too late it will have the same implications as reactive or unplanned maintenance. The costs will be very high due to the e.g. unplanned downtime. Therefore, the result of periodic maintenance depends to a large degree on the error in the statistical data as well as in the interpretation of this data. Safety margins are necessary to avoid reactive unplanned maintenance.

A different approach is condition based maintenance (CBM). This type of maintenance takes the actual condition of the equipment into consideration by measuring certain system values.

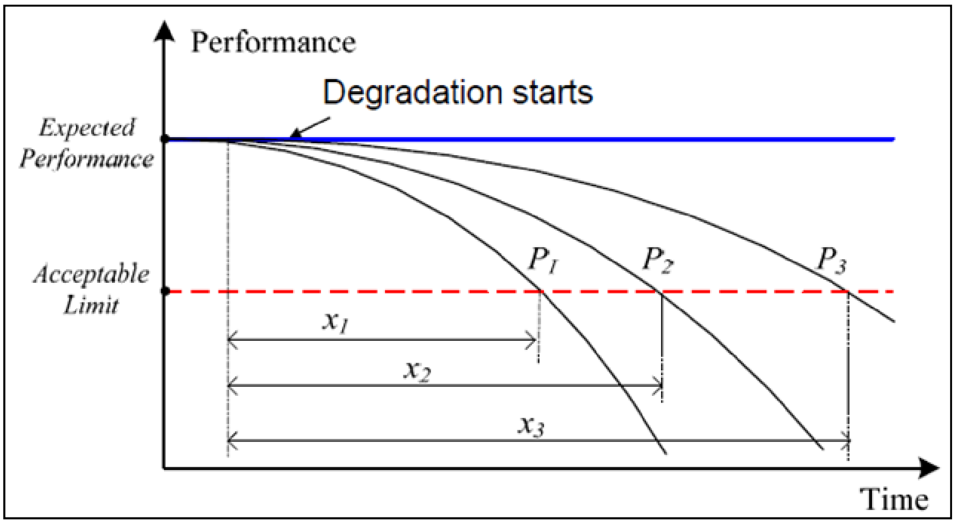

Figure 21: Performance degradation of equipment (Markeset, 2012, p. 16)

Figure 21 shows different equipment P1 to P3 with different degradation times. It becomes clear from this figure that certain circumstances for condition monitoring have to be met so it can be applied. Some are mentioned below.

- The degradation must be gradual
- The must be a possibility to detect the degradation
- An acceptability limit of the performance must be defined

A gradual development of the failure is important as instant failures cannot be monitored. Taking the measurements with sensors will give then indications (e.g. in forms of vibrations) about the state of the system. These measurements can be taken periodically or continuously depending on how fast the problem develops and also on how much of the resources shall be invested for the monitoring system.

4.3.3 Reactive or unplanned maintenance

Reactive or unplanned maintenance for offshore platforms results in:

- Large repair cost
- Loss of production
- Risk of large accidents

Unplanned maintenance is unwanted because it leads to long periods of downtime. Downtime is obviously always a cost, as the workforce must still be paid while there is no income from production. In the oil and gas and other industries these losses can have very high rates and make projects uneconomically.

Another important fact is that if maintenance is not planned and failure occurs, random large accidents can result. Thus, unplanned maintenance increases the risk of operations. For oil and gas operations these are not acceptable, as the human safety and the environment must be protected as much as possible at all times. Thus this type of maintenance should be avoided.

4.3.4 Selection of maintenance strategy

Currently more advanced and complex systems are becoming available (Markeset, 2008). Additionally, the Arctic is more challenging than other regions such as the North Sea. Due to these points there will be more errors and thus longer downtime if no additional measures are taken. Therefore the maintenance strategy becomes increasingly important to increase uptime and reduce downtime after failure (Markeset, 2008).

Different equipment requires different maintenance strategies. As a result Kumar & Markeset (2005) created Figure 22 to decide which maintenance strategy should be applied in which case. Following this flow chart diagram the outcome shall give the most overall cost effective and risk reducing solution.

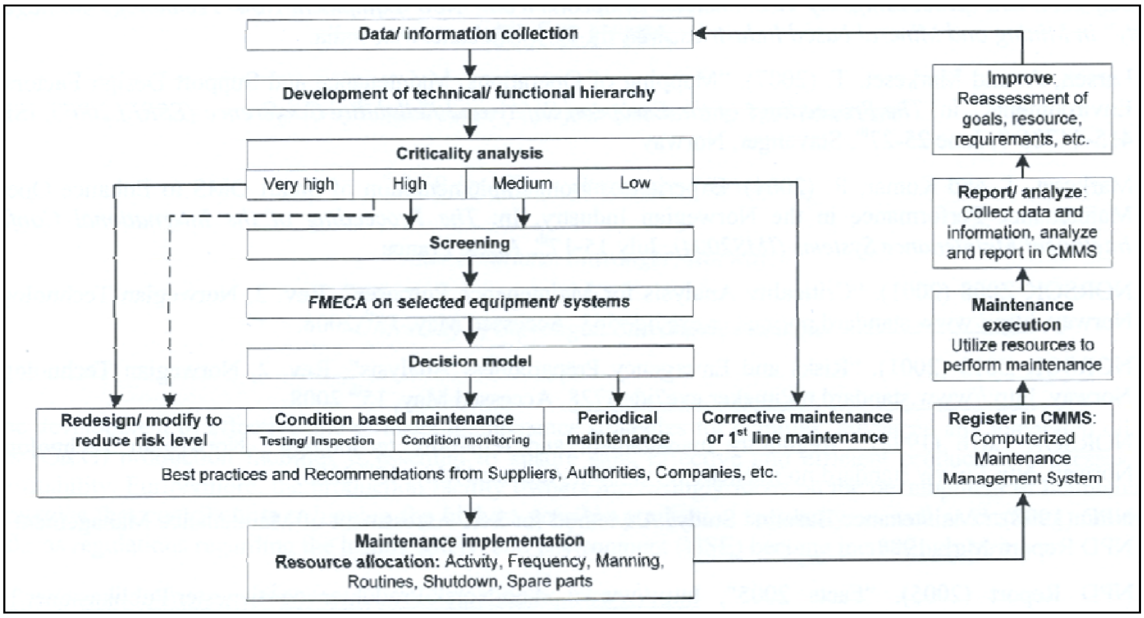

Figure 22: Maintenance strategy development process (Kumar & Markeset, 2005)

To develop the right maintenance strategy for a system, an assessment of the actual condition has to be conducted. During the assessment, data and information about the system have to be acquired.

After the assessment, the technical and functional hierarchy of the system has to be developed. Several questions must be discussed such as:

- How do single parts of the system interact with each other?
- How do system components influence each other?

One of the most important steps of this assessment is then to perform a criticality analysis. As it can be seen in Figure 22 the system components are divided into criticalities ranging from “low” to “very high”. According to the level of criticality of the system and the resulting consequences of failure one of the previously discussed maintenance strategies will be selected. If the system has a level of criticality which is too high and a failure is unacceptable the system must be redesigned.

Many of the challenges discussed in previous chapters will have to be considered when the maintenance strategy is selected. Especially the large distances in case of Arctic projects and the possible waiting on weather will require considerations of:

- Where should spare parts be stored?
- How can transport of spare parts be organized and assure in the different weather conditions?
- How will transportation of necessary workforce/ specialists be organized?
- Where should the maintenance task be performed?

The engineers and the management establishing the maintenance strategy must be aware of the challenges and risks that arise due to the Arctic environment. Improvement maintenance can be used in cases where the design of already installed systems is not appropriate or can be improved. Planned maintenance and especially condition based maintenance strategies will have advantages in Arctic environments. As the degradation of the systems will be harder to predict as statistical data about wear might not be applicable, condition monitoring delivers real time data. Costs in Arctic for transportation are much higher than in more southern and urban regions. Further, the challenges created by the weather and environment will call for better planning. This can be achieved by applying condition based maintenance. Unplanned maintenance should be avoided for critical systems in any case. As mentioned previously, the disadvantages and the risk are not acceptable if an organization wants to be profitable and reduce risk

4.4 Human factor/ ergonomic design as an enabler for improved maintainability in harsh environments

The Arctic is a particular environment which the human body hasn't adopted as well as for others. Human factors and ergonomics therefore have a large influence on efficient maintenance repair work. If human factors/ ergonomics are implemented correctly they can improve safety and performance of oil and gas operations.

4.4.1 Human factors/ ergonomics

As with most systems in any environment, maintainability is an important factor in the design. To achieve best practice regarding human factors/ ergonomics the knowledge in this field should be considered within the very first design steps.

Human factors/ ergonomics are an area that is occupied with the design of systems for humans and their needs (Wong, 2002, p. 62; Baby, 2008). The main idea is that people are different in different areas (e.g. education, body size etc.) and this should be taken into account during the engineering phase. Further the design should support the user in his tasks rather than being a hurdle. Therefore the user needs to be more involved in the design. The goal is to design-in reliability by taking the human into account (Bridger, 1995, p. 4) and that human – machine systems work safe and efficiently together (Bridger, 1995, p. 1). This is especially important in the Arctic because the human worker will have to rely on the systems to support him in his everyday tasks.

In the following section, the system design process regarding human factors/ ergonomics will be discussed.

4.4.2 Implementing human factors and ergonomics in the system design process

The importance of implementing human factors/ ergonomics into the system design lies in the improved performance and reliability of the operator of the system. Therefore the system design process shall be discussed more in depth in the following. The next figure shows the different stages of a general system design process.

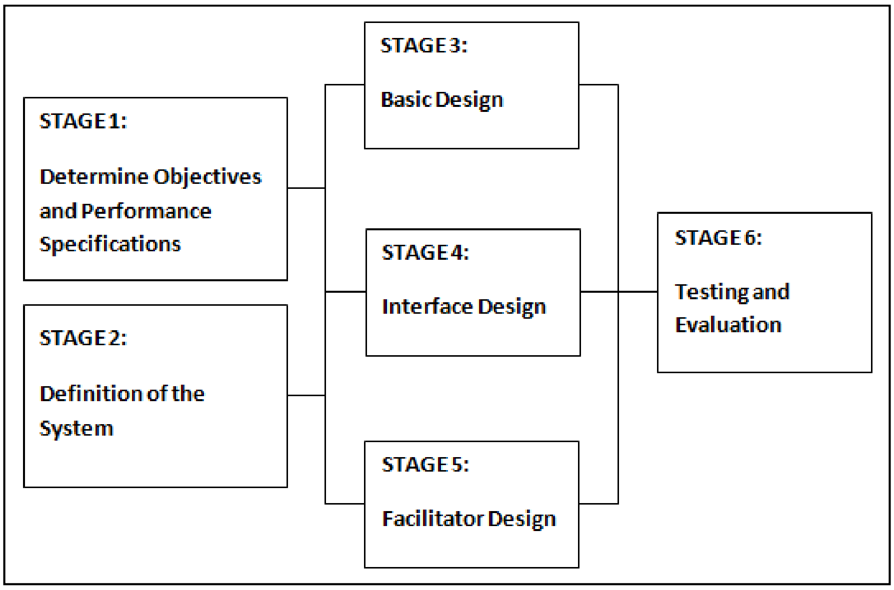

Figure 23: Major stages in the system design process (Sanders & McCormic, 1992, p. 727)

Stage one is the determination of the objectives and performance specifications of the system. This stage is closely related to stage two, where the system to be used for the application is defined. It follows stage three to stage five. These stages deal with the basic design, the interface design and the facilitator design of the system. In the last stage, number six, the system will be tested and evaluated.

In the following sections human factors/ ergonomics from each stage will be discussed in more detail. The section is based on Sanders & McCormic (1992).

4.4.2.1 Determination of the objectives and performance specifications

There are two human factors that have to be considered in this stage. First it has to be defined who the user of the system will be. This will include information about where the system is used (e.g. in a cold environment) and who will use it (e.g. an expert).

Second, the activity in the interaction between the human-machine system has to be defined. At this point it will be defined what the purpose of the system is and how it is increasing the human functional ability. In an Arctic environment this will generally be related to the cold- and darkness and the resulting operational conditions for e.g. the maintenance worker.

4.4.2.2 Definition of the system

In this stage functions are defined. It must be explicitly stated what shall be performed by the system. Human factors design criteria are used to decide whether the functions will meet the requirements of the human users or not.

4.4.2.3 Basic design

At this stage, the human factors will be used to:

- Define which parts shall be executed by humans and which by the hardware, software
- Define the human performance requirements
- Analysis and description of the tasks
- Job design

In a first step, it has to be decided which functions a human operator should execute and which functions the machine part/software shall perform. This decision is based on cost factors and the superiority of either the human part or the machine/software part. A simple question regarding the function of the system could be if the maintenance professional should remove icing covering a maintenance opening or if it is possible to include heating elements in openings to keep them ice-free.

After the function of the human has been clarified, the human performance in this function must be defined. This means that a definition has to be given what the human part must do so the machine part can fulfill its function. If the human part will not be able to meet the performance, the system must be redesigned. In this stage, it’s especially important that, the challenges discussed earlier should be implemented. A design supporting fast maintainability due to the very cold temperatures might be the goal. Much thought should be put into how efficient maintenance can be achieved.

It follows a step where the task performed must be analyzed and described. All necessary tasks that shall be done by the operator and maintenance personnel have to be collected and put into sequence.

The last step of this stage is the job design. The operator will use a machine to perform a certain job. The same applies for the maintenance worker who will have to take certain steps to e.g. exchange a filter of a motor. This also defines how much the worker will “like” his job. A well designed job will give the worker satisfaction and motivation, which will lead to higher performance of the worker.

4.4.2.4 Interface design

In the interface design stage, the connection for the human-machine and human-software are designed. These are the buttons, switches, displays, screws etc. that the worker will use to perform his task in the system. The maintenance professional might need to close certain valves if he wants to change the oil in a motor. The immediate question will be, where these valves should be located and who will close them. The task could be performed by e.g. a worker in an acclimatized control room or a worker outside in the cold wind. The interface design has a large importance regarding small things such as what size screws are and where they are located when a worker is wearing large glows. Again the actual conditions are important.

A good interface design will lead to high human efficiency and a low error rate. The human factors give input in the comparison of different arrangements for e.g. how the layout shall be chosen. There are three main points Sanders & McCormic (1992, p. 738) specifies as activities:

- Gather and interpret human factors and human performance data
- Conduct attribute evaluations of suggested designs
- Conduct human performance studies

These points have to be considered as they have effect on the interface design, which in turn has effect on the risk and performance of the human part. The overall idea is that data needs to be provided, and if not available, it shall be researched so that human factors can be taken into account.

4.4.2.5 Facilitator design

This stage deals with all the tools that help to facilitate the function of the human operator. Again, human factors need to be considered as it is important that e.g. manuals and utensils can be used efficiently. Situations in which a maintenance worker has to read a long manual in cold and snowy condition should be avoided.

The goal is to make the task as understandable as possible so the maintenance professional can achieve maximum performance.

4.4.2.6 Testing and evaluation

In this last stage, the system has to be evaluated from a human factors/ ergonomic point of view. This means that it has to be tested if the anticipated function can be fulfilled in the anticipated way by the worker.

There are four factors that have to be considered:

- Subjects

It is emphasized that the users of the system shall test the system.

- Criteria

Criteria have to be defined in which the system will be tested. They should reflect the anticipated goal of the human factors that have been taken into consideration during the design of the system.

- Experimental Procedures and Controls

To have satisfying results, the experiment has to be conducted in a controlled way to make it comparable to similar experiments.

- Research setting

Finally, the research setting has to be as close as possible to reality. This is very difficult to achieve as every human is different. The mental condition plays a big role in the use of a system (e.g. high stress in emergency situations) it can be difficult to create an adequate research setting. Sanders & McCormic (1992, p. 750) state further that the test persons will be aware of the test situation and behave differently. The lack of data, especially for cold and remote regions, might underestimate the actual stress and workload the maintenance professional might be exposed to.

4.4.3 Discussion

Humans contribute in many different ways to operational risk. According to Lehmann & Wilson (2012, p. 2), it is often the lack of communication of people that causes incidents. When people operate and maintain equipment, they can make errors. According to Jones (1995, pp. 254 - 257) these errors are due to two factors:

- The work the people do is less practical then it used to be. Due to increase automation, the tasks performed are no longer easy to understand. The design of the system plays a very big role. It needs to follow and adapt to the human needs.
- The second cause is that people get exhausted after a certain time period.

To improve the human performance during maintenance tasks, human factors and ergonomic design criteria have to be considered. As pointed out above, the “job” the human worker is performing has become less practical. Today, often electronic devices are used to establish a picture of the system health. These devices need to be designed in a way that they are easily operable in cold conditions. It becomes clear that the system design process is of uttermost importance. Monitoring and measurement devices used in Arctic conditions need to be adapted to the clothing and the bad lighting conditions. This will result in new designs that might need stronger batteries and larger buttons so they can be used with gloves.

Further, people get exhausted after a certain time period. A human factor/ ergonomic based design can decrease the time a maintenance worker spends on maintaining equipment. Due to the cold weather this will be especially important, as the time a worker can spend in the cold is very limited. Thus, the system designing process should be followed to optimize designs for maintainability, as this will lead to higher reliability.

4.5 Methods to achieve high reliability and production assurance under Arctic conditions

Especially under Arctic conditions production assurance is of major importance. As the market is becoming increasingly competitive, industrial customers require better performance of their equipment.

Achieving high reliability and production assurance means to reduce downtime and to increase uptime. Downtime and uptime form together the major states a system can be in. Figure 24 gives an overview of "Uptime and Downtime" related terms.

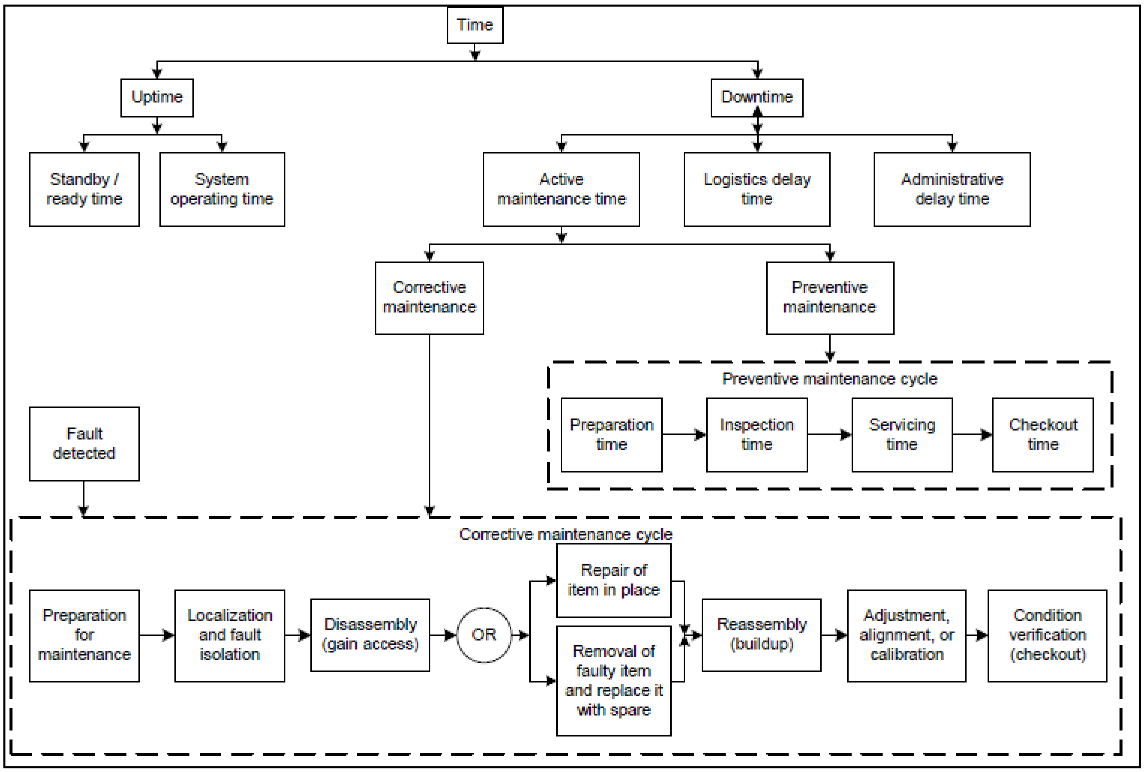

Figure 24: System uptime and downtime (Markeset, 2012, p. 13)

It can be seen in the figure that uptime can be divided into:

- Standby/ ready time
- System operating time

On the contrary downtime can be developed into:

- Active maintenance time
- Logistics delay time
- Administrative delay time

Active maintenance is further divided into

- Preventive maintenance

- Corrective maintenance

The main goal of operations is to achieve as much uptime in a system as feasible. The assessment system regarding its maintenance strategy will give the optimal solution. If e.g. preventive maintenance is performed, logistic and administrative delays become less likely. The actual health of the system will be predictable, allowing for better planning and production assurance.

Production assurance is defined as “activities implemented to achieve and maintain a performance that is at its optimum in terms of the overall economy and at the same time consistent with applicable framework conditions” (International Standard ISO, 2008, p. 6). Thus, to achieve higher performance, systems need to be specifically designed regarding their functional and technical requirements.

The following overview shows different measures that can be influenced to achieve higher reliability and performance of a system regarding overall operations and design.

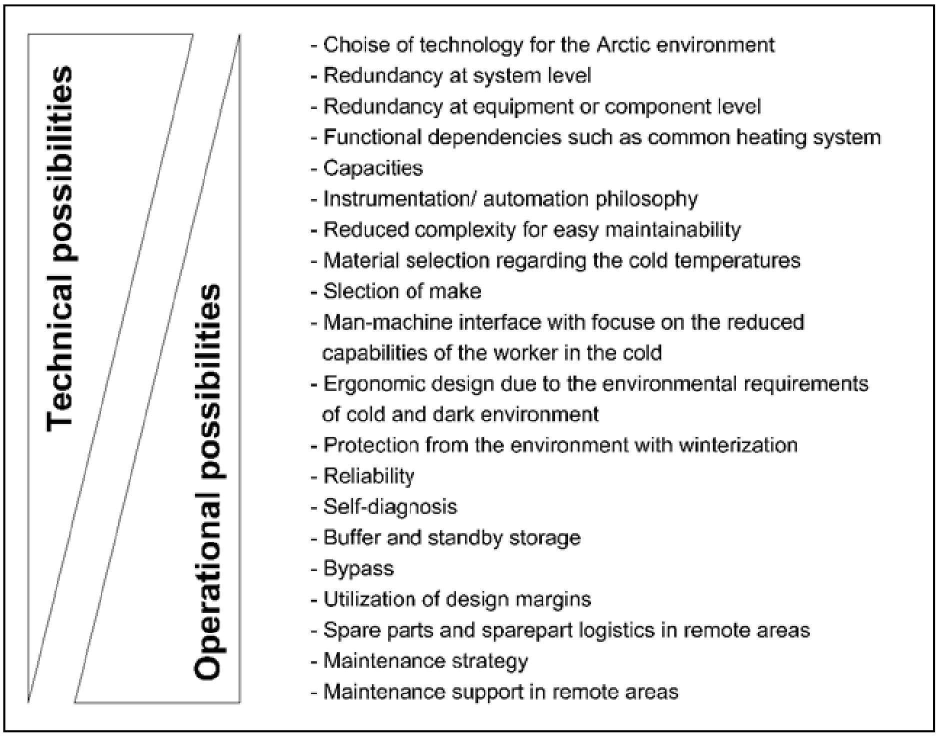

Figure 25: Measures to influence production performance (modified, original by International Standard ISO (2008))

It can be seen in this figure the environment (e.g. cold climate and remoteness) is the key influence which needs to be considered to improve the design of technical equipment. Further, logically it can be seen that the environmental factors have a major impact on the operations that are necessary to optimize performance of a system. The overall goal is to create systems that have optimized RAMS (reliability, availability, maintainability, supportability) characteristics by applying the above mentioned measures (Markeset, 2010).

The availability has a large impact on the production performance.

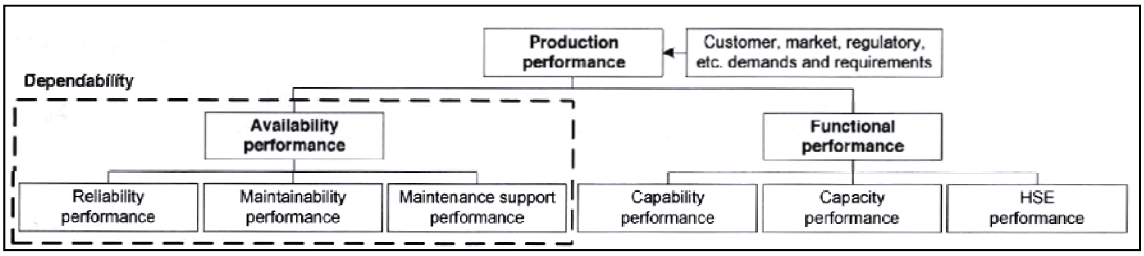

Figure 26: The production performance concept (modified by Markeset (2010), original by Barabady et al (2009))

Figure 26 shows the influencing factors on availability performance:

- Reliability performance
- Maintainability performance
- Maintenance support performance

Reliability performance is the achieved percentage of the designed reliability. If a system fails above average, the reliability performance will be low. Reliability can be designed into a system, but it is often impossible to establish 100% reliable systems. As discussed in the challenges reliability will be especially influenced by the cold temperature in the Arctic. As little experience with current systems has been made in this climate, the reliability design will need to have design margins to achieve optimized performance. This means, for example, that it can be advantageous to select materials with higher performance in cold conditions.

The maintainability performance will, just as the reliability performance, be largely influenced by the environment. If there is no possibility to increase reliability (due to cost or feasibility) designing for maintainability is the alternative. In the Arctic, especially the effect of the cold temperature and bad lighting conditions, will negatively affect maintainability. Cold temperatures and wind reduces the working time a worker can spend on a task outside. The clothing limits the workers abilities. Cold can further lead to icing and snow on openings, reducing the accessibility of equipment.

Finally, maintenance support performance must be optimized to achieve optimal maintenance performance. As the Arctic is a very remote and inaccessible region, spare part delivery must be well planned. Delays can result, due to waiting on weather or sea ice restricting operations.

To summarize, it can be said that increased availability will increase production assurance as increased production availability is achieved. To achieve high availability the influencing measures in Figure 25 shall be applied to achieve optimal production performance of a system.

5 Goliat FPSO

The following chapter is based on information has been made available by Eni Norge, to be used in this thesis (Rekdal, 2012). Further information's have been gathered on the website of Eni Norge AS (2013).

5.1 Introduction

The Goliat field was discovered in 2000. It consists of the Kobbe and the Realgrunnen formations. The development takes place with a joint cooperation between Eni Norge AS (operator, 65%) and Statoil (35%). Production is planned to start in late 2014. The estimated recoverable reserves are 174 million barrels of oil. It is, according to Eni Norge, the first oil field that will be developed in the Barents Sea.

The field development consists of a cylindrical FPSO (Floating Production Storage and Offloading) by "Sevan Marine" which will be connected to 22 wells in eight subsea templates. Installation of the FPSO is planned in summer 2014.

Figure 27: Sevan 1000 FPSO (Eni Norge AS, 2013)

The process deck will have a diameter of 107m, while the main deck will measure 102m. The elevation of the main deck will be 44m with a normal loaded draft of 30m (Rekdal, 2012, p. 3).

Produced oil will be stored in cargo tanks in the hull. The produced gas will be reinjected into the Kobbe reservoir. To store the oil, it must be stabilized on the platform making it necessary to implement separation equipment. The oil will then be offloaded to tankers and shipped to the market. It is important to mention that Goliat will be supplied with electrical power by a cable from shore, to ensure energy supply and reduced pollution due to exhaust.

5.2 Environmental conditions

In the following section the environmental conditions of the Goliat field shall be briefly highlighted.

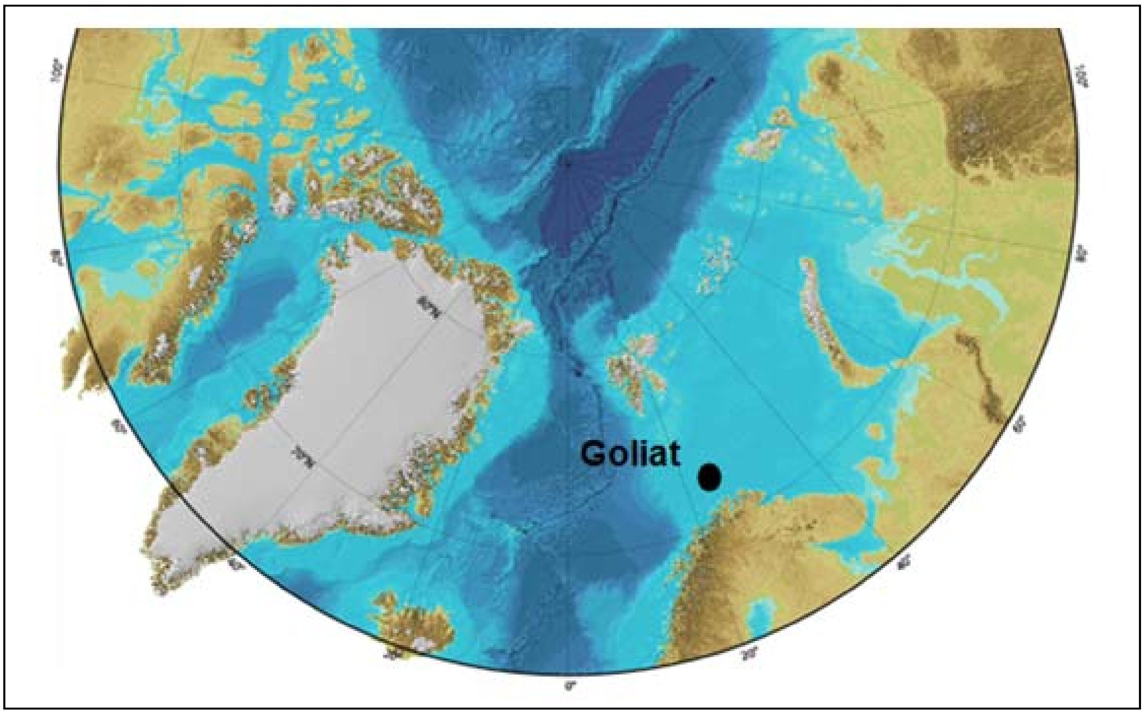

Figure 28: Goliat (modified, original by National Geophysical Data Center (2012))

The Goliat field is located in the Norwegian Barents Sea. This region lies within the region that is considered to be Arctic.

The next image shows the 100 years temperature range in course of a year.

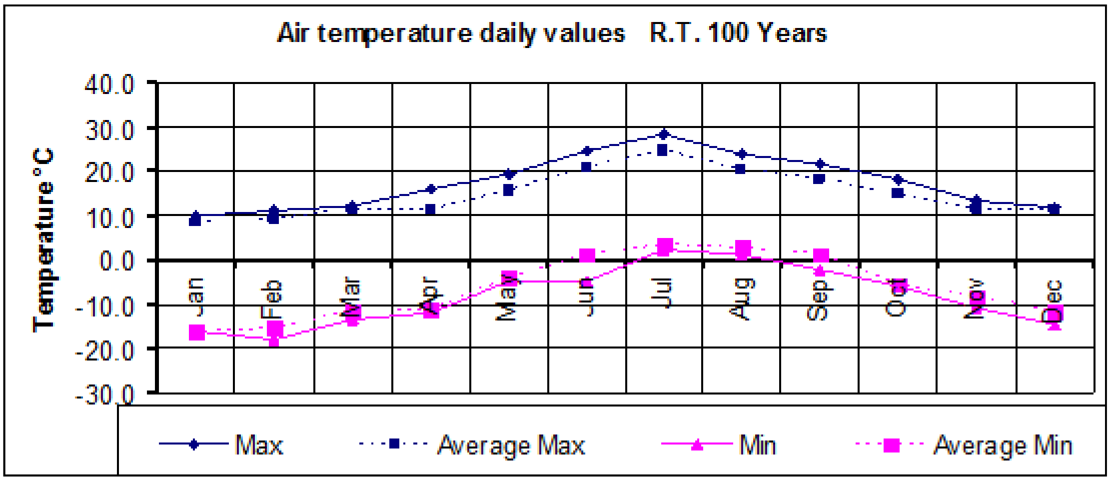

Figure 29: Expected temperature range for the Goliat field (Rekdal, 2012, p. 7)

The minimum average temperature in January and February are expected to be around -15°C. Sea ice and icebergs will most likely not occur at the Goliat location (NORSOK, 2007, p. 27).

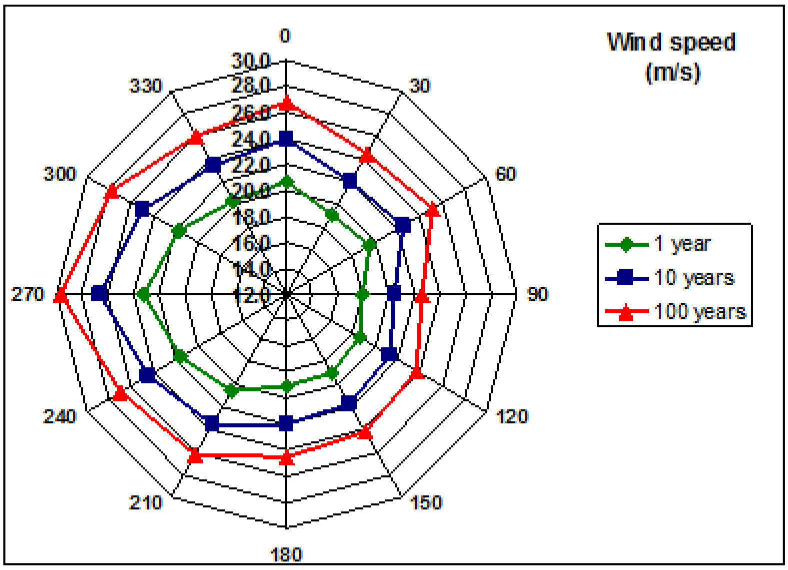

Figure 30: Expected wind speed/ direction for the Goliat field (Rekdal, 2012, p. 7)

According to Figure 30, rather high wind speeds can be expected primarily from an western direction. The maximum wind speed to occur in 100 years equals 108 km/h (30 m/s); in 10 years this value equals approximately 100 km/h (27 m/s) and every year 80 km/h (26 m/s).

Weather data shows that strong winds from the western direction are significantly warmer then the less strong winds from the eastern direction. Thus, the possibility for a combination of cold temperatures and strong winds, which will lead to a strong wind chill effect, is low.

Additionally, other factors such as remoteness and darkness, which have been presented previously, apply and must be considered in the design.

5.3 Winterization measures of the Goliat FPSO

The following chapter will discuss some of the winterization measures which are designed into the FPSO to overcome the challenges of the Arctic.

According to Rekdal (2012, p. 8) the FPSO's main deck will be sufficiently elevated to avoid effects from sea spray that could generate ice build-up on the deck. In addition, there are sufficient capacities available to cope with accumulations of spray icing on the hull and snow on top of the platform. Thus, the floating stability can be kept even under large additional load accumulations.

Rekdal (2012, p. 11) points out that the main principal for the design of the FPSO is to install shielding against the environment such as rain, snow and wind. According to this principle, it has been decided to enclose as much equipment as possible in the utility area. The process area has a risk for gas leakage and gas accumulations. The walls are therefore semi-opened and only the roof is fully closed in this area. This allows for sufficient ventilation of the area as well as protection for the workers against wind, snow and rain. In case of an explosion the main structure and fire divisions will remain intact. The next image gives a closer view of the hull of the Goliat platform.

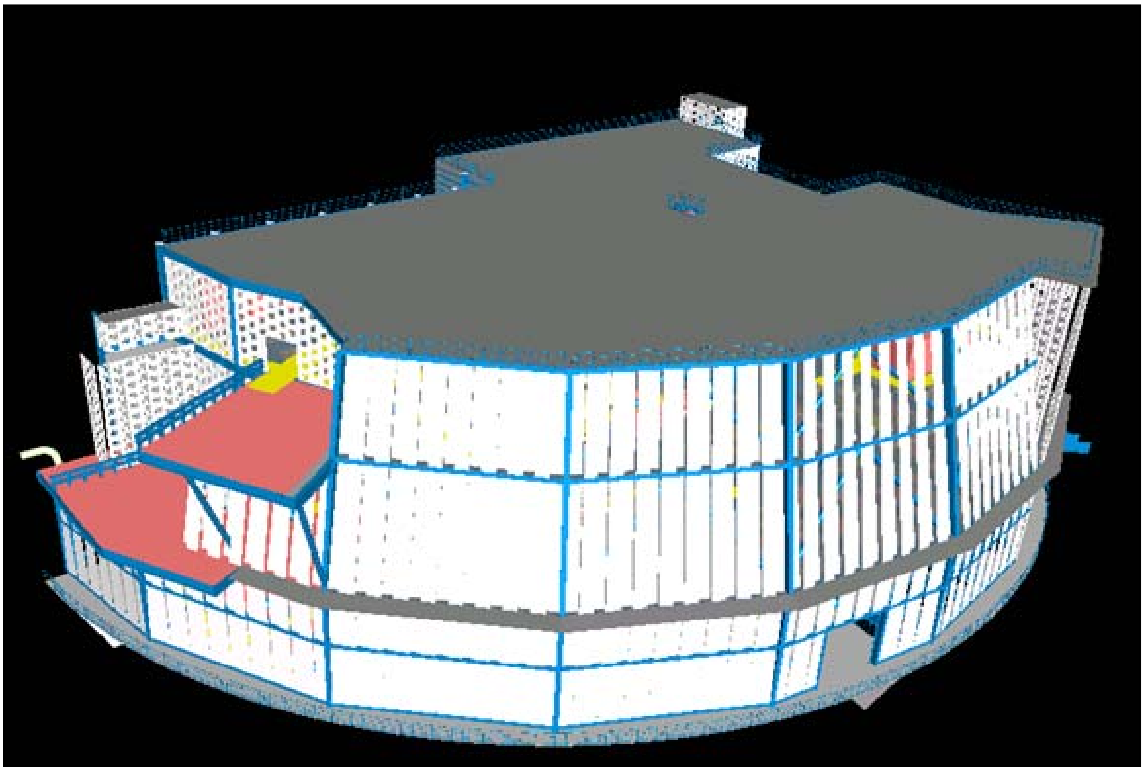

Figure 31: Goliat platform winterization wall (Rekdal, 2012, p. 13)

The wall will have multiple positive effects (Rekdal, 2012, p. 16). The roof will cover all process areas so that less water will have to be drained from the platform. Further escape routes and equipment are protected from the outside environment so that there is less need for special protection systems. Since the walls are semi-opened there is no need for mechanical ventilation. Finally, the wall and roof will protect the areas against falling ice that might have built up on cranes on the FPSO. Furthermore, the flare tower will be cantilevered over the outside hull to avoid ice falling onto the main deck which is shown in the figure below.

Figure 32: Goliat with cantilevered flare (APTOMAR AS, 2012)

Although the wall will protect large areas of the platform, there is still need for large amounts of heating and heat tracing. Therefore, the platform will be supplied with electricity via a cable from land. In addition, the platform itself will be equipped with a high efficiency generator (Eni Norge, 2013). This will improve reliability for energy supply. All electrical cabinets are heated to avoid ice accumulation. Further heating is installed on liquid carrying pipelines to avoid freezing. An important measure is the heating of the ventilation intakes to avoid ice crystals entering the ventilation system. These crystals could lead to water accumulations in the ventilation systems. Additionally, snow-drift simulations have been performed to identify areas with large snow pile-ups.

The working schedules for the workforce are adapted according to the weather conditions. Due to the conditions, the workforce will only be allowed to work in the cold for a certain period of time. To protect the workers against the effects from the cold, the general working suits are improved with some smaller layers of wool. A major improvement has been made with the survival suits for evacuation and during helicopter transportation (Lewis, 2013). The new suits have better insulation on hands and feet. Additionally, the way the suits are put on has been improved for easier use. Further, a signal is now not only sent to air transportation vehicles, but also to ships to improve detectability during rescue operations.

6 Summary and conclusion

In this Master thesis operations and maintenance challenges for Arctic offshore platforms are discussed. These challenges have a large impact on the feasibility of future projects.

In chapter one the outlines of the thesis are laid and the problem is stated. Here the different questions are formulated that will be discussed in the following chapters. Further the delimitations are defined. The local extend of this thesis covers the Arctic in general but focuses on the Norwegian Barents Sea.

In chapter two the theoretical background is discussed. Here oil and gas developments in Arctic regions are discussed. It becomes clear that the development is just beginning. Further the possible geographical extend of the Arctic is defined. This is difficult as there are different opinions about the Arctic extend as characteristic conditions can not only be found above the 66.56° north latitude. Further this section includes a short definition of operations and maintenance.

Engendering and management is based on observation of the environment. We must design and manage according to the local conditions that apply. Chapter three therefore covers in depth challenges that can be expected. The physical environment such as ice and cold temperatures are described. This includes also operational challenges such as human factors or necessary design changes which are achieved by winterization. Further challenges related to the remote location for e.g. communication and the transport of supplies are highlighted.

Challenges are then in chapter four discuss with regards to maintenance and reliability. The importance of the correct maintenance strategy is discussed as it has a major influence on operations. Due to the benefits of planned maintenance on the overall productivity this type of maintenance is suggested. If sufficient resources are available condition based maintenance (CBM) should be applied in the Arctic as it allows for better planning regarding spare part delivery times. Additionally in this chapter the importance of a design for human factors/ ergonomics is pointed out and discussed regarding the system design process. Finally measures to improve the reliability and production assurance from the ISO 20815 Petroleum, petrochemical and natural gas industries - Production assurance and reliability management (2008) are suggested.

In the final chapter five the Goliat FPSO (Floating Production Storage Offloading) is presented as an example for a winterized platform. The Goliat field will be the first field which is developed with an offshore platform in the Norwegian Barents Sea. The platform, which will be operated by Eni Norge, has been specifically designed to withstand the harsh Arctic environment. The environment the platform will be placed in will be shortly discussed. Finally, measures such as a winterized hull are shortly presented.

The challenges and solutions presented in this thesis show the difference of the Arctic to other regions. It is therefore of importance that first of all the engineers and managers of companies that intend to explore the Arctic become aware of these challenges. New designs and technologies are on the rise. A knowledge base must be established to better share already gained experiences. The impact of maintenance on the overall running cost of offshore platforms in the Arctic will make further research in this field necessary.

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Declaration

I hereby declare that I have written this Master thesis independently. Only named sources have been used. Literally assumed bodies of thoughts have been indicated.

Stavanger, 15.06.13

Place, Date

Signature