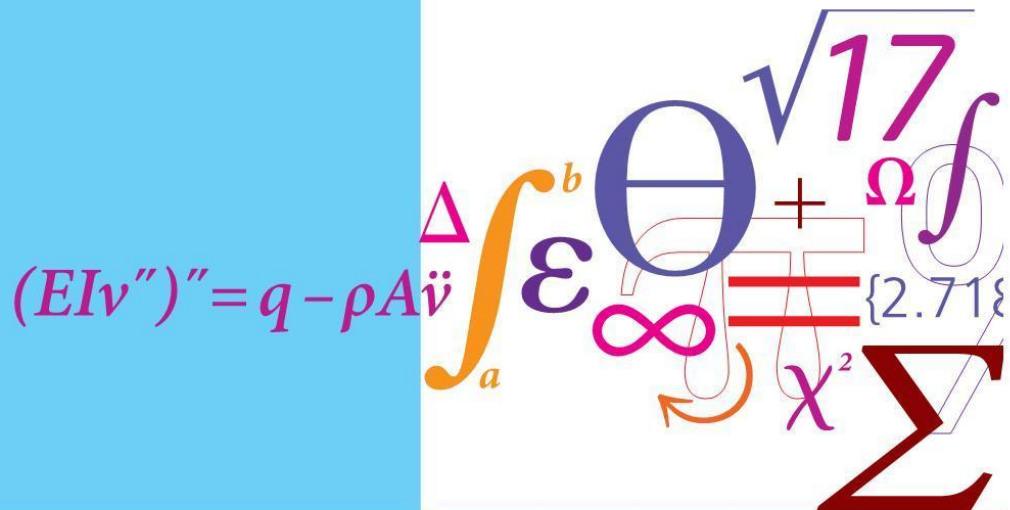


Estimate of risk and hazard on the maritime traffic in the waters of Greenland

Master Thesis



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1 Abstract

A Bayesian network illustrating the connections between the most common hazardous situations marine traffic encounters in Greenland is presented here. This is achieved by analysing primarily qualitative data in conjunction with experience. Quantitative data will also be applied to the extent that it is possible, as the data is limited. A risk analysis is undertaken which describes the different situations in-depth, explaining the individual situations and the links between them in order to get an overview of the possibility for the numerous combinations that could occur.

The qualitative data is gathered from interviews carried out with current and former sailors who have experience sailing in the waters of Greenland. The sailor's experiences are used in order to provide estimates of how the different situations progress and are connected with each other in the Bayesian network. Furthermore, these experiences provide a basis for making estimations of the various individual possibilities. This amounts to estimations of the individual and the combined situations that can arise, resulting in calculations giving an overall estimation of the probability of a ship being exposed to dangerous situations of varying degrees.

All calculations will be executed in the freeware program AgenaRisk. These calculations are done on the basis of Bayes' equation and amount to the possibilities for each individual situation. Some of these individual situations will be divided into categories describing dangerous situations and critical situations. The remaining situation are residual situations that are not necessarily dangerous, most of these are common and pose only a minor danger, if any at all.

A sensitivity analysis will be conducted placing focus on the situation that is concerned with rescue missions. This will only be performed in relation to the situation concerning a rescue mission as this situation is the worst possible outcome.

2 Introduction

There has always been hazards linked with sailing ships no matter where in the world this has been done, indeed there will always be an increased hazard when sailing in the waters of Greenland. This is primarily due to the harsh conditions in that region; the constant low temperatures, limited number of inhabitants, decreased possibilities for communication and constraints placed on successful rescue missions increase the hazards when navigating the waters of Greenland.

This project aims to analyse some of the various factors and potential hazards that are involved while sailing through the waters of Greenland. However, it does not include environmental factors. These are:

- Collision (with ship, ice or ground)
- Damage to the ship, cargo or crew
- Beset in ice
- Sinking or capsizing
- Icing (decrease in stability)
- Lack of training / information
- Voyage planning
- Traffic
- Weather
- Bad seamanship (human factor)
- Rescue mission

The intended objective will be achieved by estimating the extent of the potential for the occurrence of the various hazards while sailing in Greenland and subsequently the different hazardous scenarios will be analysed. Through these efforts a calculation will be made of the overall estimated potential for the occurrence of the various hazardous scenarios.

If there are any doubts about the possibility a worst case scenario will always be proclaimed. In order to acquire a realistic view of these estimations the probabilities will be gathered through empirical data and interviews with sailors who have experience sailing through the waters of Greenland. There is a limited amount of statistical data simply because not all small or minor accidents or near misses are reported as they should. Therefore, the data that are available will be flawed.

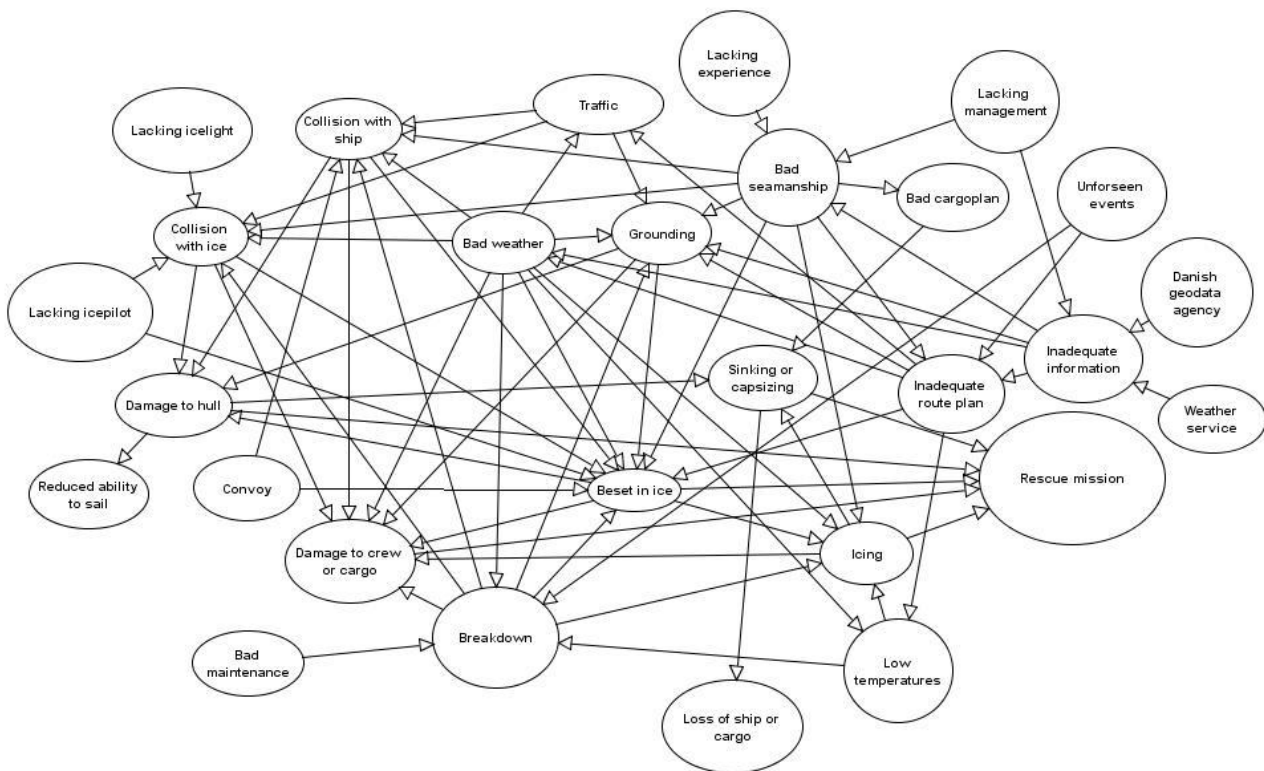
The interviews will be completed with sailors who often sail the waters of Greenland and therefore have a thorough understanding of how the conditions influence the maritime sector. The answers will be based on the individual sailor's beliefs and experiences and will be an estimate. In fact, the answers will give the best estimate as possible but will still be an estimate.

The calculations will be done within a Bayesian network which will describe the different scenarios and the manifold possibilities of the outcomes. A large network will be created and the overall possibilities will be calculated. This will then be divided up into individual networks starting from the main hazard in order to be able to evaluate the individual hazards. The calculations will be performed in the freeware program AgenaRisk. This program uses Bayes' equation for the calculations.

This project is completed by a holder of an STCW 95 A-II/2 and STCW 95 A-III/1 certificate, therefore previous experience gained from different types of ships and in-depth training will be applied.

3 Main hazards

All potential hazards have been identified and all possible connections found. With this information a complete Bayesian network can be completed. The complete network can be seen in appendix 1 and in the following:



3-1 - Total Bayesian network

As can be seen from the complete network different nodes are connected to each other through other nodes. One situation can lead to another which then leads to other situations. The nodes that have many parents and children are categorized as main hazards that will be evaluated more thoroughly throughout the project. The remaining nodes are residual nodes, these are the parent or children nodes.

The main hazards are:

- Damage to hull
- Collision with a ship
- Collision with ice
- Beset in ice
- Bad seamanship
- Inadequate information
- Inadequate route planning
- Grounding
- Breakdown
- Traffic
- Weather
- Sinking or capsizing
- Damage to crew or cargo or general average
- Low temperatures
- Icing
- Rescue mission

For each hazard there are two possibilities which must be taken into consideration, first the possibility that the ship will be in a situation where this hazard is present, secondly, the possibility that the ship is exposed to the hazard. The possibility for the situation (PS) and the possibility of exposure (PE) will, for some hazards, be documented or the result will be given. In some situations the PE will be redundant as some situations only have a specific outcome. If the damage cannot get any worse then the PE is redundant.

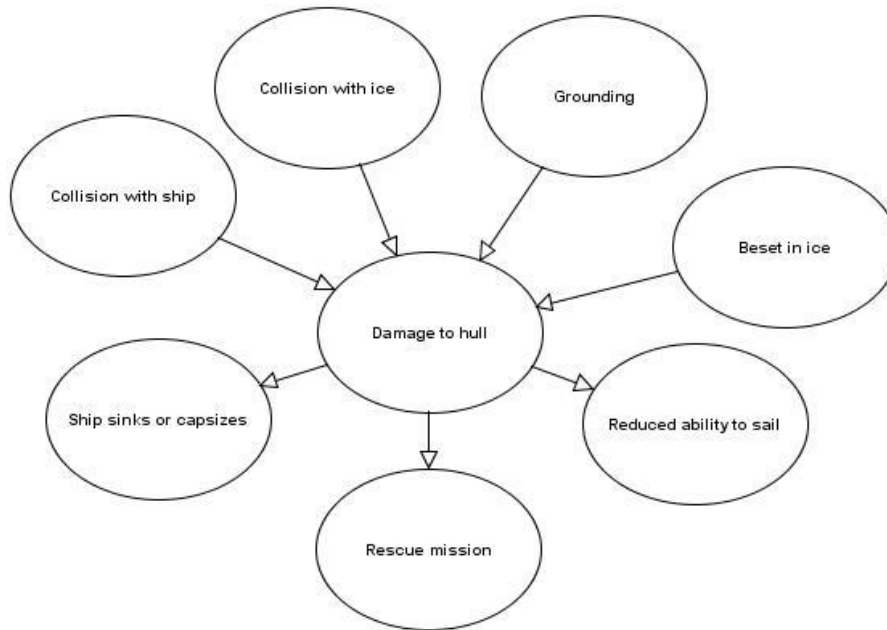
Individual Bayesian networks have been created for the main hazards in order to break the network down as the whole network is intricate and the individual networks allows for a better overview of the main hazards.

The main hazards and children nodes will be calculated based on an evaluation of the different scenarios and various combinations of hazards. The possibility for some hazards has already been documented or will be assessed through interviews with sailors.

3.1 Damage to the hull

The main hazard “Damage to the hull” covers any type of damage to the hull. No form of damage to the hull is desired but in some situations the damage will only be minor which enables the ship to proceed to the nearest port without complications. This also includes ships with a double hull where only the outer layer has been breached and no flooding inside the main part of the ship has occurred.

The Bayesian network for the main hazard “Damage to the hull” is as follows:



3-2 - Bayesian network - Damage to the hull

As can be seen from the network it is primarily an exogenous source that can cause damage to the hull, the damage inflicted to the hull has to come from a solid source that is powerful enough to bend the steel. In some rare cases damage to the hull can occur either as a result of corrosion from a corrosive material on board that has leaked out or on account of rust. These cases have not been included, however, as they are rare and corrosion from rust primarily occurs in older ships with very low maintenance.

Damage to the hull could occur in the event that the ship has a collision with either a ship or ice, strikes the ground or becomes beset in ice. When a ship is beset the edges of ice can strike the hull, inflicting damage. The surrounding ice will move with the current and the wind, pushing against the hull.

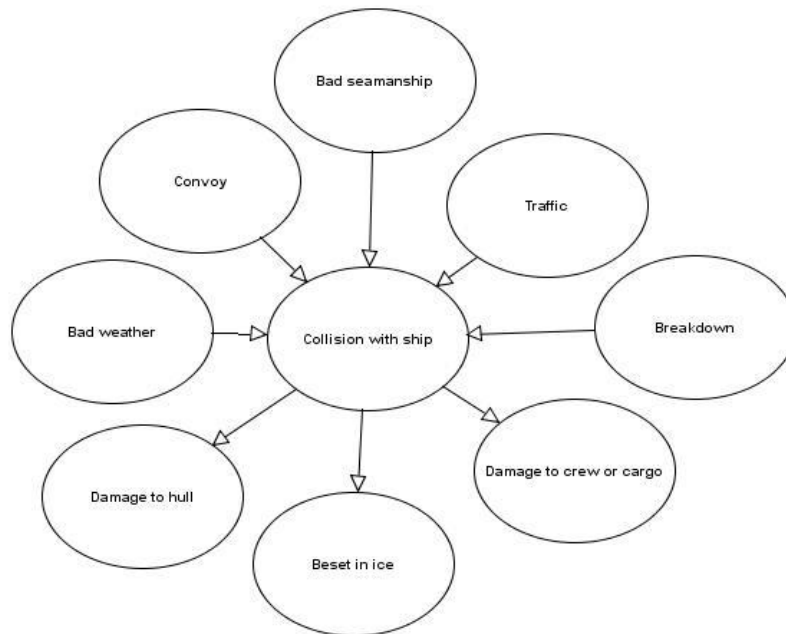
Most of the larger ships are so called 2- or 3-room ships which means that they can have 2 or 3 rooms flooded, without sinking. The stability of the ship will be influenced depending on the rooms that are flooded and any ship with a flooded room will need to proceed to the nearest port for repairs if this is possible in the given situation. If too large a volume of the ship has been flooded this will lead to the ship sinking or capsizing.

Damage to the hull could pose a threat to the environment as a spillage of oil or other hazardous materials could take place.

3.2 Collision with a ship

Many initial events can cause a collision with another ship. Some can be self-inflicted and others due to an exogenous source. These events could be a breakdown on board if the ship loses power, thrust or manoeuvrability. Any of these events are particularly bad if the ship is in an area with

traffic, in a convoy or any other hazards are nearby such as ice or ground. If other ships experience a breakdown they will pose a hazard to the ship in question. The node “Traffic”, symbolises that other ships are in the vicinity of the ship in question, therefore a collision with a ship is impossible if there is no traffic. The more severe the traffic the higher is the risk for a collision. The Bayesian network looks like this:



3-3 - Bayesian network - Collision with ship

Lacking good seamanship could influence a collision if the sailor is inattentive, does not obey the rules of navigation or has made a bad route planning. A bad route planning could also cause the ship to end up in bad weather but this could also happen inadvertently. A ship in traffic under the influence of bad weather has a higher risk of colliding with another ship as its manoeuvrability and visibility are always better in good weather.

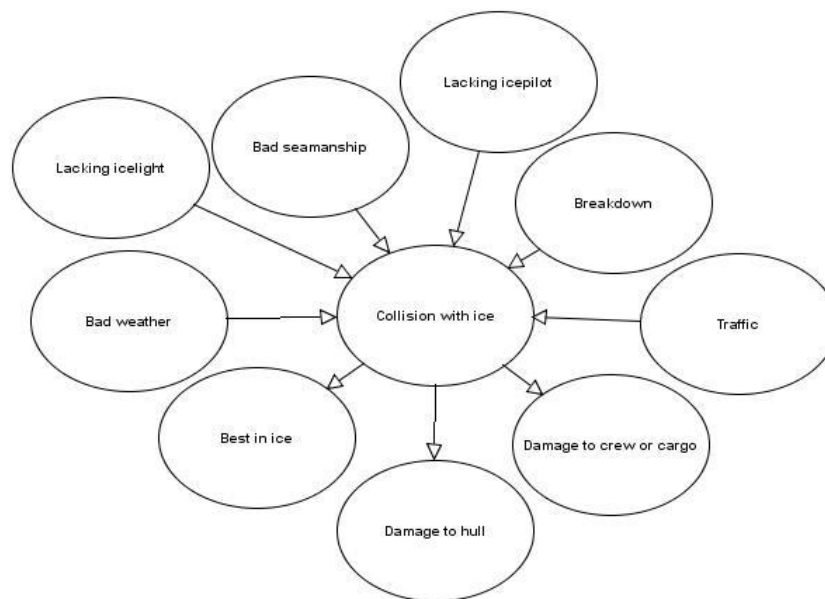
If two ships collide the hull could get damaged on both ships. Many factors influence the degree of damage in a collision. A collision will always cause the ships in question to become still so that the degree of damage can be investigated and this increases the risk of getting beset in ice. If the traffic is heavy and the passage is narrow this increases the possibility of a collision as the ships have to sail close to each other. This also applies when ships are in a convoy; here the ships sail in a row in a passage of ice and if any ship in the line has trouble this could affect the other ships behind it as these could collide with it if they are not able to stop before hitting it. Ships try to avoid this by keeping a distance but if the distance is too large there is a risk that the ice would close in.

If a ship has a breakdown that disables its manoeuvrability it must clearly signal this to other ships in order for the other ships to navigate around it. This is done on the radio and with lights or day signals. If the breakdown happens in heavy traffic there is a high probability that ships could collide. Navigational equipment could also break down, resulting in the ship sailing blindly and unable to identify itself to other ships, this is especially critical if the visibility is decreased. If the visibility is decreased and the ship is unable to identify itself it must use gongs and the ship's whistle in the hopes that another ship will hear it.

In bad weather some ships may have to stray from their original route or the manoeuvrability could be reduced, increasing the risk for a collision.

3.3 Collision with ice

A collision with ice could describe a situation where a ship hits a floating piece of ice but it also covers a situation where a ship is sailing through ice that is thin enough for the ship to break but then comes across ice that is too thick to break with its own power.



3-4 - Bayesian network - Collision with ice

If a ship collides with ice the same factors relative to the node “Collision with ship” apply. Though in this situation a collision will most likely be self-inflicted. The collision is not self-inflicted if the ship collides with ice as a consequence of not colliding with another ship. Given the choice a collision with ice is to be preferred over a collision with a ship as only one ship will be in danger. In addition, the possibility for a collision with ice is highly reduced if the ship uses an ice light and an ice pilot. Almost all ships use an ice light, almost none use an ice pilot. The sailors on most ships have sufficient experience so that no ice pilot is necessary.

If a ship collides with ice as a result of bad seamanship it could be on account of the sailor being inattentive to his or her surroundings or if the sailor has misread the ice charts and sails too close to the broken ice, or if the ship sails into an area where the ice becomes too thick for the ship to break it.

If the ship experiences a breakdown sending the ship adrift with no propulsion the ship could collide with ice as it does not have the ability to navigate around it.

In areas with a predominance of icebergs there is a tendency for the appearance of heavy fog which decreases the visibility. In these situations other aids must be used; here the radar is the best aid as larger icebergs appear on the radar screen. Icebergs that are too small to appear on the radar are usually too small to pose a risk to a traditional trade ship but this is not always the case, therefore

other precautions need to be in place. In heavy fog and ice the speed is decreased in order to minimize possible damage from ice so as to create more time to spot the ice visually. Moreover, an additional person will be stationed on the bridge in order to act as a lookout. Most ships collide with smaller pieces of ice on purpose in order to remove them and as a consequence hereof these ships plan to change parts of the steel structure of the bow every time the ship is in dry dock. The forces from the water also contribute to the need for changing the steel.

In bad weather or in swells the threat from ice is greater as the ice no longer is stationary. Large pieces of ice floes can be thrown around and heavy winds can gather these in formations that becomes impervious. Icebergs have been calved from glaciers that were created from compressed snow, consequently icebergs only consists of freshwater. It follows therefore, that 90% of the ice is located under water. With this large portion of mass and surface under water this means that the current and not the wind is the primary factor in driving the iceberg forward. This is important to remember when trying to circumnavigate an iceberg.

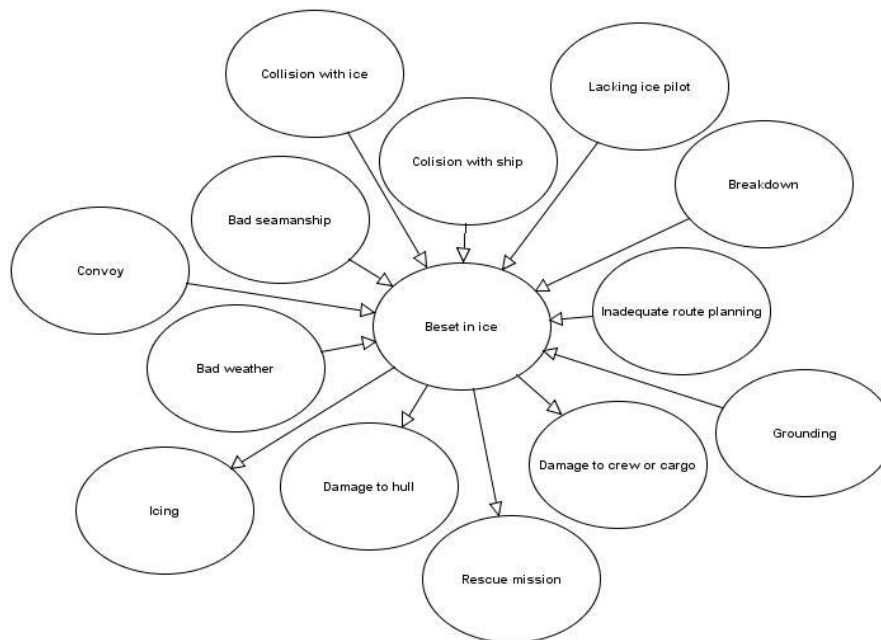
Royal Arctic Line (RAL) is the largest provider of transport by sea in Greenland. In some areas they sail all year round on the condition that the areas are ice free. RAL operates with the term “ice free areas”, these areas either have no ice or only glacial ice as glacial ice is easier to circumnavigate compared to pack ice.

Colliding with ice can create damage to the hull and possibly make the ship beset in ice if the sheets of ice behind it close in and become solid and too thick to break.

3.4 Beset in ice

If a ship is beset in ice it is stuck in ice without the possibility of moving from a given position on its own power. The way a ship becomes beset is if it sails in an area with too much ice and the ice closes behind it or if the ship is stationary and the ice then accumulates around the ship. The ship could become stationary if it loses power, has had a grounding, a collision or by choice. If the ship is stationary by choice and becomes beset then this is a case of bad seamanship.

A ship that becomes beset without being stationary could find itself in this situation as a result of bad weather, lacking route planning or bad seamanship. These situations could lead to a ship entering into waters with more ice than expected, resulting in the ice closing in behind it.



3-5 - Bayesian network - Beset in ice

When a ship is beset the surrounding edges of ice will push on the hull and thereby possibly damage the hull. If the ice is moving due to the wind and current this could potentially push the ship towards larger pieces of ice or ground, causing a collision or grounding. In a worst case scenario, the ship could sink. When beset there is a chance that the rudder could get damaged when the ice pushes on it.

The node “Beset in ice” is the node with the most parents, therefore this is the outcome scenario from most types of situations. In order for a ship to become beset, pack ice needs to be present. Pack ice is large sheets of flat ice; the amount of this is measured in parts of ten such that 6/10 means that any given surface in the area is covered in 60% ice.

According to the Canadian Coast Guard:

“non-ice-strengthened ships with an open water speed of about 12 knots can become hopelessly beset in heavy concentrations of relatively light ice conditions, whereas ice-strengthened ships with adequate power should be able to make progress through first-year ice of 6/10 to 7/10 concentrations. Such ships are often able to proceed without any assistance other than routing advice. In concentrations of 6/10 or less, most vessels should be able to steer at slow speed around the floes in open pack ice without coming into contact with very many of them.”¹

First-year sea ice is ice that has no more than one year growth, it grows in the fall and winter but does not survive the spring and summer months. The thickness typically ranges from 0.3 metres to 2 metres.

¹ <http://www.ccg-gcc.gc.ca/Icebreaking/Ice-Navigation-Canadian-Waters/Navigation-in-ice-covered-waters>

The Canadian Coastguard gives four points of advice on how to behave when sailing in ice:

“Experience has proven that in ice of higher concentrations, four basic ship handling rules apply:²

1. keep moving - even very slowly, but try to keep moving;
2. try to work with the ice movement and weaknesses but not against them;
3. excessive speed almost always results in ice damage; and
4. know your ship's manoeuvring characteristics.”

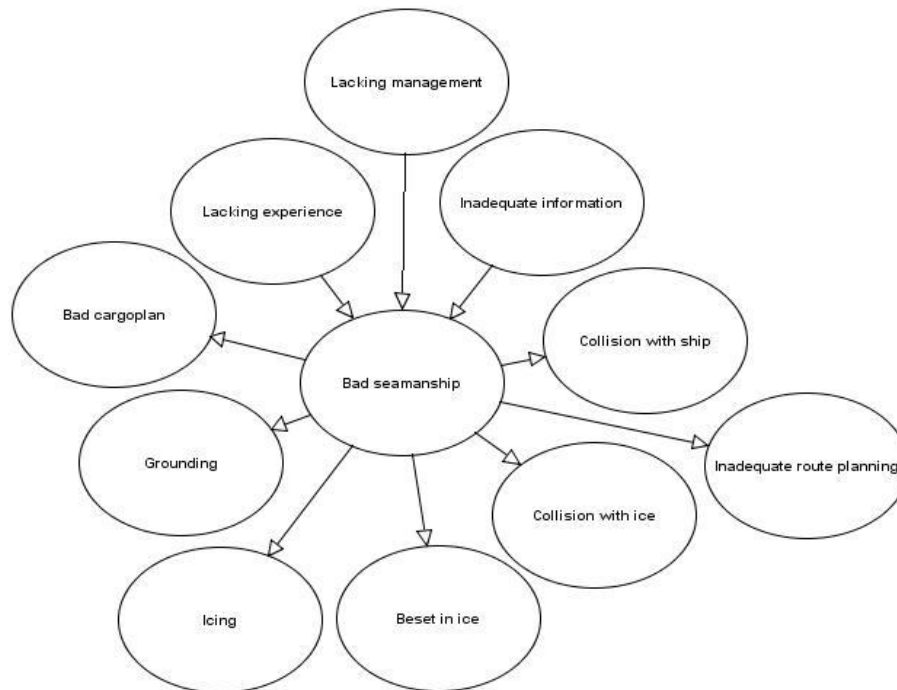
In other parts of the world when a ship is beset the common way of setting it adrift is to use icebreakers but not in Greenland. There is no icebreaker service in Greenland and a beset ship is therefore forced to wait until the ice melts or is broken in another manner. But if necessary the ship's owner can request an icebreaker from Canada, this is only possible on the west coast of Greenland.

3.5 Bad seamanship

The term “seamanship” is used in conjunction with many different types of legislation and covers many different things but the essence of the term is that any sailor at any given time is required to show good seamanship, meaning that the sailor should always do the correct thing in any given situation. The sailor should not cut corners or misbehave but always show respect towards other ships, the environment, other people or when performing a job.

² <http://www.ccg-gcc.gc.ca/Icebreaking/Ice-Navigation-Canadian-Waters/Navigation-in-ice-covered-waters>

Any given sailor is taught to comply with this and to most this is a sacred term to live and work by but sailors are humans and humans make mistakes, and when operating in an environment such as Greenland the crew will be impacted by the low temperature, and the lack of light and visibility. These mistakes could also be influenced by lacking experience, lacking management or inadequate information or equipment.



3-6 - Bayesian network - Bad seamanship

The node “Bad seamanship” covers the human factors involved in sailing ships. As can be seen on the Bayesian network the human factor can also be influenced by bad or wrong information, this combined with an inexperienced sailor or a sailor exposed to fatigue that cannot detect the mistake only enhances the possibility of errors. If the sailor is lacking experience or has received wrong or inadequate information the sailor could be unaware that he or she is exhibiting bad seamanship.

Humans exposed to the elements in an arctic environment tend to make more mistakes than they otherwise would as the conditions demands constant attention to everything in their surroundings and:

“long periods of time exposed to darkness, reduced visibility and cold temperatures have detrimental effects on cognitive capabilities as well as physical.”³

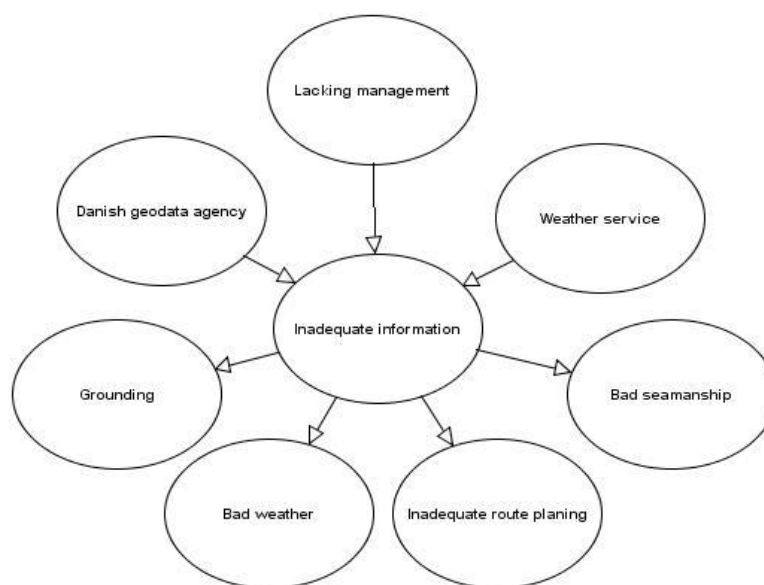
This combined with the fact that sailors normally work many hours daily, often with no periods of more than 6 hours to rest, can only lead to human errors. The tradition prescribes 6 hours work then 6 hours rest every day for the officers on the bridge, the engine officers has fewer hours on the weekends and traditionally they work 12 hours straight on other days. Some ships have begun to stray away from the traditional working plan as it has become recognised that 6 hours of rest is not enough for a complete night’s sleep and dividing the sleep into two could lead to fatigue. It is not uncommon for an officer to work 14-16 hours a day, especially if a large operation needs to be carried out such as a port call or cleaning of the cargo holds.

³ <http://blog.lr.org/2012/08/the-issues-of-working-in-arctic-conditions/>

3.6 Inadequate information

When navigating a ship, no matter where in the world, different types of information on the area and conditions are needed. Some static information is gathered from publications found on board all vessels; this is information on the nature of the area such as radio channels to use for communication, placement of buoys and lights and sunken ships etc., without this information the sailor could technically be sailing blindly unaware of the dangers and perils ahead. These publications need to be updated regularly, some ships use paper publications that have to be updated manually but most have made the switch to electronic publications that are updated online. Therefore, these publications are not considered as a hazard. The information given to the sailors in paper charts is inadequate, the reason for this is covered in another chapter of this project.

Dynamic information given to the sailors is concerned with the weather, these are frequently updated and are considered adequate.



3-7 - Bayesian network - Inadequate information

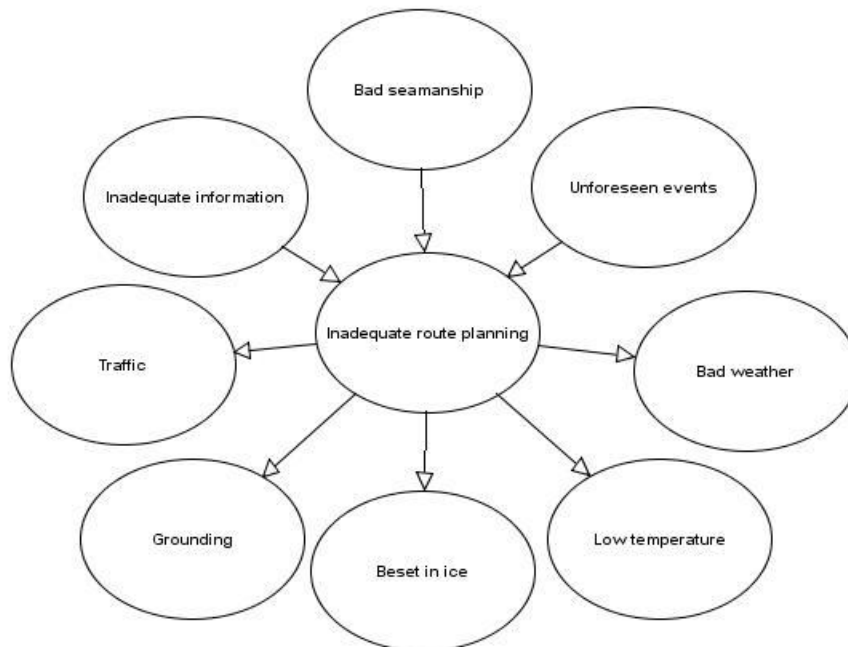
The node “Inadequate information” could theoretically cover any area in the world and is not specifically peculiar to Greenland. The information that could be flawed from certain providers is specific to Greenland.

It is important to have a good link of command to ensure that all the necessary information is provided to the sailor at the helm as he or she is the one making the critical decisions, sometimes this is done in a split second. On a ship the captain’s standing orders are the first rules to obey by when having to make a critical decision. No standing orders are the same as they reflect the individual captain’s command philosophy but they all contain a list concerning what to do in particular critical situations compiled for the specific ship and captain.

The management ashore and on board have the responsibility that information is passed on to the remaining crew. Lacking management could result in information not getting passed on or misinformation, resulting in inadequate information.

3.7 Inadequate route planning.

Inadequate route planning is influenced by three factors: inadequate information, bad seamanship and unforeseen events.



3-8 - Bayesian network - Inadequate route planning

Unforeseen events are as the name says unforeseen, this could be anything from sudden changes in weather to unexpected traffic or ice, which can result in the ship needing to change its course from the original route plan.

If the route planning is influenced by bad seamanship this could mean that not all necessary information has been enclosed in the planning and if an emergency situation emerges then the sailors would have to find this information at a critical time instead of it being found in advance.

If the sailor is given wrong or inadequate information the basis for creating the route plan is misguided, resulting in an inadequate or wrong route plan. When creating a route plan the navigator has many different considerations. The route is planned in a chart from berth to berth. It is drawn in the chart in a way that hazards are avoided and when possible fairways are used. In the first instance, a route is found that bypasses land, shallow ground and other underwater hazards. Most of this information is located in the chart, therefore it is important that these are accurate and up-to-date. In the charts some information is variable as ships can sink creating an underwater obstacle or buoys can be relocated. Corrections for the charts will be sent out in order for the navigator to implement them, some use electronic charts which are updated automatically. If the ship crosses under a bridge the air draft should be considered and when navigating in shallow waters it is important to consider the squat effect, the size of this at different speeds for any ship should be common knowledge to the navigator making the passage planning.

In the route the distances are measured; knowing the ships service speed the date and time is roughly known in different positions. The route is then reconsidered taking into account the weather and ice information given. If troublesome weather crosses the path of the route in the specific

timeframes found, a change should be made to steer around this. When navigating in Greenland not only the weather information is considered at this stage but also the ice charts. The spread of the ice, the thickness and the concentration is considered and areas that are outside of the limitations of the ship are avoided. In some situations the possibility to participate in a convoy arises, this enables some ships to travel beyond their limitations. At this stage the prediction of tides and currents and checks of local regulations and warnings are also considered, this is done in tide tables and in the nautical publications.

Along the route routing and reporting services (VTS), and the availability of contingencies in case of emergencies are marked together with no-go areas in the charts.

3.8 Grounding

As stated earlier, the information given in charts is inadequate and therefore sailors cannot be sure of what the seabed looks like in some places. This gives an increased possibility for a grounding. Other factors such as bad seamanship, weather, traffic, a breakdown or lacking route planning could cause a grounding.

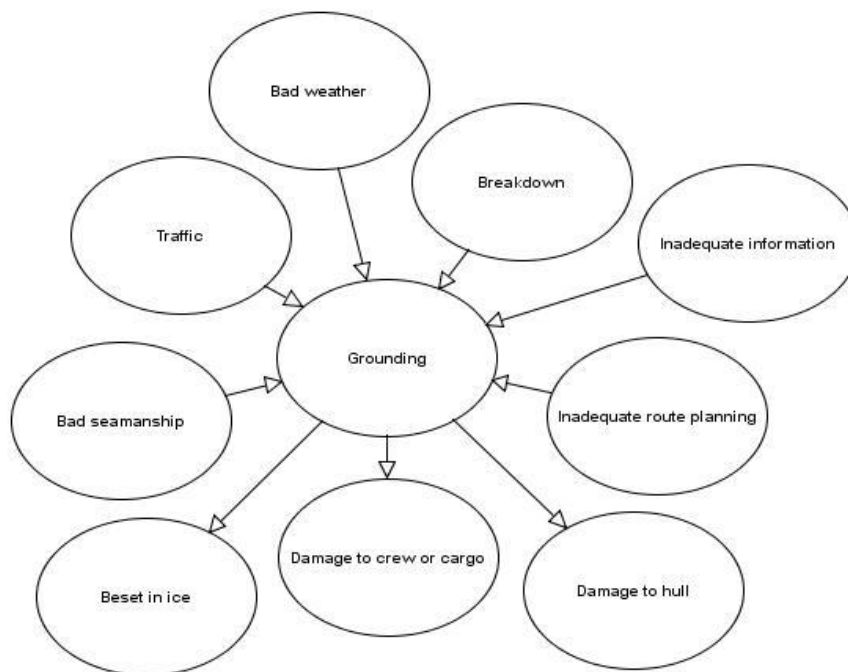


Table 3-9 - Bayesian network - Grounding

Bad seamanship could lead to a grounding if the sailor is inattentive of his or her surroundings. The sailor has sonar available which can indicate if shallow ground is closing in, but this does not help if it is a steeply submerged seafloor.

In bad weather, the manoeuvrability could be compromised or the necessity for a ship to sail closer to the shore could be increased, thereby increasing the possibility of a grounding.

When a ship has to circumnavigate other ships in traffic that ship is forced to stray from the original route into waters that could be uncharted. This also applies if there is a lacking route planning as there could occur situations that may have been foreseen but were not due to the lacking route

planning. If a route is planned to go through an area where the ground is too shallow for the ship to sail or too much squat will occur this is an inadequate route plan.

If the ship has a severe breakdown causing the main engine to be stopped the ship will be adrift with no propulsion. If the ship is in the vicinity of ground or sheers this could lead to a grounding.

No ship's crew desires to become grounded unless the ship has started to sink or capsize, in this case a grounding is desired as it could prevent the ship from sinking completely.

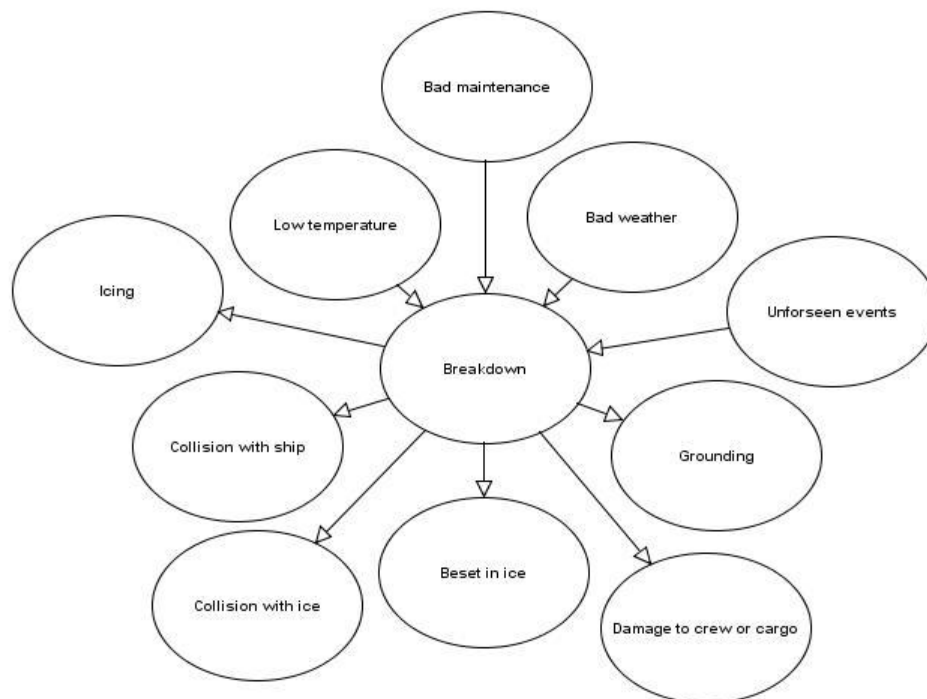
If a ship is grounded it is either able or unable to free itself. If unable, it could get assistance from other ships or tug boats, depending on the size of the grounded ship, the location and the surroundings. If able, the extent of the damage, if any, should be evaluated before setting the ship adrift. If the damage to the hull is large enough for the ship to be flooded, it is not desired to remove the ship from the ground before the crew and eventually cargo and other goods have been removed, and plans for the ship have been made.

When evaluating the extent of the damage the first thing the crew will do is to look at the monitor showing the water level alarms, if water has penetrated the hull and has started to fill certain parts of the ship the alarms will sound. If no water level alarms have sounded the crew will start to sound the ballast tanks in order to see if water has penetrated the outer hull. If no water penetration is found in any parts of the ship a survey of the outer hull and the conditions of the ground should be made. The most practical way of doing this is with a diver or submersible camera but in some situations this is not possible. If the captain decides to try to set the ship afloat he should be aware of the conditions of the ground as sharp sheers could rip the hull. The most optimal conditions for a grounding is on a soft seabed of sand. Information on the seabed can in most cases be found in the nautical charts. When setting the ship adrift again compartments that were dry after the grounding could get flooded as the ground could have blocked any potential damage to the hull.

If it is found that water is penetrating the hull considerations for an evacuation should be made. In Greenland it could in most cases be in the best interest of the crew and passengers to stay on board if the ship is not immediately about to sink. This is the case if there is nothing ashore and if the elements are raging.

3.9 Breakdown

A breakdown covers a wide range of possible situations. These could occur as failing hydraulics, engine breakdown, steering failure, failure of auxiliary systems, a breakdown of navigational equipment or rescue equipment. Any mechanical or electric installation are exposed to the possibility of a breakdown no matter how well-maintained they are. All larger trade ships have a well-defined maintenance plan, this does not exclude breakdowns. Minor breakdowns will be an almost daily occurrence, larger breakdowns that could have an influence on the ship's ability to continue the planned route are rare and almost always unexpected.



3-10 - Bayesian network - Breakdown

Not only breakdowns on the main engine could potentially stop the ship. Any ship is equipped with auxiliary engines that supply the ship with electricity, if these should fail, the emergency generator will kick in, if that also fails it is called “black ship”. A ship can only run on the emergency generator for a limited time, as this only supplies the bare necessities onboard and this typically runs on diesel whereas the main engine typically runs on fuel oil and the diesel will run out eventually. In accordance with Danish law, most sources should be supplied for a minimum of 36 hours.⁴ Some components are run on batteries in case of an emergency. If the ship is unable to maneuver this could indicate a failure of the steering engine or rudder.

A ship uses many different aids when sailing, most are used to navigate or to identify the ship in relation to other ships. The primary ones are the radar, AIS, weather measuring equipment, depth measuring equipment, communication equipment, navigational lights and search/ice-lights. This equipment can fail if it loses power, becomes covered in ice or if it is destroyed. Most of this equipment is connected to antennas on the monkey island, these are vulnerable to bird strikes. At night large flocks of birds rest on the water surface, if these are disturbed by the ship this can send

⁴ <https://www.retsinformation.dk/Forms/R0710.aspx?id=27686>

them off flying at the same time. Many of these will get blinded by the powerful ice light, causing them to hit and possibly destroy the equipment on the monkey island.

A breakdown that causes the ship to be adrift with no propulsion or to lose navigational equipment exposes the ship to being beset in ice, to colliding with ice or a ship or to become grounded. A breakdown could cause damage to the cargo if this cargo is dependent on a constant supply of heat, inert gas or air flow. The crew is also dependent on many systems on board but could also be exposed to danger if a fire or explosion occurs in the engine or auxiliary systems.

An engine breakdown, could be small or large. The larger the impact, the smaller the possibility. A large breakdown could be anything that would need the main engine to be stopped, this could happen if there was a leakage on the lube oil, fuel oil, cooling water or air systems, or if a component failed as a bend connecting rod, a cracked cylinder liner, a failing piston ring or many other components. Not all ships have redundancy on the main engine but redundancy is common on most other systems. In the case where only one main engine is present and this has a large breakdown that forces it to be stopped the ship will be adrift without propulsion and the anchor will need to be dropped if the extent of the water depth is not too large.

When sailing in ice the sea chest will get filled with ice, heavily reducing the amount of water that is able to be sucked through it, if it is at all possible. Therefore, ships use water from the ballast tanks for cooling, this runs in a closed circuit getting chilled again in the ballast tanks. This type of cooling increases the risk of failure of the cooling system. For the same reason, water from the ballast tanks are also used for firefighting, this method increases the risk of instability during firefighting as large amounts of water are rapidly moved from one part of the ship to another, challenging the stability.

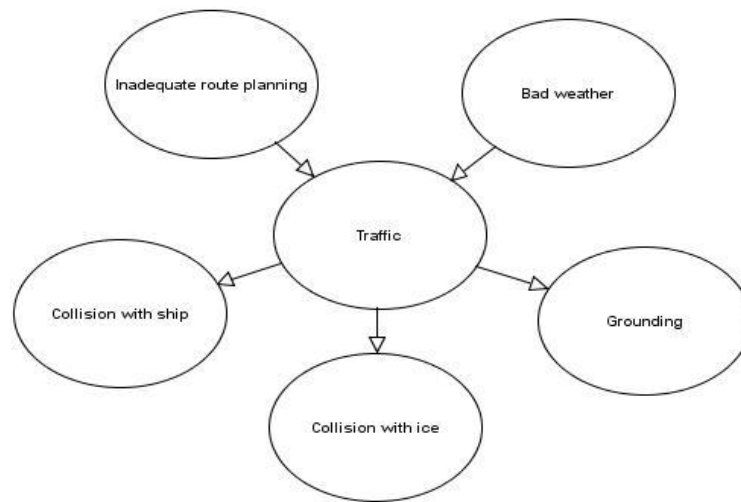
The engine crew will, in case of any type of breakdown, always try to correct or mend the problem straight away. If this is not possible it will be done as soon as time permits, either when spare parts or expert assistance are available or if necessary, in dock. Most failures can be mended by the crew including larger breakdowns on the main engine.

3.10 Traffic

The node “Traffic” symbolises any event where two ships are in the vicinity of each other.

Encountering traffic is almost inevitable, even though it is possible not to encounter any on some parts of a trip, especially on the east coast. The primary question is how severe this traffic is and how close ships need to sail, depending on the surroundings. In narrow passages, fairways and port entrances ships will need to sail closer to each other compared to when sailing on open water. On open water, large amounts of ice, could cause ships to come closer than they would otherwise.

Bad weather or inadequate route planning could cause a ship to become enclosed in traffic or come closer to traffic than it would normally. Traffic could lead to a grounding or collision when the ship is forced to circumnavigate other ships.



3-11 - Bayesian network - Traffic

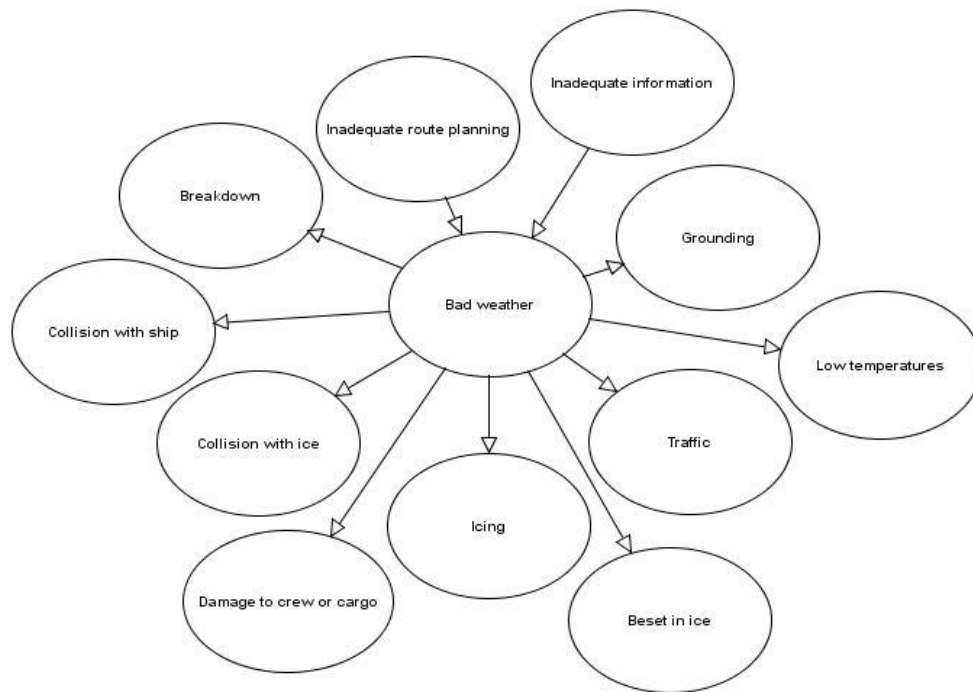
When a ship encounters another ship, there are clear and precise navigational rules to follow, called “international regulations for preventing collisions at sea”. One of the first things stated in the rules is that all sailors should exhibit good seamanship towards others. It describes how ships should interact with each other in different situations, in order for them to avert a collision. In some situations ships can be in a special situation making manoeuvring and evasion limited or impossible, in these cases this is indicated by lights at night and day signals during the day and then the rules change so that the other ship has to navigate around the ship with the limitations.

The traffic is primarily concentrated on the west coast of Greenland, south of latitude 70° N, hence few people inhabit the remaining areas. A total of 56.483 (2013) people live in Greenland and of this number approximately 2.500 reside on the east coast. The remaining parts are mostly frequented by cruise ships during the summer period (June-September).

3.11 Bad weather

The node “Bad weather” covers any type of weather that can challenge a ship during its normal operation such as wind, rain, hail, fog or snow.

Lacking or wrong information, mainly weather information could cause the ship to end up in bad weather. If a route plan is made without considering the known weather information or if a route plan is not changed in accordance with new information during the trip this could cause the ship to end up in bad weather.



3-12 - Bayesian network - Bad weather

Any type of ship will at all times try to navigate around bad weather but sometimes this is not an option. If the weather is severe enough a ship can take precautions to minimize the effect on the ship, crew and cargo. This could be done by changing the direction of sailing, dropping anchor or by seeking refuge in a sheltered area near the coast.

Navigating around bad weather can be costly in fuel and time consumption or if the ship misses its laycan. Laycan is short for “laydays and cancellation” and is the period where the ship must present itself to the charterer, if late the contract can be cancelled. Especially with oil tankers the laycan is important, as the charterer often speculates about cancelling the contract because oil prices often change quickly. This can result in ships taking unnecessary risks in order to make the laycan.

Some types of bad weather challenge the visibility of the crew, such as hail, rain, fog or snow. When the visibility is decreased, the crew rely on technical equipment to guide them; this is primarily the radar but AIS is also practical for identifying other ships by name, status and size. The radar can also be used for radar index navigation and identifying ice. A decrease in visibility will always increase the possibility for a collision or grounding.

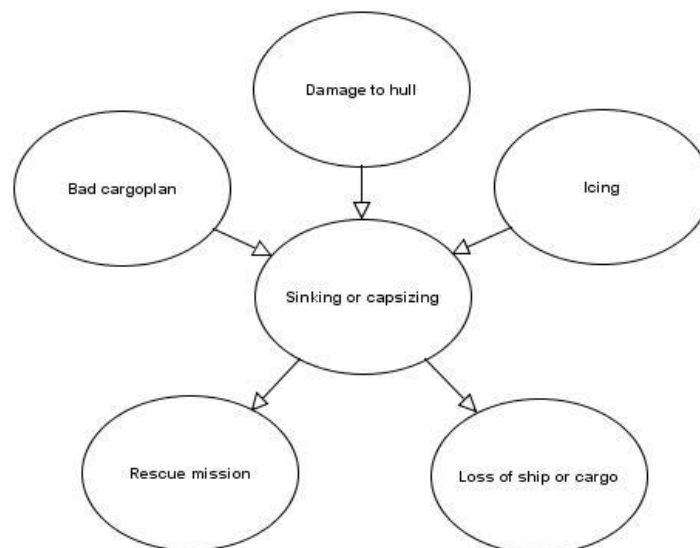
In bad weather the crew should abstain from working on deck and other open surfaces as there is an increased risk of falling overboard or getting injured. If there are high seas and a powerful wind, and if the work is absolutely necessary it should only be performed with extreme caution and protective gear.

Humans are vulnerable to the elements. Long periods of time exposed to darkness, reduced visibility and cold temperatures have detrimental effects on cognitive capabilities as well as physical capacity.⁵

Bad weather in the form of wind needs to be present in order for a ship to become iced as sprays of water combined with low temperatures are essential. Increased winds can decrease the need for low temperatures in order for the ship to become iced as the chill factor sets in. If equipment on board is exposed to bad weather this could fail causing a breakdown.

3.12 Sinking or capsizing

The largest disaster a ship can be exposed to is a sinking or capsizing. If a ship sinks or capsizes the reason is most likely that there has been a damage to the hull causing the ship to flood. However, it could also be caused by a change in stability, either from icing or from a poorly planned cargo plan. If the cargo plan is made in a way that it affects the stability this could be owing to either bad seamanship or misinformation coming from the shipper of the cargo.



3-13 - Bayesian network - Sinking or Capsizing

If a ship sinks completely it becomes fully submerged in water. In shallow waters a ship only sinks partially. If a ship starts to sink in the vicinity of shallow waters it is advised to sail the ship aground in order to minimise the risk of the ship sinking entirely, increasing the possibility of saving lives and cargo. This should only be done if the circumstances allow it.

If a ship capsizes or keels over it is turned on its side or ends up in an upside down position. If the ship maintains enough flotation it will not sink and if the stability is not inverted the ship could upright itself again. This is primarily possible for smaller boats like lifeboats, these types of boats are called self-righting.

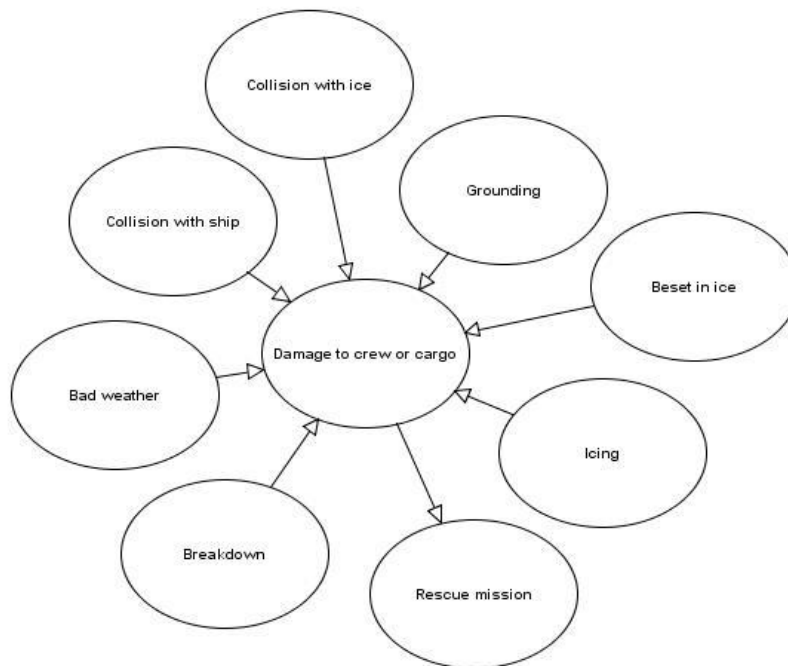
⁵ <http://blog.lr.org/2012/08/the-issues-of-working-in-arctic-conditions/>

Any unplanned sinking will lead to a rescue mission with the possibility of losing lives. The ship and cargo will more than likely be lost, depending on the circumstances surrounding the incident. In case of a sinking or capsizing, a rescue mission is inevitable. In Greenland closed rescue boats are recommended as these reduce the exposure to the elements. They are typically installed as either a freefall boat or davit-launched lifeboats. A freefall boat is mounted on the aft part in a way that it will launch away from the ship, davit-launched lifeboats are placed on the side of the ship and have to be lowered after boarding.

3.13 Damage to crew or cargo or general average

This hazard covers three different concepts, damage to the crew or to the cargo, or the situation of general average. All three concepts have similarities, therefore these are described as a whole.

General average is a legal principle describing the notion that all parties in a sea venture proportionally share any losses resulting from a voluntary sacrifice of part of the ship or cargo to save the rest in an emergency.⁶



3-14 - Bayesian network - Damage to crew or cargo

Any type of collision (with ice, ship or ground) poses a danger to the crew or cargo as a collision can be a violent episode. Cargo can become loose and fall overboard or simply get damaged by the collision itself. If water gets into the cargo it could get destroyed. If the cargo is reliant on support from the ship such as inert gas or heating this could get cut off, destroying the cargo.

Bad weather or if the ship gets iced could destroy cargo that is reliant on support from the ship as bad weather could cause containers or other solid cargo placed on deck to become loose and be thrown into the water. The crew is vulnerable to bad weather and icing of the ship, and therefore it

⁶ http://en.wikipedia.org/wiki/General_average

poses a danger to them. If the ship is iced the crew will always attempt to remove the ice, this is a dangerous situation, especially if done in bad weather.

Getting beset in ice poses a danger to the cargo as this could get left behind on an evacuated ship that is adrift. A ship that is beset poses a threat to the crew because the crew will try to get the ship adrift again and if this is impossible there is a risk that the supplies of food, water and oil could run out, leaving the crew exposed to the elements.

If a crewmember gets injured or falls ill, the navigators have medical training which enables them to aid injured persons. To assist them, they have medical handbooks and medicine in the ship's hospital, if additional assistance is needed Danish ships can contact Radio Medical Denmark which offers support in the form of a doctor that is on call 24 hours a day to guide the crew. If the condition of the patient is so severe that he or she needs to go to a hospital immediately a rescue mission will be put in place and the patient will, if considered practical, be picked up by a helicopter and flown to a hospital for treatment.

Any ship that exceeds a distance of 200 NM from the coast of Greenland must have a medicine chest A, if the 200 NM limit is never exceeded and the ship never moves north of Thule or Scoresbysund a medicine chest B is sufficient.⁷

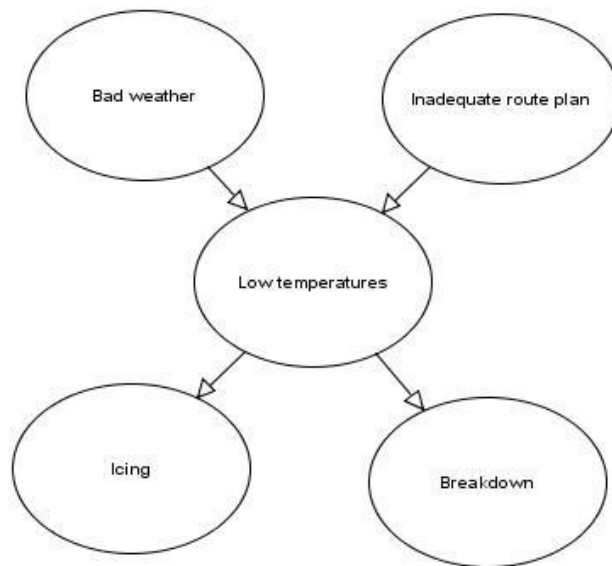
If cargo is lost at sea this is usually cargo not in bulk but typically containers. The loading master has the responsibility to ensure that all containers are lashed securely before departure. Changes in stability or if the ship starts to list can cause the lashing to come loose and thereby causing the containers to fall overboard or get damaged. If cargo is lost or damaged during shipping the bill of lading is typically made in accordance with the "Protocol to Amend the International Convention for the Unification of Certain Rules of Law Relating to Bills of Lading" commonly known as the Hague-Visby rules. Although most countries have adopted the Hague-Visby rules, some countries only comply with the "International Convention for the Unification of Certain Rules of Law relating to Bills of Lading" commonly known as the Hague rules. The United States has until now only adopted the Hague rules. The principle difference between the two set of rules is that the Hague-Visby rules give a carrier far greater bargaining power than the shipper, compared to the Hague rules.

3.14 Low temperatures

Any ship navigating through Greenland will undoubtedly encounter low temperatures but low temperatures are only a problem if they are too low. The definition of what too low a temperature is, is dependent on the individual ship. The classification societies have a standard called the design service temperature; any temperature under the design service temperature is regarded as too low a temperature. The average design temperature for a traditional trade ship is -10° C.

⁷ <https://www.retsinformation.dk/forms/r0710.aspx?id=27710>

A ship that encounters bad weather has a high risk of being exposed to low temperatures as the chill factor increases as the wind speed increases. When creating the route plan it is necessary to take the weather into account, just as it is necessary to take the temperatures into account.

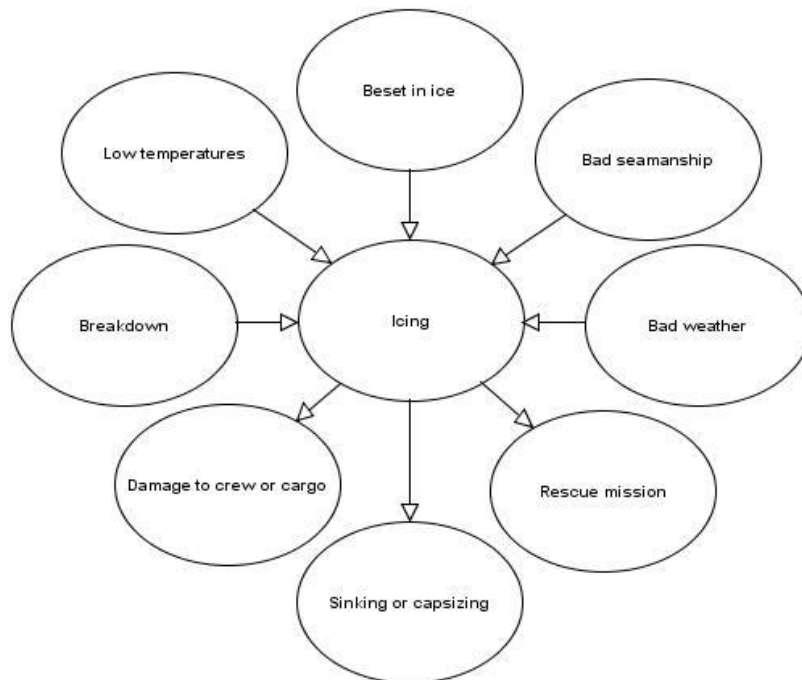


3-15 - Bayesian network - Low temperatures

The hull structure and equipment are vulnerable to low temperatures. It is important that fresh water, ballast and oil tanks are placed correctly or fitted with heating in order to prevent freezing and leaking. All deck equipment and pipes should have heating or draining because in low temperatures hydraulics will start to fail leaving several components useless or partly useless. Outboard hydraulics will fail first as they are more exposed to the elements. On a ship typically the lifeboats, some valves, pumps, winches, cranes and the anchors are outboard and are reliant on hydraulics. It is always possible to manually use the winches or anchor but this is not easy, especially if these are covered in ice. On a ship with a design temperature of -10°C the equipment will start to fail below this temperature.

3.15 Icing

Icing is unwanted on any ship as the ice becomes an added mass on the ship, changing the stability. Capsizing, extreme rolling and/or pitching and topside flooding can occur as a result of the loss of stability and extra weight from the ice burden.⁸ If navigational or communication equipment become iced, they could get damaged or rendered useless, the same applies to most other equipment on deck.



3-16 - Bayesian network - Icing

Low temperatures combined with winds could lead to ice accumulation or icing due to sprays, this is most likely in air temperatures below 2°C and wind speeds of above 20 knots (10 m/s).⁹ The higher the sea state and wind speeds the more ice will accumulate on the ship. The combination of bad weather and low temperatures is needed in order for a ship to become iced, as icing is not possible without sprays of water in an environment that is cold enough for the water to freeze. If there are no waves or swells it is almost impossible to get water sprays on deck. If the weather conditions are bad enough the ship could experience “Green water”, where the entire bow of the ship gets submerged in water.

When water sprays on the ship the pellets will start to freeze when they hit the ship's construction and equipment. Slowly these will build up creating a thicker and thicker layer of ice. This ice acts like an added mass on the ship challenging the stability and if not removed in time the crew will need to evacuate the ship before the situation becomes so severe that the ship risks sinking or capsizing.

The shipbuilder can make provisions that can reduce the amount of icing. The vessel's bow should be designed to reduce the effects of water spray freezing and collecting. Bridge wings and deck

⁸ http://www.vos.noaa.gov/MWL/dec_05/ves.shtml

⁹ http://ww2.eagle.org/content/eagle/en/rules-and-resources/rules-and-guides.html#/content/dam/eagle/rules-and-guides/current/special_service/151_vesselsoperatinginlowtemperatureenvironments

houses should be specially designed or enclosed to protect equipment and crew. Vessel stability should take into account the effects of ice build-up on the hull.¹⁰ Ships with a large superstructure and a low freeboard are more exposed to destabilization due to icing.

NOAA has developed a table describing “Threshold Wind Speeds for Icing to Occur on Various Length Ships”, this can be seen below.¹¹

Threshold Wind Speeds for Icing to Occur on Various Length Ships						
Vessel Length (meters)	15	30	50	75	100	150
Significant wave height - $h_{1/3}$ (meters)	0.6	1.2	2.0	3.0	4.0	6.0
Wind Speed at 200 km (108 nmi) fetch (m/s)	5.0	7.4	9.8	12.5	15.0	20.0

Table 3-17 - Threshold Wind Speeds for Icing to Occur on Various Length Ships

This table is a rough guide but it describes that the larger the ship is the higher the waves and the faster the winds it can withstand before getting iced. The load type and handling characteristics of the ship also influences the amount of icing.

Physically removing ice that has already built up is the best method, this can be done by hitting the ice with heavy objects, additionally, different chemicals can be used, and the most common is rock salt. Some chemicals used also corrode metal, therefore caution should be taken when using chemicals. Any removal of ice should be done in due time and only when the weather conditions do not pose a threat to the crew.

"Ice-phobic" coatings can be applied to ships, this coating is water repellent and can, to some extent, prevent icing. When ice has built up on this coating, it can be removed more easily. This cannot be used on all surfaces as it becomes too slippery for people to walk on. The coating also has to be reapplied constantly as water sprays and ice can destroy it.

There is work done on an ultrasonic vibration system that should prevent ice built up and the removal of ice that has already been built up on marine structures but this is a thing of the future.¹²

3.16 Rescue mission

A rescue mission is the situation where at least one individual needs to be evacuated from the ship. One or more persons could be evacuated if those persons have fallen ill or if they have had an injury. If the ship is rendered useless after a disaster the entire ship needs evacuation.

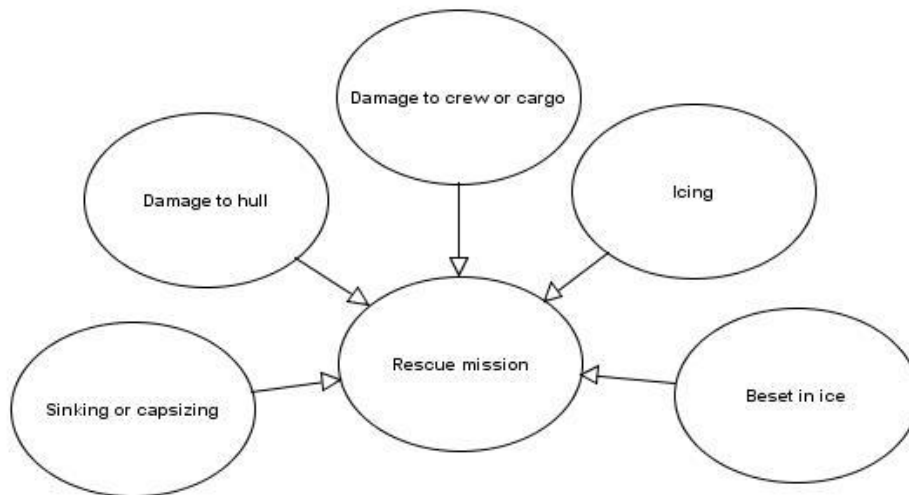
If the ship sinks, an evacuation and rescue mission is inevitable. A severe damage to the hull where the ship is taking in water could lead to an evacuation, especially if the engine room gets flooded, preventing the ship from proceeding on its route. If a ship becomes beset in ice and the prospect of getting adrift is unforeseeable within a reasonable amount of time, a rescue mission could be needed. If a ship becomes iced, the normal procedure is to remove the ice. However, bad weather

¹⁰ Guide for vessels operating in low temperature environments, ABS

¹¹ http://www.vos.noaa.gov/MWL/dec_05/ves.shtml - Research Oceanographer Dr. James E. Overland

¹² <http://www.google.com/patents/US8217554>

could make this impossible or futile and if the amount of ice on the ship is severe enough that the stability and thereby the welfare of the crew is put in danger, a rescue mission and the abandoning of the ship could be the only viable solution. A rescue mission could be launched solely for rescuing one or more of the crew members or passengers if they have been injured or taken ill to a degree that cannot be managed on board. On a trade ship the officers are trained in taking care of illnesses and injuries; on some larger passenger ships medical staff are on board.



3-18 - Bayesian network - Rescue mission

The likelihood for a rescue mission will always be influenced by many factors and therefore for some ships the probability will always be higher than others. Looking at an individual ship with a professionally trained crew where all the equipment is up-to-date, the possibility for a rescue mission will be unlikely, however, this does not mean that it is entirely impossible.

Different types of evacuation equipment are used for different types of ships. A traditional trade ship with less than 20 crew members could have a freefall boat placed at the aft part, this can be dropped into the water quickly, securing a fast escape. If there is not a freefall boat a closed davit-launched lifeboat will be onboard. This type of lifeboat is launched by lowering it into the water by a davit, the procedure is slower but the danger of it hitting the ice when launched is lesser. A cruise ship will not be able to have free-fall boats for all the passengers as there will not be room for that many in the aft part, they will most likely be equipped with closed davit-launched lifeboat. Some might be equipped with life rafts, however, this is not advised as these have a limited effect against the elements when sheltering the people on board.

During an evacuation there is a possibility that the crew or especially passengers, if any, could get injured as this is a stressful and sometimes chaotic situation. The crew will have practiced a rescue mission many times and this becomes a routine for them. For passengers this is unlikely to be a routine even though they will have received instructions upon departure and passenger ships are equipped with signs and posters instructing the passengers.

The majority of the coastline in Greenland is vast nothingness and distances between inhabited settlements are great. This poses a threat to people after an evacuation as there is no place to go or to be picked up. The rescue boats could sail to the coast but here there is no protection against the elements and no food or water. Therefore, the rescue boats only have the option to sail towards the nearest settlement, however, as these distances could be enormous there is a possibility that this

could take a long time, exposing the people to injury from the elements and low temperatures, or the crowded conditions in the rescue boat. Any rescue boat is equipped with food, water and medicine in order to sustain the people on board for a shorter period of time.

When it becomes clear that an evacuation of the ship is unavoidable the crew will send out emergency signals. These will not only be received by command stations ashore but also by ships in the vicinity that will come to assist the ship. If the evacuated ship is a traditional trade ship with a crew of less than 20 a single trade ship in the vicinity is sufficient to rescue and accommodate the crew. If the evacuated ship is a passenger ship with up to 2-3000 people on board many ships are needed for an evacuation; even another large passenger ship will not be able to rescue and accommodate that amount of people, not even for a short period. Due to the vastness, any efforts to rescue anybody in a secluded area from a shore based unit will inevitably take time, exposing the people to especially low temperatures. If there are a large number of passengers this will prolong the process increasing the risk that some rescue boats or persons will be lost.

4 Residual hazards

The main hazards have been chosen as these are the influential ones with many different parents and children. Besides the main hazards, other residual hazards have been displayed as these will be the parent or the child nodes to the main hazards. The residual hazards that will be the parent to a main hazard will have their probability assessed. The children nodes will have their probability calculated. The residual possibilities are:

- Bad maintenance
- Loss of ship or cargo
- Reduced ability to sail
- Lacking ice pilot
- Lacking ice light
- Convoy
- Lacking experience
- Lacking management
- Bad cargo plan
- Unforeseen events
- Danish Geodata Agency
- Weather service

4.1 Bad maintenance

Bad maintenance can lead to a breakdown of any mechanical or electrical part of the ship. All ships have a maintenance plan, some better than others. All of the crew should always strive to maintain the ship in the best possible condition but this could be made more difficult if the maintenance budget is low, spare parts are in deficit or the maintenance program is not maintained.

The training that an engineer must complete in order to work on a ship and the comprehensive information material on the different systems onboard should ensure that lacking experience should not influence the maintenance. Even the best run ship with an up-to-date maintenance system,

abundant spare parts and a good maintenance budget can experience insufficient maintenance as all systems are delivered with a maintenance plan from the manufacturer but sometimes the manufacturer has supplied wrong or insufficient information. When taking all of these factors into consideration, the possibility that bad maintenance will be present on a ship is estimated at 10%. If bad maintenance is present, the possibility of a breakdown is estimated at 20%.

4.2 Loss of ship or cargo

If the ship sinks, the ship will most likely be lost, as will the cargo, depending on the situation and the kind of cargo. If the ship sinks, the possibility that the ship and the cargo will be lost is very high. There is a small possibility that the ship will sink in shallow ground allowing for some or all of the cargo to survive. If the cargo is of a nature of that which can survive a sinking this could be a cargo consisting of rocks or other goods of that nature. If the ship sinks, the possibility that the ship and cargo will be lost is estimated at 99%.

4.3 Reduced ability to sail

The ability to sail can be reduced if the ship has a damage to the hull. This is dependent on the severity of the damage. In some situations the ship will be able to sail on its own power to the nearest port to get repairs, in other situations external power and support is needed in the form of one or more towboats.

Depending on where on the ship the damage has occurred, other external parts of the ship can also be damaged, contributing to the ship being unable to sail. This is mainly if a damage to the rudder is present but the thrusters could also get damaged. If a ship uses azimuth thrusters instead of traditional propulsion the ship will have more power but its thrusters could be exposed to damage.

If the ship has sustained damage to the hull then the possibility that the damage is severe enough that the ship's ability to sail is reduced is estimated at 60%.

4.4 Lacking ice pilot

The term "ice pilot" is in Greenland better known as the term "known man". If a ship is lacking a known man there are no resources on board that have knowledge on the specific area and the dangers surrounding navigating in ice. This could lead to a collision with ice or becoming beset in ice if the ship sails into an area where the ice can close in behind it.

After conducting interviews with sailors that frequent the area around Greenland, it can be concluded that only very few ships use a known man from ashore as most ships have navigators on board that are familiar with the area and have experience sailing arctic waters; this navigator is also referred to as a known man. The possibility that a known man from shore is brought on board is estimated at 5%. If there is not a known man on board, the possibility that the ship will collide with ice or become beset is estimated at 5%.

4.5 Lacking ice light

An ice light is used on ships after dark to spot ice. This is a large projector typically placed on the monkey island or in the stern and it can be controlled from the bridge. A navigator is always present on the bridge of any moving ship. At night, a second person will typically be placed on the bridge to be a lookout, spotting for ice or any other dangers.

Without an ice light, the ice will be more difficult to identify, therefore almost all ships have their light on at night. The possibility that a ship does not have its light on is estimated at 5%. If a ship, sailing at night, is not using an ice light the possibility that it will collide with ice is estimated at 30%, but as the calculations will be done for an entire day, including daytime, the probability will be set at 15%, when estimating that the amount of time with daylight is the same as night. For the same reason, the 5% probability that the ice light is not on also has to be set at half the value at 2.5%.

4.6 Convoy

When ships sail in a convoy this can have many advantages and disadvantages. The advantages when sailing in a convoy in ice are that the strongest built ship, the one with the most power will sail in front to break the ice in order to make a path for the ships that follow. This reduces the risk of getting beset or colliding with ice and it allows weaker ships to pass through an area which they normally would not be able to. The disadvantages are that a ship has a long breaking distance, so if a ship in front experiences problems and reduces speed or becomes still the ships that follow could collide with it or with each other. This risk could be diminished if a large enough distance is kept between the ships but if the distance is too large there is a risk that the path will close in with ice before all the ships have passed through it. If this happens, the ships that did not make it through before it closed could get beset in ice. All ships in a convoy will always be in radio contact with each other in order to communicate if any problems emerge.

The possibility that a ship would engage in a convoy is estimated at 10%. The possibility that a ship would collide with another in a convoy is estimated at 5%, and the possibility that a ship gets beset in ice in a convoy is likewise estimated at 5%.

4.7 Lacking experience

If a navigator is lacking experience this could lead to bad seamanship. Navigators go through a thorough education before becoming a master mariner. An extensive amount of manuals are available to a navigator, and other navigators are at their disposal, only a telephone call away. Usually, only one navigator is present on the bridge and this navigator is often required to make quick decisions. If a navigator is lacking experience sometimes the wrong assessment of a situation will be made. The possibility that a navigator is lacking experience is estimated at 10%. If a navigator is lacking experience the possibility that this will lead to bad seamanship is estimated at 20%.

4.8 Lacking management

Lacking management can lead to bad seamanship or lacking information. The management could either be from the shipping company or the leaders in the crew, such as the captain or the chief engineer. They have the responsibility that information and guidelines are passed on to the remaining crew. If this is not done with due diligence or if misinformation has been passed on this could give rise to serious consequences further on down the line. The possibility that lacking management could occur is estimated at 10%. The possibility that bad seamanship could occur as a result of lacking management is estimated at 10%. If lacking management is present the possibility that inadequate information is present is estimated at 35%. The reason that lacking management has less influence on bad seamanship compared to inadequate information is that the human factor plays in favour of bad seamanship.

4.9 Bad cargo plan

Bad seamanship can lead to a bad cargo plan which can subsequently lead to the ship sinking. A bad cargo plan can cause the ship to sink if the cargo is placed in inappropriate positions which challenge the strength and stability of the ship.

Before the cargo plan is compiled the navigator receives information regarding the cargo, this typically has to do with the weight and size of the cargo. Some types of cargo are more easily dealt with than others. There are fewer calculations to be done with cargo in bulk compared to containers or odd sized cargo. All calculations are done on computers but the input comes from the shipper of the cargo. There have been previous examples which have demonstrated that the weight of cargo has not been stated correctly, for instance, the weight of containers, causing the cargo plan to become faulty. The reason for declaring a lighter weight on a container is that some companies charge by weight. In some ports containers are weighted when they are placed on board in order to bypass this problem. If bad seamanship is present, the possibility of a bad cargo plan is estimated at 15%. If the cargo plan is inaccurate this could work in favour of the ship or to its disfavour, therefore, the possibility that the ship sinks or capsizes as a result of a bad cargo plan is estimated at 10%.

4.10 Unforeseen events

Technically an unforeseen event can affect anything as it is an unknown occurrence. In this project the focus has been on the events where an unforeseen occurrence is most likely to take place and has the greatest impact. These are the main hazards “breakdown” and “lacking route planning”. These main hazards are the ones influenced by most minor factors as anything from a misreading in a table to not lubricating an engine part well enough could lead to an unforeseen event of the types mentioned.

It is not easy to estimate the possibility of an unforeseen event. Based on experience the possibility is estimated at 10%. If an unforeseen event occurs the possibility of a breakdown is estimated at 15%, and the possibility of an inadequate route plan is estimated at 10%.

4.11 Danish Geodata Agency

The Danish Geodata Agency is responsible for collecting geographical information required for the making of nautical paper charts.

As stated on the homepage for the Danish Geodata Agency:

“The vastness of the sea area and the Greenland archipelago means that there are many places along the coast of Greenland, where no systematic and comprehensive surveys have been done. This means that there are still areas where the nature of the seabed is unknown.”¹³

In the paper charts blank areas appear where no information is known. In Royal Arctic Line (and probably other companies), the navigators share information between the different ships regarding where the errors exist in the paper charts when these are discovered. These errors could be a wrong position of a depth contour or underwater sheers not visible in the chart. In general, the contours of the coastline are illustrated well in paper charts allowing for radar index navigation.

Recognizing the dangers for a ship navigated by an inexperienced sailor in the waters of Greenland, The Danish Geodata Agency has created the homepage navigation.gl, where advice is given on all aspects of navigating a ship in Greenland. On this homepage it is also stated that:

“Mariners should be aware that the majority of the paper charts for Greenland were originally compiled in the 1960s. The source material on which these paper charts are based had limitations, especially with regard to their geometric accuracy. The positioning of the information in these paper charts (i.e. topography, including the coastline, and hydrography) is therefore not accurate.”

Electronic charts are constantly in development but currently these are primarily done for the areas surrounding the larger ports; these charts are accurate and up-to-date. For other areas the electronic charts are based on the paper charts.

This conclusion is reached that the information given to the sailors concerning charts is inadequate and therefore the possibility that a navigator has inadequate information in the form of charts is estimated at 15%. The possibility that inadequate information from charts will lead to inadequate information overall is estimated at 50%. The remaining 50% covers the situation where the ship has knowledge on board that recognises the given information is wrong and knows the correct information.

4.12 Weather service

It is very important that the weather service is reliable, the data supplied is reliant and that the information is constantly available. Weather forecasting is something that never can be done with an absolutely correct prediction, since it is only a prediction. The weather predicting models that are used are getting better and better but as the timeframe increases the reliability of the predictions decline.

¹³ <http://eng.gst.dk/nautical-charts-navigation/greenland-waters/#.VPWjyC4V6xw>

Most trade ships have a good internet connection and therefore data is always available. As a backup, ships have a navtex which is still operational in Greenland, and Aasiaat Radio transmits weather forecast four times a day on VHF or MF/HF, this also includes specific local weather. The Ice Service at the Centre for Ocean and Ice at the Danish Meteorological Institute produces ice charts covering Greenland's Waters.

Therefore the possibility of an undependable forecast or a lacking forecast is estimated at 1%. If an incorrect forecast has been given or no forecast has been given at all the possibility that the navigator has received inadequate information is 100%.

5 Node possibilities

For the calculations to be made some possibilities need to be found for the different hazards. As stated earlier, some possibilities have been estimated beforehand on grounds of known data or experiences. The remaining hazards need to be evaluated by professional sailors who often sail the waters of Greenland. The sailors are asked to give their professional estimation of what they assess are the different possibilities. It is important to remember that the opinions expressed by the sailors are professional estimates based on the individual's personal experience. This probably reflects the truth but might not in all cases due to the fact that if a sailor has experienced a violent episode, this episode will weight highly in his or her mind and might influence the answers.

It is important to clarify, what a "damage" could be as this is used in most of the nodes and the word is open for interpretation. A damage could be anything from paint being scraped off the hull to an external source penetrating the hull.

For each individual node a possibility for the outcome has been evaluated for each combination of parent nodes. For some nodes this includes > 100 assessments for each node, for others only 1. After all of the possible outcomes have been evaluated, the Bayesian networks can be drawn in the freeware program AgenaRisk. After drawing the networks all of the evaluated possibilities for each node and the combinations of parent nodes can be entered into the program, this then returns the possibility for the individual node. All calculations are done on the basis of Bayes' equation.

5.1 Parent nodes

Nodes that do not have parents have been evaluated as an individual and no calculated possibility for the individual node has been made. These types of nodes are called parent nodes as they do not have parents, only children.

These parent nodes and their individually estimated probability can be seen here in table 4-1.

Event	Possibility for event to be true
Lacking ice pilot	95 %
Lacking ice light	2.5 %
Convoy	10 %
Bad maintenance	10 %
Lacking experience	10 %
Lacking management	10 %
Unforeseen events	10 %
Danish Geodata Agency	15 %
Weather service	1 %

Table 5-1 - Parent nodes

5.2 Children nodes

Children nodes are nodes that only have parents and no children. The probability for these nodes are calculated on the basis of the parent nodes.

In this model there are three children nodes, “Reduced ability to sail”, Loss of ship or cargo” and “Rescue mission”. The first two only have one parent whereas “Rescue mission” has five. These nodes are the worst case scenarios where the situation cannot get any worse.

5.2.1 Reduced ability to sail

Damage to hull	FALSE	TRUE
FALSE	1.00	0.40
TRUE	0.00	0.60

Table 5-2 - Reduced ability to sail

This table shows that if there is a damage to the hull then the possibility that the ship’s ability to sail is reduced is estimated at 60%. Hereafter, the program can calculate that the estimated probability that a ship will experience a situation where its ability to sail is reduced as a result of a damage to the hull is 3.119%.

5.2.2 Loss of ship or cargo

Sinking or capsizing	FALSE	TRUE
FALSE	1.00	0.01
TRUE	0.00	0.99

Table 5-3 - Loss of ship or cargo

If the ship has sunk or capsized it is estimated that there is a 1% chance that the ship and cargo will not be lost as very specific circumstances are needed in order that a sunken or capsized ship is not

completely lost. Given these values it has been calculated that the estimated possibility of losing the ship or cargo is 1.743%.

5.2.3 Rescue mission

Beset in ice	FALSE															
Icing	FALSE								TRUE							
Sinking or capsizing	FALSE				TRUE				FALSE				TRUE			
Damage to crew or cargo	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Damage to hull	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.80	0.90	0.80	0.00	0.00	0.00	0.00	0.80	0.80	0.80	0.80	0.00	0.00	0.00	0.00
TRUE	0.00	0.20	0.10	0.20	1.00	1.00	1.00	1.00	0.20	0.20	0.20	0.20	1.00	1.00	1.00	1.00

Table 5-4 - Rescue mission

As can be seen from the numbers, if the ship sinks or capsizes it is evaluated that the possibility for a rescue mission is 100%, as no crew should stay on board a sunken or capsized ship, and if the crew evacuates they will need to be rescued. If the ship has sunk or capsized, all other nodes become redundant and despite all the other nodes the outcome will always be 100%.

If a ship sustains a damage to the hull it has been estimated that there is a 20% chance that a rescue mission is needed as the scope of the damage can vary.

Damage to the cargo will most likely not trigger a rescue mission but damage to crew members or passengers will. It has been estimated that in 10% of the cases the situation will be so bad that a rescue mission will be needed. In this evaluation only episodes caused by the nodes present in this network are taken into account. If daily accidents such as bruises and scrapes were taken into account the number would have to be much smaller.

If the ship becomes iced it is estimated that there is a 20% probability that the ship must be evacuated and therefore a rescue mission is necessary. This is due to the fact that the degree of icing and the effect on the stability can vary from one ship to another.

Beset in ice	TRUE															
Icing	FALSE								TRUE							
Sinking or capsizing	FALSE				TRUE				FALSE				TRUE			
Damage to crew or cargo	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Damage to hull	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.30	0.30	0.30	0.30	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.30	0.00	0.00	0.00	0.00
TRUE	0.70	0.70	0.70	0.70	1.00	1.00	1.00	1.00	0.70	0.70	0.70	0.70	1.00	1.00	1.00	1.00

Table 5-5 - Rescue mission

If the ship is beset this trumps all other nodes and it is estimated that if the ship is beset then in 70% of all cases a rescue mission is necessary.

When summing up all of these estimations the calculation has been carried out and it has been established that the overall estimated possibility for a rescue mission is 6.140%. This probability is a high estimate. The reason for this is that every node leading up to it has been estimated from the point of view of a worst case scenario and the node "Rescue mission" is the ultimate outcome.

5.3 Nodes with parents and children

5.3.1 Collision with ship

Traffic	FALSE															
Bad weather	FALSE								TRUE							
Convoy	FALSE				TRUE				FALSE				TRUE			
Bad seamanship	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Breakdown	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TRUE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5-6 - Collision with ship

As can be seen in the above table, there is no possibility to collide with another ship if another ship is not in the vicinity.

Traffic	TRUE															
Bad weather	FALSE								TRUE							
Convoy	FALSE				TRUE				FALSE				TRUE			
Bad seamanship	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Breakdown	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.99	0.80	0.95	0.80	0.95	0.65	0.90	0.65	0.95	0.80	0.95	0.80	0.90	0.60	0.90	0.60
TRUE	0.01	0.20	0.05	0.20	0.05	0.35	0.10	0.35	0.05	0.20	0.05	0.20	0.10	0.40	0.10	0.40

Table 5-7 - Collision with ship

If another ship or more ships are in the vicinity and no other factors are in play there is a 1% chance of colliding. This is probably smaller but 1% is the smallest percentage used in these calculations, except for 0%. The 1% applies for the situations where the ship is unable to evade the other ship.

If the ship has a breakdown this could cause the ship to be adrift with no propulsion and thereby collide with the other ships. A breakdown could also affect the equipment on board, causing the ship to sail blindly and unable to spot the other ships except visually and unable to identify itself to other ships via the AIS. It is estimated that in these situations there is a 20% possibility of colliding with another ship. If a breakdown has occurred most other nodes become redundant.

If a ship is in a convoy it is estimated that there is a 5% possibility of colliding with other ships as these are close by in the path in which the ship is steaming. A ship in a convoy exposed to bad weather has an estimated 10% probability for a collision. If the ship is in a convoy and experiences a breakdown this increases the possibility significantly; this is estimated at 35%. Combining this with bad weather increases the risk, this is estimated at 40%.

The sum of the estimations leads to the calculation that there is a 0.602% chance for a ship to collide with another ship.

5.3.2 Collision with ice

Trafic	FALSE															
Breakdown	FALSE															
Bad weather	FALSE								TRUE							
Bad seamanship	FALSE				TRUE				FALSE				TRUE			
Lacking icelight	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		TRUE
Lacking icepilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.99	0.95	0.85	0.85	0.90	0.90	0.85	0.85	0.90	0.90	0.80	0.80	0.90	0.90	0.80	0.85
TRUE	0.01	0.05	0.15	0.15	0.10	0.10	0.15	0.15	0.10	0.10	0.20	0.20	0.10	0.10	0.20	0.15

Table 5-8 - Collision with ice

It can be seen in this table that the estimated possibility of a collision with ice is 1%, even though none of the other nodes has been fulfilled. The reason for this is that ships in Greenland, on a daily basis, collide with ice on purpose as a means of getting through the ice and it is estimated that in some rare cases some of this ice is too thick to sail through. In that sense, a collision with ice could occur even when everything is done properly.

When the ship does not have an ice pilot there is a possibility that the ship could sail into waters with ice that is too thick to break as this sometimes requires local knowledge, therefore it is estimated that if the ship has no ice pilot there is a 5 % possibility of colliding with ice.

If the ship has no ice light it is almost impossible to spot ice or anything else that does not have a transponder. It is estimated that if a ship does not have an ice light at night there is a 30% possibility that it would collide with ice. As this only applies at night, the possibility is set at 15% on the estimation that the amount of daytime is equal to the time of darkness.

In bad weather the ice is not always stationary and the manoeuvrability of the ship is decreased, increasing the chance of a collision. Bad weather alone is estimated to have a possibility of 10% for a ship to collide with ice, combining this with lacking ice light it is estimated that this possibility is increased to 20%.

Trafic	FALSE															
Breakdown	TRUE															
Bad weather	FALSE								TRUE							
Bad seamanship	FALSE				TRUE				FALSE				TRUE			
Lacking icelight	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		TRUE
Lacking icepilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
TRUE	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

Table 5-9 - Collision with ice

If the ship has a breakdown it is estimated that there is a 15% chance of colliding with ice, either because the ship is unable to remove itself from the ice or because it is unable to identify the ice as an obstacle. A breakdown combined with bad weather is estimated to increase the possibility for a collision to 20%. In case of a breakdown, all other nodes are rendered redundant.

Traffic	TRUE															
Breakdown	FALSE															
Bad weather	FALSE								TRUE							
Bad seamanship	FALSE				TRUE				FALSE				TRUE			
Lacking icelight	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE
Lacking icepilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.99	0.95	0.85	0.85	0.90	0.90	0.85	0.85	0.90	0.90	0.80	0.80	0.90	0.90	0.80	0.85
TRUE	0.01	0.05	0.15	0.15	0.10	0.10	0.15	0.15	0.10	0.10	0.20	0.20	0.10	0.10	0.20	0.15

Table 5-10 - Collision with ice

The difference between the situations where there are traffic and not, are not different as the traffic does not change anything significantly as it has been estimated that traffic alone only constitutes a 1% probability.

Traffic	TRUE															
Breakdown	TRUE															
Bad weather	FALSE								TRUE							
Bad seamanship	FALSE				TRUE				FALSE				TRUE			
Lacking icelight	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE
Lacking icepilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.75
TRUE	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.25

Table 5-11 - Collision with ice

The combined estimations has been calculated and the estimated possibility for any given ship to collide with ice is 6.184%. Here it is important to note that this estimate is distributed over an entire year and in the summer periods this could only be lower whereas in the winter where there is more ice this should be considered equally higher. The reason that there is an estimated higher probability for a collision with ice compared with a collision with a ship is that there is more ice than ships and ships can make an evasive manoeuvre whereas ice cannot, this combined with the fact that ships often hit ice on purpose.

5.3.3 Damage to hull

Collision with ship	FALSE								TRUE							
Collision with ice	FALSE				TRUE				FALSE				TRUE			
Grounding	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE
Beset	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.50	0.60	0.50	0.80	0.50	0.60	0.45	0.80	0.50	0.60	0.50	0.80	0.50	0.60	0.45
TRUE	0.00	0.50	0.40	0.50	0.20	0.50	0.40	0.55	0.20	0.50	0.40	0.50	0.20	0.50	0.40	0.55

Table 5-12 - Damage to hull

If the ship gets beset it is estimated that there is a 50% possibility that the hull will get damaged. This is dependent on the hull structure and ice class. If the ship is grounded the ship will be stationary on the ground, whereas when it has becomes beset the ship can move with the ice. Therefore, it is estimated that a grounding will result in a 40% possibility of damaging the hull.

It is estimated that the difference between the situations where a ship collides with either a ship or ice is no different as the ship in both cases collides with an obstacle hard enough to damage the hull that it cannot remove with its own power. Therefore for both situations it is estimated that there is a

20% possibility that the hull will get damaged and if both situations have occurred there is no difference.

In the unlikely event that the ship is grounded, beset and collides with an obstacle it is estimated that the possibility will be slightly higher than when it is merely beset.

When combining all of the estimated possibilities, the calculations sum up to an estimate of 5.199% possibility to create damage to the hull at any given time when navigating the waters of Greenland.

5.3.4 Damage to crew or cargo

Collision with ice	FALSE															
Collision with ship	FALSE															
Beset in ice	FALSE															
Grounding	FALSE								TRUE							
Icing	FALSE				TRUE				FALSE				TRUE			
Breakdown	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.90	0.99	0.85	0.95	0.90	0.95	0.80	0.95	0.90	0.95	0.85	0.95	0.90	0.95	0.80
TRUE	0.00	0.10	0.01	0.15	0.05	0.10	0.05	0.20	0.05	0.10	0.05	0.15	0.05	0.10	0.05	0.20

Table 5-13 - Damage to crew or cargo

In bad weather it is estimated that there is a 10% possibility for damage to crew or cargo because in bad weather the ship will experience rolling and pitching movements that could cause injury to the crew as moving around the ship becomes more difficult and there is a possibility that the cargo could come loose and thereby get damaged. If the cargo is oil, the movements of the ship from bad weather should not influence this. Dry goods in bulk could move and if a large amount of this gathers in one side of the ship this could lead to the ship heeling.

A breakdown has a higher impact on the ship than it has on the crew or cargo. The crew is dependent on support systems on board to supply ventilation, keep food fresh and supply water, especially if a water generator is used. Therefore, a breakdown will most likely only be a threat to the crew in the long run. Some types of cargo are reliant on support from the ship, this could be either heat, inert gas or air flow. Some containers could be reliant on cooling but this could be redundant in places like Greenland, unless the temperature has to be kept constant. The impact from a breakdown is estimated at 1%.

The combination of a breakdown which sets the ship adrift with no propulsion in bad weather is one of the worst combinations as the ship's movements become unaccountable, thereby strongly increasing the possibility of damage. Consequently, the possibility of sustaining damage when this combination is present, is estimated at 15%.

If the ship is iced the threat to the crew will primarily consists of damage from the elements as they attempt to remove the icing. The icing could also disable components that the crew or cargo are reliant on, such as pipe systems, davits, pumps or winches. It is estimated that the possibility for damage from icing is 5%.

When a ship has an impact with the ground this can be a violent episode which can send shimmers down the ship; this could cause damage to the crew or cargo. After a grounding there is a possibility

that the cargo will be left behind if the crew evacuates the ship. Therefore, it is estimated that in the event of a grounding there is a 5% possibility of danger to the crew or cargo.

Collision with ice	FALSE															
Collision with ship	FALSE															
Beset in ice	TRUE															
Grounding	FALSE								TRUE							
Icing	FALSE				TRUE				FALSE				TRUE			
Breakdown	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.85	0.90	0.85	0.90	0.85	0.90	0.80	0.90	0.85	0.90	0.85	0.90	0.85	0.90	0.80
TRUE	0.10	0.15	0.10	0.15	0.10	0.15	0.10	0.20	0.10	0.15	0.10	0.15	0.10	0.15	0.10	0.20

Table 5-14 - Damage to crew or cargo

It has been estimated that there is a 10% possibility for damage if the ship becomes beset as the primary danger to the crew is when or if they try to set the ship adrift again. Being beset poses a greater risk to the cargo as there is a good possibility that this will be left behind, exposed to the elements if the crew have to evacuate the ship. When the ship is beset in ice a breakdown becomes redundant. Being beset in bad weather increases the possibility, especially for the crew, therefore a combination of being beset and bad weather is estimated at 15%.

Collision with ice	FALSE															
Collision with ship	TRUE															
Beset in ice	FALSE															
Grounding	FALSE								TRUE							
Icing	FALSE				TRUE				FALSE				TRUE			
Breakdown	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.80	0.90	0.85	0.90	0.80	0.85	0.85	0.85	0.80	0.85	0.85	0.85	0.80
TRUE	0.10	0.10	0.10	0.20	0.10	0.15	0.10	0.20	0.15	0.15	0.15	0.20	0.15	0.15	0.15	0.20

Table 5-15 - Damage to crew or cargo

As any type of collision is violent, the possibility for damage from a collision is estimated at 10%. Combining this with a breakdown in bad weather will only increase the possibility for damage to the crew or cargo.

Collision with ice	FALSE															
Collision with ship	TRUE															
Beset in ice	TRUE															
Grounding	FALSE								TRUE							
Icing	FALSE				TRUE				FALSE				TRUE			
Breakdown	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.80	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.80
TRUE	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.20	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.20

Table 5-16 - Damage to crew or cargo

Collision with ice	TRUE															
Collision with ship	FALSE															
Beset in ice	FALSE															
Grounding	FALSE								TRUE							
Icing	FALSE				TRUE				FALSE				TRUE			
Breakdown	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.80	0.90	0.85	0.90	0.80	0.85	0.85	0.85	0.80	0.85	0.85	0.85	0.80
TRUE	0.10	0.10	0.10	0.20	0.10	0.15	0.10	0.20	0.15	0.15	0.15	0.20	0.15	0.15	0.15	0.20

Table 5-17 - Damage to crew or cargo

If the ship collides with ice or another ship it is estimated that the outcome will be the same, therefore if the ship collides with ice the possibility for damage to the crew or cargo will be estimated at 10%, the same as for a collision with a ship.

Collision with ice	TRUE															
Collision with ship	FALSE															
Beset in ice	TRUE															
Grounding	FALSE								TRUE							
Icing	FALSE				TRUE				FALSE				TRUE			
Breakdown	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.80	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.80
TRUE	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.20	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.20

Table 5-18 - Damage to crew or cargo

Collision with ice	TRUE															
Collision with ship	TRUE															
Beset in ice	FALSE															
Grounding	FALSE								TRUE							
Icing	FALSE				TRUE				FALSE				TRUE			
Breakdown	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.80	0.90	0.85	0.90	0.80	0.85	0.85	0.85	0.80	0.85	0.85	0.85	0.80
TRUE	0.10	0.10	0.10	0.20	0.10	0.15	0.10	0.20	0.15	0.15	0.15	0.20	0.15	0.15	0.15	0.20

Table 5-19 - Damage to crew or cargo

If the ship collides with ice and another ship the outcome is estimated to be the same as the situation where the ship only collides with one of the two. It follows therefore, that the outcome will be the same as if it only collides with one or both.

Collision with ice	TRUE															
Collision with ship	TRUE															
Beset in ice	TRUE															
Grounding	FALSE								TRUE							
Icing	FALSE				TRUE				FALSE				TRUE			
Breakdown	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.80	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.80
TRUE	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.20	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.20

Table 5-20 - Damage to crew or cargo

When combining all of the estimations the calculations have been done and it has been established that it can be estimated that there will be a possibility of 2.303% that the crew or cargo will be exposed to damage when navigating the waters of Greenland.

5.3.5 Traffic

Bad weather	FALSE		TRUE	
Inadequate route plan	FALSE	TRUE	FALSE	TRUE
FALSE	0.8	0.75	0.75	0.7
TRUE	0.2	0.25	0.25	0.3

Table 5-21- Traffic

It is almost inevitable that ships would encounter traffic and more times than often traffic is not a problem. The problem only arises when there is too much traffic or if the ship experiences traffic in conjunction with another problem like a breakdown that traffic becomes a problem. Bad weather or an inadequate route plan can cause the ship to navigate an area that it would not have if the plan had been made correctly or if it had not encountered bad weather.

Summing up the estimations it has been calculated that there is an estimated possibility of 20.652% for a ship to encounter traffic. The reason that this number is so low is that a ship can have a long haul at open sea without any ships in the vicinity. As soon as a ship closes in on a harbour the possibility increases significantly. This possibility is calculated for an entire trip from berth to berth.

5.3.6 Bad weather

Inadequate route plan	FALSE		TRUE	
Inadequate information	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.85	0.85	0.85
TRUE	0.10	0.15	0.15	0.15

Table 5-22 - Bad weather

Bad weather is unpreventable and for a ship to end up in bad weather does not necessarily mean that something will happen to the ship, crew or cargo. This is all dependent on the type of ship, equipment and the experience of the crew.

A navigator has to rely on the weather information given that they have a minimum of possibilities to predict the weather themselves. They can acquire the information from different providers to compare it and they can get satellite pictures and try to predict the forthcoming weather. They are also taught this during training to become a navigator. When the navigator plans the route he or she has to take the weather into account, if this is done improperly or if the information given is incorrect or not precise it is estimated that there is a possibility of 15% of ending up in bad weather. It is also important to get the newest information on route when available, as short term predictions are always the most reliant.

It had been calculated that there is an estimated possibility of 10.634% of ending up in bad weather for any given ship in Greenland. Included in this estimate is the idea that the ship will try to navigate around bad weather where possible and if not possible this may not pose a threat.

5.3.7 Grounding

Traffic	FALSE															
Bad seamanship	FALSE															
Inadequate information	FALSE								TRUE							
Breakdown	FALSE				TRUE				FALSE				TRUE			
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Inadequate route planning	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.99	0.90	0.90	0.80	0.80	0.75	0.75	0.95	0.95	0.90	0.90	0.80	0.80	0.75	0.75
TRUE	0.00	0.01	0.10	0.10	0.20	0.20	0.25	0.25	0.05	0.05	0.10	0.10	0.20	0.20	0.25	0.25

Table 5-23 - Grounding

When planning a route plan the navigator needs to take the seabed and water depth into account, if this has not been done properly the route could mistakenly be placed through an area where the depth is too shallow for the ship. The possibility for this is estimated as being minimum, therefore it is set at 1%.

In bad weather a ship can divert from its planned route to seek shelter from the weather or change its sailing direction so that the waves hit the hull in a more favourable direction, increasing the possibility for a grounding. Therefore, if bad weather is present it is estimated that a minimum possibility of 10% for a grounding is present.

In case of a breakdown, the ship could either be adrift with no propulsion or be sailing blindly or both. It is estimated that in this case there will be a possibility of 20% for the ship to become grounded. If bad weather is included the possibility is estimated to increase to 25%.

Given inadequate information, the navigator could be unaware that an obstacle is present under water and thereby navigate into this. This could also include the situation where no information or wrong information is given about the seabed in charts. It has been estimated that the possibility for a grounding, exclusively due to inadequate information, this being from charts, should be low. Therefore, it is estimated at 5%. Ships today have equipment on board to warn them if shallow ground is closing in, and in areas that are often frequented by ships such as areas near ports the electronic charts are adequate and up-to date.

Traffic	FALSE															
Bad seamanship	TRUE															
Inadequate information	FALSE								TRUE							
Breakdown	FALSE				TRUE				FALSE				TRUE			
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Inadequate route planning	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.99	0.95	0.90	0.90	0.80	0.80	0.75	0.75	0.95	0.95	0.90	0.90	0.80	0.80	0.75	0.75
TRUE	0.01	0.05	0.10	0.10	0.20	0.20	0.25	0.25	0.05	0.05	0.10	0.10	0.20	0.20	0.25	0.25

Table 5-24 - Grounding

In order for a ship to become grounded due to bad seamanship it is necessary that the sailor exhibits extremely bad seamanship. Luckily, this is a rare occurrence and therefore the possibility for a grounding exclusively as a result of bad seamanship is estimated at 1%.

Traffic	TRUE															
Bad seamanship	FALSE															
Inadequate information	FALSE								TRUE							
Breakdown	FALSE				TRUE				FALSE				TRUE			
Bad weather	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Inadequate route planning	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.99	0.99	0.90	0.90	0.80	0.80	0.75	0.75	0.95	0.95	0.90	0.90	0.80	0.80	0.75	0.75
TRUE	0.01	0.01	0.10	0.10	0.20	0.20	0.25	0.25	0.05	0.05	0.10	0.10	0.20	0.20	0.25	0.25

Table 5-25 - Grounding

Traffic in itself does not pose a great threat to getting a ship grounded. It is estimated that the possibility is 1%. However, when combining traffic with a breakdown or bad weather this can worsen the situation.

Traffic	TRUE															
Bad seamanship	TRUE															
Inadequate information	FALSE								TRUE							
Breakdown	FALSE				TRUE				FALSE				TRUE			
Bad weather	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Inadequate route planning	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.99	0.95	0.90	0.90	0.80	0.80	0.75	0.75	0.95	0.95	0.90	0.90	0.80	0.80	0.75	0.75
TRUE	0.01	0.05	0.10	0.10	0.20	0.20	0.25	0.25	0.05	0.05	0.10	0.10	0.20	0.20	0.25	0.25

Table 5-26 - Grounding

When combining all of the estimated possibilities the calculation for the estimated possibility for an overall grounding is calculated at 2.519%.

5.3.8 Beset in ice

Bad weather	FALSE															
Bad seamanship	FALSE															
Collision with ice	FALSE															
Collision with ship	FALSE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.95	0.95	0.95	0.75	0.75	0.75	0.75	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75
TRUE	0.00	0.05	0.05	0.05	0.25	0.25	0.25	0.25	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25

Table 5-27 - Beset in ice

An ice pilot is taken on board because the pilot knows the different hazards and conditions in the local area. Without a pilot's expertise there is a chance that the ship could get beset if the crew reads the ice incorrectly or if they navigate into an area with more ice than expected. If a ship does not acquire a pilot it is most likely because the ship's crew are known in the local area. Without an ice pilot it is estimated that there is a 5% possibility of getting beset in ice.

In a convoy the ships that are not the first in the row are probably already sailing in ice that they are not able to break so the conditions for becoming beset are already present. If the ship lags behind and the ice closes in, it could get beset. If something happens to a ship in front of the ship, causing the ship in question to become still, the ice could close in on it. For these reasons it is estimated that the possibility to become beset is 5%.

If a ship gets grounded and therefore is unable to move this can enable the ice to gather around the hull and cause the ship to become beset. The hull will act like an obstacle blocking the path of the moving ice, allowing it to gather around the hull. When the ship is grounded the possibility for getting beset is estimated at 25%. If it was known that the ship was grounded and unable to free itself and known that there is enough ice in the area the possibility would have been almost 100%, the 25% is arrived at when considering that it is unknown if the ship is able to free itself and the extent of the damage and the condition of the surrounding ice is unknown. This principle applies to all estimations in this project.

If the ship is grounded, all other factors are redundant except for the weather.

If the ship is navigating using an inadequate route plan there is a possibility that the navigator who planned the route had not considered the conditions and amount of ice that is present on route. This creates an estimated possibility of 10% of becoming beset.

Bad weather	FALSE															
Bad seamanship	FALSE															
Collision with ice	FALSE															
Collision with ship	FALSE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75
TRUE	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25

Table 5-28 - Beset in ice

If the ship experiences a breakdown that disables the equipment on board, the crew is unable to get forecasts or to spot the ice on radar or visually when using an ice light, increasing the possibility that it could enter into an area with too much ice. If the breakdown also renders the ship unable to manoeuvre either by power or by rudder, the ship could drift into an area with ice or the ice could gather around the hull more easily as the ship is not moving. It is estimated that a breakdown creates a possibility of 15% of getting beset. In case of a breakdown some other factors become redundant.

Bad weather	FALSE															
Bad seamanship	FALSE															
Collision with ice	FALSE															
Collision with ship	TRUE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75
TRUE	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25

Table 5-29 - Beset in ice

After a collision with another ship the ships will become still in order to investigate the extent of the damage and if needed in order to assist the other ship. The ships could be still for a long or short

period of time, depending on the damages. The longer that it does not move, the greater the possibility for becoming beset. It is estimated that there is a 10% possibility for becoming beset after a collision with another ship.

Bad weather	FALSE															
Bad seamanship	FALSE															
Collision with ice	FALSE															
Collision with ship	TRUE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75
TRUE	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25

Table 5-30 - Beset in ice

In case of a breakdown it is redundant if the ship collides with a ship or ice, just as everything else is redundant when the ship is grounded, in these scenarios.

Bad weather	FALSE															
Bad seamanship	FALSE															
Collision with ice	TRUE															
Collision with ship	FALSE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75
TRUE	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25

Table 5-31 - Beset in ice

It is estimated that a collision with ice or with another ship renders the same possibility as when it becomes beset.

Bad weather	FALSE															
Bad seamanship	FALSE															
Collision with ice	TRUE															
Collision with ship	FALSE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75
TRUE	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25

Table 5-32 - Beset in ice

Bad weather	FALSE															
Bad seamanship	FALSE															
Collision with ice	TRUE															
Collision with ship	TRUE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75
TRUE	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25

Table 5-33 - Beset in ice

If the ship has collided with ice or with another ship it is estimated that it is redundant if it collides with the opposite of the two.

Bad weather	FALSE															
Bad seamanship	FALSE															
Collision with ice	TRUE															
Collision with ship	TRUE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75
TRUE	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25

Table 5-34 - Beset in ice

Bad weather	FALSE															
Bad seamanship	TRUE															
Collision with ice	FALSE															
Collision with ship	FALSE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.95	0.90	0.95	0.90	0.75	0.75	0.75	0.75	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75
TRUE	0.05	0.10	0.05	0.10	0.25	0.25	0.25	0.25	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25

Table 5-35 - Beset in ice

If a ship becomes beset as a consequence of bad seamanship this is due to lack of diligence on the sailor's part.

Bad weather	FALSE															
Bad seamanship	TRUE															
Collision with ice	FALSE															
Collision with ship	FALSE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75
TRUE	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25

Table 5-36 - Beset in ice

If a breakdown is present bad seamanship becomes redundant.

Bad weather	FALSE															
Bad seamanship	TRUE															
Collision with ice	FALSE															
Collision with ship	TRUE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75
TRUE	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25

Table 5-37 - Beset in ice

After a collision bad seamanship could increase the possibility of becoming beset if the sailor choses to stay still for longer than necessary but the possibility is estimated to be small, therefore it is rendered redundant.

Bad weather	FALSE															
Bad seamanship	TRUE															
Collision with ice	FALSE															
Collision with ship	TRUE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75
TRUE	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25

Table 5-38 - Beset in ice

Bad weather	FALSE															
Bad seamanship	TRUE															
Collision with ice	TRUE															
Collision with ship	FALSE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75
TRUE	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25

Table 5-39 - Beset in ice

Bad weather	FALSE															
Bad seamanship	TRUE															
Collision with ice	TRUE															
Collision with ship	FALSE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75
TRUE	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25

Table 5-40 - Beset in ice

Bad weather	FALSE															
Bad seamanship	TRUE															
Collision with ice	TRUE															
Collision with ship	TRUE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75	0.90	0.90	0.90	0.90	0.75	0.75	0.75	0.75
TRUE	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25	0.10	0.10	0.10	0.10	0.25	0.25	0.25	0.25

Table 5-41 - Beset in ice

Bad weather	FALSE															
Bad seamanship	TRUE															
Collision with ice	TRUE															
Collision with ship	TRUE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75	0.85	0.85	0.85	0.85	0.75	0.75	0.75	0.75
TRUE	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25	0.15	0.15	0.15	0.15	0.25	0.25	0.25	0.25

Table 5-42 - Beset in ice

Bad weather	TRUE															
Bad seamanship	FALSE															
Collision with ice	FALSE															
Collision with ship	FALSE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.90	0.70	0.70	0.70	0.70	0.90	0.90	0.90	0.90	0.70	0.70	0.70	0.70
TRUE	0.10	0.10	0.10	0.10	0.30	0.30	0.30	0.30	0.10	0.10	0.10	0.10	0.30	0.30	0.30	0.30

Table 5-43 - Beset in ice

When bad weather is present the entire picture changes as bad weather creates movement in the ice, making it possible to become beset more quickly. Bad weather alone is estimated as presenting a possibility of 10% for a ship becoming beset.

If a ship is grounded in bad weather the ice can accumulate more rapidly around the hull, increasing the possibility of it becoming beset. This is estimated to increase to 30%.

Bad weather	TRUE															
Bad seamanship	FALSE															
Collision with ice	FALSE															
Collision with ship	FALSE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70
TRUE	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30

Table 5-44 - Beset in ice

Bad weather increases the possibility of becoming beset in case of a breakdown. This is estimated to increase to 20%.

Bad weather	TRUE															
Bad seamanship	FALSE															
Collision with ice	FALSE															
Collision with ship	TRUE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70
TRUE	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30

Table 5-45 - Beset in ice

Any type of collision with either ice or a ship was estimated to be 10% in calm weather, when adding bad weather to the equation this is estimated to increase to 15%.

Bad weather	TRUE															
Bad seamanship	FALSE															
Collision with ice	FALSE															
Collision with ship	TRUE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70
TRUE	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30

Table 5-46 - Beset in ice

Bad weather	TRUE															
Bad seamanship	FALSE															
Collision with ice	TRUE															
Collision with ship	FALSE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70
TRUE	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30

Table 5-47 - Beset in ice

Bad weather	TRUE															
Bad seamanship	FALSE															
Collision with ice	TRUE															
Collision with ship	FALSE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70
TRUE	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30

Table 5-48 - Beset in ice

Bad weather	TRUE															
Bad seamanship	FALSE															
Collision with ice	TRUE															
Collision with ship	TRUE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70
TRUE	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30

Table 5-49 - Beset in ice

Bad weather	TRUE															
Bad seamanship	FALSE															
Collision with ice	TRUE															
Collision with ship	TRUE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70
TRUE	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30

Table 5-50 - Beset in ice

Bad weather	TRUE															
Bad seamanship	TRUE															
Collision with ice	FALSE															
Collision with ship	FALSE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.90	0.90	0.90	0.90	0.70	0.70	0.70	0.70	0.90	0.90	0.90	0.90	0.70	0.70	0.70	0.70
TRUE	0.10	0.10	0.10	0.10	0.30	0.30	0.30	0.30	0.10	0.10	0.10	0.10	0.30	0.30	0.30	0.30

Table 5-51 - Beset in ice

A sailor exhibiting bad seamanship is challenged when the ship is situated in bad weather as more factors have to be taken into account. Therefore, the possibility has been estimated to increase to 10%.

Bad weather	TRUE															
Bad seamanship	TRUE															
Collision with ice	FALSE															
Collision with ship	FALSE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70
TRUE	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30

Table 5-52 - Beset in ice

Bad weather	TRUE															
Bad seamanship	TRUE															
Collision with ice	FALSE															
Collision with ship	TRUE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70
TRUE	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30

Table 5-53 - Beset in ice

Bad weather	TRUE															
Bad seamanship	TRUE															
Collision with ice	FALSE															
Collision with ship	TRUE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70
TRUE	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30

Table 5-54 - Beset in ice

Bad weather	TRUE															
Bad seamanship	TRUE															
Collision with ice	TRUE															
Collision with ship	FALSE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70
TRUE	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30

Table 5-55 - Beset in ice

Bad weather	TRUE															
Bad seamanship	TRUE															
Collision with ice	TRUE															
Collision with ship	FALSE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70
TRUE	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30

Table 5-56 - Beset in ice

Bad weather	TRUE															
Bad seamanship	TRUE															
Collision with ice	TRUE															
Collision with ship	TRUE															
Breakdown	FALSE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70	0.85	0.85	0.85	0.85	0.70	0.70	0.70	0.70
TRUE	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30

Table 5-57 - Beset in ice

Bad weather	TRUE															
Bad seamanship	TRUE															
Collision with ice	TRUE															
Collision with ship	TRUE															
Breakdown	TRUE															
Inadequate route planning	FALSE								TRUE							
Grounding	FALSE				TRUE				FALSE				TRUE			
Convoy	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE
Lacking ice pilot	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70
TRUE	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30

Table 5-58 - Beset in ice

For this node there are many considerations to take into account. Some of the parent nodes have more clout than others, such as grounding or breakdown, as these render some of the other nodes redundant as it is indifferent to becoming beset if the ship is lacking an ice pilot if it has become grounded or has had a breakdown. After considering all of the different combinations of nodes the overall calculations have been made and it has been established that the estimated possibility for becoming beset when sailing in Greenland is 6.669%. This risk could seem to be a bit on the high side, especially when considering that it is not all year round that the conditions are adequate enough to become beset, particularly in some areas. The reason that this possibility is so high is that there are many different scenarios that could lead to a ship becoming beset. It should also be taken into consideration that the calculations are done for an entire year, decreasing the possibility during the summer periods and increasing it during the winter periods, and some ships do not sail during the winter periods, where this possibility is increased.

5.3.9 Breakdown

Low temperatures	FALSE								TRUE							
Unforeseen events	FALSE				TRUE				FALSE				TRUE			
Bad maintenance	FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE	TRUE		FALSE
Bad weather	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.90	0.80	0.75	0.85	0.80	0.75	0.70	0.95	0.90	0.80	0.75	0.80	0.80	0.75	0.70
TRUE	0.00	0.10	0.20	0.25	0.15	0.20	0.25	0.30	0.05	0.10	0.20	0.25	0.20	0.20	0.25	0.30

Table 5-59 - Breakdown

As stated earlier in this project, daily breakdowns are inevitable but small breakdowns that do not influence the safety of the ship, crew or cargo are redundant in these estimations. A large breakdown that does pose a risk to the safety of the ship has been estimated as being impossible unless one of the four nodes have been fulfilled.

A breakdown as a consequence of bad weather is estimated at 10%. Bad weather could destroy or ice the equipment, rendering it useless. Bad weather could also damage the rudder, disabling the ship's manoeuvrability.

The primary cause of a breakdown will most likely be bad maintenance. The engine crew always have a long list of duties and tasks to be done, some are more important than others and it is therefore always a question of prioritising. If the prioritising is managed incorrectly some parts could be exposed to more wear and tear than desired increasing the risk of a breakdown. Many different sources could lead to bad maintenance, these could also be exogenous from the manufacturer, spare parts manufacturer or the shipping company. It is estimated that if bad

maintenance is present on a specific part, there is a 20% possibility that the part will suffer a breakdown. This will apply to all equipment on the ship, from a connecting rod in the main engine to a light bulb in the navigational lights.

It is estimated that an unforeseen event will result in a 15% possibility that a breakdown will occur. Unforeseen events are hard to predict, if not impossible.

In low temperatures some equipment will breakdown with a 100% certainty, this is primarily equipment placed outboard in vulnerable positions while other equipment almost never have a breakdown. Therefore the overall estimation is that there is a 5% possibility that any piece of equipment on board has a breakdown as a consequence of low temperatures.

The calculation results in an estimate of a 4.365% possibility of experiencing a breakdown.

5.3.10 Icing

Beset in ice	FALSE															
Low temperatures	FALSE								TRUE							
Bad seamanship	FALSE				TRUE				FALSE				TRUE			
Bad weather	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Breakdown	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.80	1.00	1.00	0.85	0.75
TRUE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.20	0.00	0.00	0.15	0.25

Table 5-60 - Icing

Icing is impossible unless a combination of low temperatures and bad weather is present. Low temperatures are not the design temperature but temperatures below 2°C, as stated earlier icing normally only occurs below this temperature.

The degree of icing can be managed by the manner that the ship is manoeuvred. If the ship changes direction compared to the waves and swells the amount of icing can be decreased as the sprays are reduced; the crew can also remove some of the accumulated ice. Therefore, the possibility for a ship becoming completely iced to the point of no return is estimated at a 10% possibility when low temperatures and bad weather are present. Combining this with a breakdown that renders it impossible to change direction in the sea state is estimated to increase the possibility to 20%.

The combination of low temperatures, bad weather and bad seamanship is estimated at a 15% possibility as bad seamanship can lead to the ship's direction towards the sea state not being managed correctly.

Beset in ice	TRUE															
Low temperatures	FALSE								TRUE							
Bad seamanship	FALSE				TRUE				FALSE				TRUE			
Bad weather	FALSE		TRUE		FALSE		TRUE		FALSE		TRUE		FALSE		TRUE	
Breakdown	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.25	0.25	1.00	1.00	0.25	0.25
TRUE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.75	0.00	0.00	0.75	0.75

Table 5-61 - Icing

If the ship is beset in ice and unable to free itself it is exposed completely to the elements with a minimum possibility of escaping an icing. It is only if the ice is solid in a large range around the ship that no sprays will accumulate on the hull. This typically occurs when the ship has been beset for a period of time. Therefore, it is estimated that a beset ship has a 75% possibility that it will become iced.

The calculated total estimated possibility that a ship will become iced is calculated at 0.965%. In this calculation it is important to note that this is completed for an entire year and in the winter periods this should increase as it equally decreases in the summer periods.

5.3.11 Low temperatures

Inadequate route plan	FALSE		TRUE	
Bad weather	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.55	0.95	0.50
TRUE	0.00	0.45	0.05	0.50

Table 5-62 - Low temperatures

As bad weather and low temperatures often appear at the same time, especially as the chill factor increases as the wind increases, it is estimated that if bad weather is present, then there should be a possibility of 45% that low temperatures are also present.

An inadequate route plan where the temperatures have not been taken into account has been estimated as giving a possibility of 5% of ending up in an area with low temperatures. It is estimated that when combining the two nodes the possibility will increase to 50%.

The calculation for the estimated probability of a ship being exposed to low temperatures is calculated at 4.906%.

5.3.12 Sinking or capsizing

Damage to hull	FALSE				TRUE			
Bad cargo plan	FALSE		TRUE		FALSE		TRUE	
Icing	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.80	0.90	0.75	0.70	0.65	0.60	0.50
TRUE	0.00	0.20	0.10	0.25	0.30	0.35	0.40	0.50

When a ship becomes iced the ship can experience a massive change in stability, this could cause the ship to sink or capsize. If the ship has become iced it is estimated that there is a 20% possibility that the ship will sink or capsize.

When the ship is loading the cargo it is important to know the correct weight of the cargo and place it in the correct position, if done incorrectly this could also create a change in the stability large enough for the ship to sink or capsize. It is estimated that a bad cargo plan presents a possibility of 10% for a sinking or capsizing.

As both icing and a bad cargo plan can change the stability of the ship, the combined situation of the two, must pose a risk higher than the one for icing alone, this is therefore estimated at 25%.

As a damage to the hull does not necessary mean that the hull has been breached, the possibility of a sinking or capsizing is estimated at 30%. Combining a damage to the hull with a node that poses a threat to the stability will only increase the possibility of a sinking or capsizing.

The overall estimated possibility for a sinking or capsizing is calculated at 1.761%.

5.3.13 Bad cargo plan

Bad seamanship	FALSE	TRUE
FALSE	1.00	0.85
TRUE	0.00	0.15

Table 5-63 - Bad cargo plan

If a sailor exhibits bad seamanship it is estimated that there is a possibility of 15% that the cargo plan will be flawed. The calculation for the estimated possibility for a bad cargo plan is estimated at 0.506%. This should be very low as all the calculations today are done by computers, limiting the navigator's influence on the cargo plan.

5.3.14 Bad seamanship

Lacking experience	FALSE				TRUE			
Lacking management	FALSE		TRUE		FALSE		TRUE	
Inadequate information	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.95	0.90	0.85	0.80	0.85	0.80	0.80
TRUE	0.00	0.05	0.10	0.15	0.20	0.15	0.20	0.20

Table 5-64 - Bad seamanship

When a sailor exhibits bad seamanship this will almost always be done unconsciously as most sailors are proud to uphold the code of exhibiting good seamanship. When given inadequate information or experiencing wrong or inadequate management this could influence the sailor's conduct in a way that he or she would exhibit misguided seamanship. It is estimated that inadequate information poses a possibility of 5% and lacking management 10% that a sailor exhibits bad seamanship. Combining the two increases the amount of misguidance, and therefore it is estimated that this increases the possibility to 15% for bad seamanship.

When a sailor is inexperienced the sailor has less possibility to figure out that he or she has been misguided, therefore increasing the possibility of exhibiting bad seamanship. It is estimated that a maximum of 20% should apply for this node as there are always more than one navigator on board a vessel for support.

The calculation of the overall estimated possibility for a sailor to exhibit bad seamanship is 3.374%.

5.3.15 Inadequate information

Danish geodata agency	FALSE				TRUE			
Weather service	FALSE		TRUE		FALSE		TRUE	
Lacking management	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.65	0.00	0.00	0.50	0.50	0.00	0.00
TRUE	0.00	0.35	1.00	1.00	0.50	0.50	1.00	1.00

Table 5-65 - Inadequate information

It has been estimated that if lacking management is present, then there will be a 35% possibility that the crew will be misguided and receive inadequate information.

Data from the weather service include weather, ice charts and temperatures, if the information given from the weather service is wrong or inaccessible then the information will be inadequate. Therefore, the calculations have been done with a possibility of 100%.

The reason that “Weather service” is 100% and “Lacking management” is 35% and not 100% is that misguidance in the form of lacking management could be exposed as flawed by the sailor, whereas flawed information from the weather service is not as transparent, regardless of experience.

The Danish Geodata Agency is responsible for achieving the information that is printed in the paper charts that sailors rely on. These are constantly updated but many are still misleading, wrong or inaccessible. The electronic charts are used more frequently as these are precise. Therefore, it has been estimated that there is a 50% possibility that the sailor will have inadequate information, given that the information in the paper chart is inadequate. This is estimated on the basis that sailors share information on the unknown areas mutually.

The calculation for the estimated overall possibility that a sailor will have inadequate information is calculated at 11.370%.

5.3.16 Inadequate route plan

Bad seamanship	FALSE				TRUE			
Inadequate information	FALSE		TRUE		FALSE		TRUE	
Unforeseen events	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
FALSE	1.00	0.90	0.90	0.85	0.90	0.85	0.80	0.75
TRUE	0.00	0.10	0.10	0.15	0.10	0.15	0.20	0.25

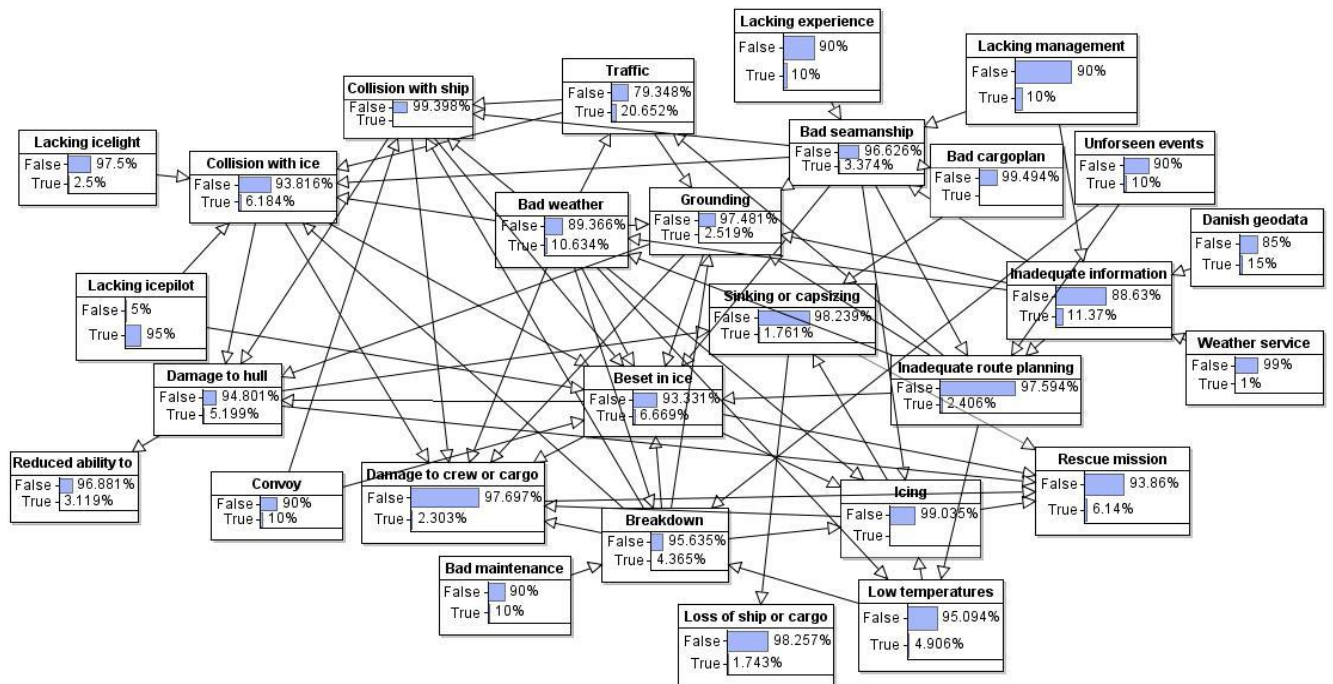
Table 5-66 - Inadequate route plan

It has been estimated that the amount of unforeseen events that could influence an inadequate route plan should not exceed 10% as most situations that could influence it have already been covered.

As most sailors are professionals they should be able to figure out if they are given wrong information in some situations, therefore it has been estimated that there is a possibility of 10% that inadequate information could lead to an inadequate route plan. For the same reason bad seamanship is also estimated at 10%. Any combination of any of these parent nodes will only increase the possibility for an inadequate route plan. The estimated possibility is calculated at 2.406%.

5.4 Total node possibilities

The total Bayesian network with all the individual node probabilities included can be seen here. It is important to note that the size and shape of the nodes have no influence on the value of clout on the node. The program is not able to display a possibility if the size is less than 1%, therefore, for some nodes only the “false” probability is stated.



5-67 - Total Bayesian network with probabilities

All calculations done result in an estimate for the possibility of the individual situations occurring.

All the calculated estimations are summed up in this table.

Situation	Possibility for true [%]
Damage to hull	5.199
Collision with ice	6.184
Collision with ship	0.602
Damage to crew or cargo	2.303
Reduce ability to sail	3.119
Traffic	20.652
Bad weather	10.634
Grounding	2.519
Beset in ice	6.669
Breakdown	4.365
Sinking or capsizing	1.761
Icing	0.965
Bad seamanship	3.374
Loss of ship or cargo	1.743
Low temperatures	4.906
Inadequate information	11.370
Inadequate route plan	2.406
Bad cargo plan	0.506
Rescue mission	6.140

Table 5-68 - Calculated probabilities

It is important to note that if a node has a high probability this does not necessarily mean that this node poses a greater hazard to the ship. Some nodes do not necessarily pose any danger to a ship but can contribute to becoming a danger, especially combined with other nodes. Some nodes have a high probability as this is inevitable, such as traffic, bad weather or low temperatures. Other nodes will be a danger to the ship and these will be the ones that should always be avoided. They are:

- Damage to hull
- Collision with a ship
- Collision with ice
- Beset in ice
- Grounding
- Breakdown
- Sinking or capsizing
- Icing

As these will always be a danger to a ship they are the ones posing a real threat to any ship sailing in Greenland. The average of the estimated possibilities of these is calculated at 3.533%. Therefore, it is estimated that there is a 3.533% probability that a ship will be exposed to a dangerous situation when navigating the waters of Greenland.

Some of these dangerous situations are not necessarily critical and some should be avoided by the ship, crew and cargo. The children nodes with no children are the critical scenarios with no other possible outcome, as the situation cannot get much worse this also includes the node "Sinking or

capsizing” and “Damage to crew or cargo or general average”. These could be fatal and should always be avoided at any cost. The ones that most likely are fatal are:

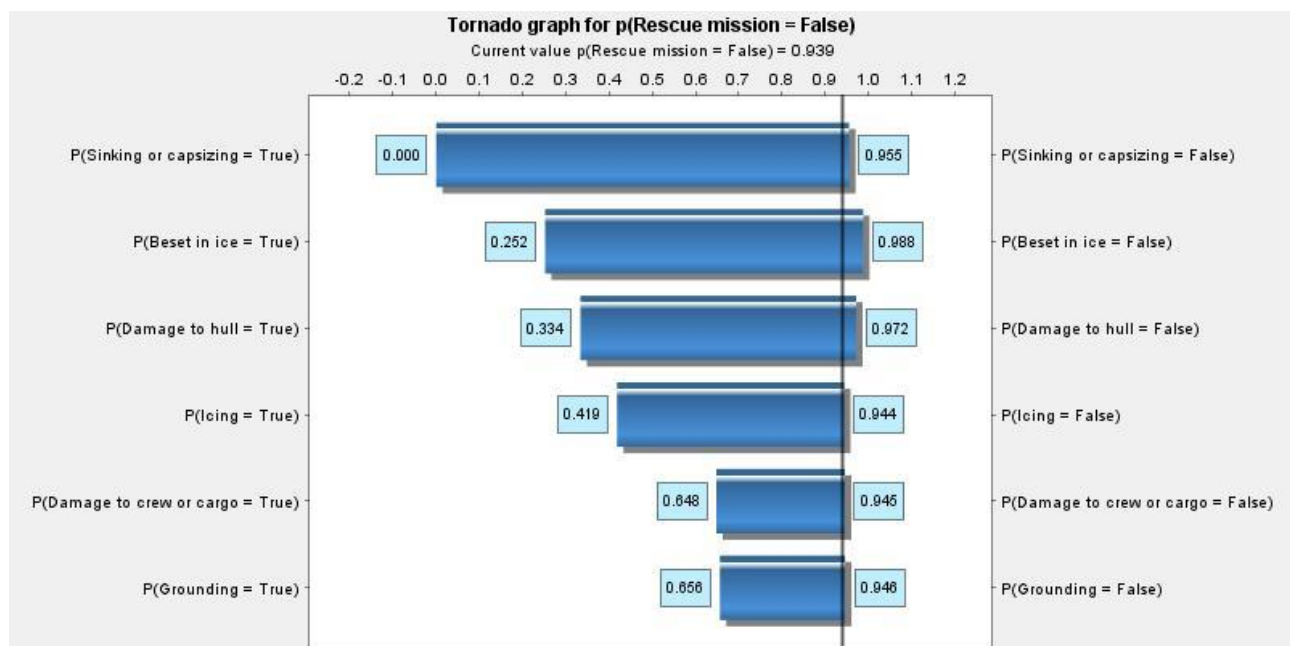
- Sinking or capsizing
- Damage to crew or cargo or general average
- Loss of ship or cargo
- Reduced ability to sail

The node “Rescue mission” is also a child node with no children, this is, however, not included here as it is a consequence that does not necessarily influence the ship or the cargo.

The average of the estimated critical possibilities is calculated at 2.232%. The estimated critical probability is calculated to be smaller than the one for the estimated probability for dangerous situations, this is to be expected and desired as a critical situation is worse than a dangerous situation.

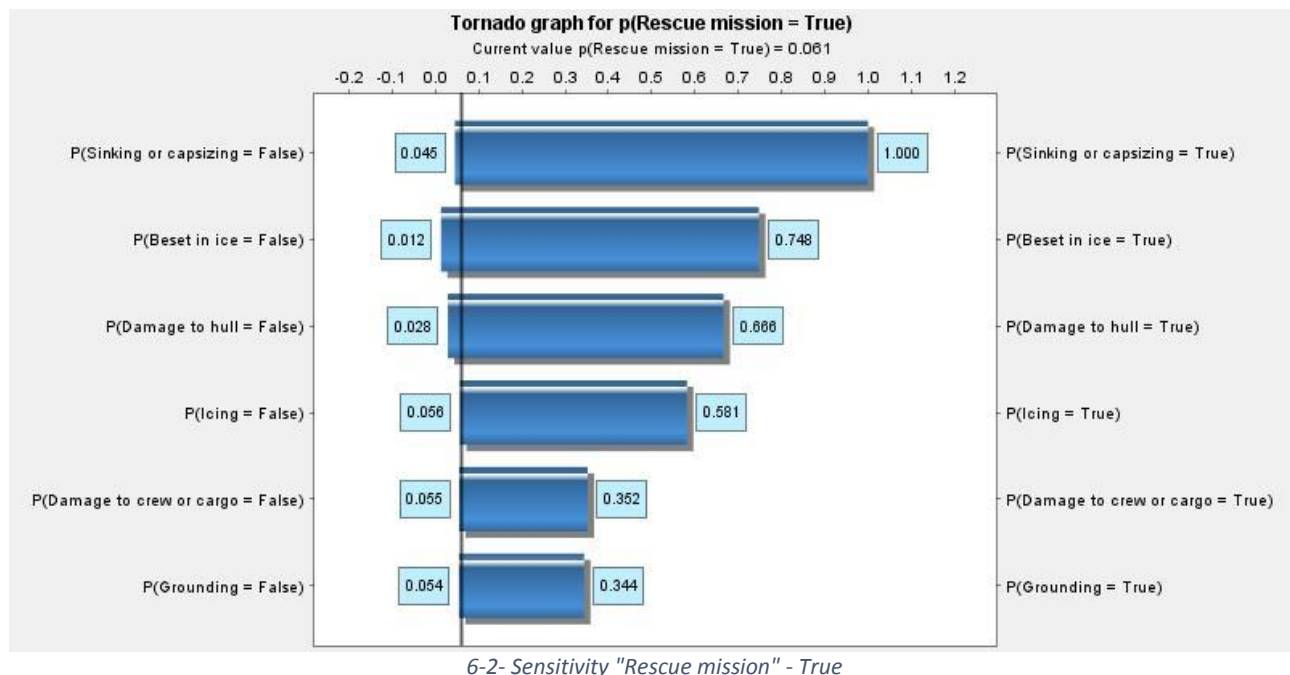
6 Sensitivity analysis

As all percentages used in the calculations are based on educated estimations a sensitivity analysis has been made on the node “Rescue mission” as the target node. The reason for choosing this node is that it is the worst scenario possible. The analysis is made using all the remaining nodes as sensitivity nodes except for “Loss of ship or cargo” and “Reduce ability to sail”, as these are purely children nodes with no influence on other nodes. This sensitivity analysis can be seen in appendix 3 & 4. From these analyses it becomes obvious that the nodes with the highest clout are the parent nodes of “Rescue mission” but “Grounding” has almost as much influence as “Damage to the crew or cargo”. The analysis is made in tornado graphs and can be seen here.



6-1- Sensitivity "Rescue mission" - False

As it has been estimated that there is a 100% possibility that a rescue mission will take place if the ship sinks or capsizes this means that the node “Rescue mission” will naturally be very sensitive to the node of “Sinking or capsizing”.



As a grounding can have far-reaching consequences for a ship and the node “Grounding” is a parent of the node “Damage to crew or cargo” it can naturally be assumed that the node “Rescue mission” will be sensitive to the node “Grounding”.

7 Conclusion

This project shows the correlation between different situations a ship, crew and cargo could be exposed to in the waters of Greenland in order to facilitate a better understanding of various hazardous scenarios. The likelihood of each hazard has been evaluated on its own and in different scenarios with other hazards. This amounts to a risk analysis that describes the correlation between different hazardous situations. The risk analysis promotes an in-depth understanding of the connections between the different hazardous scenarios, in order to provide greater insight into how the different situations interact with each other, creating or diminishing a dangerous situation.

An estimated possibility for all given combinations of situations has been completed and the probability that a given ship, crew or cargo will be exposed to any given situation has been calculated using the Bayes’ equation and presented in a Bayesian network showing the connections between all possible hazardous situations and the individual possibility. Subsequently, the situations have been divided into dangerous situations, critical situations and residual situations. The residual hazards do not necessarily pose a danger to the ship, crew or cargo but combined with other situations these could.

The dangerous situations have a high likelihood of posing a danger to the ship, crew or cargo and should always be avoided. These situations could be survived by the ship, crew or cargo. The

critical situations must at any cost always be avoided as these most likely will have a devastating effect on the ship, crew or cargo. It has been calculated that the estimated probability that a ship, crew or cargo will be exposed to a dangerous situation is 3.533% and the estimated probability for a critical situation is calculated to be 2.232%. It is expected that the estimated probability for a critical situation should have a lesser probability than the estimated probability for a dangerous situation, and this is also the case.

As all calculations in this project are purely based on educated estimations and limited data, it would be wrong to conclude anything with a high degree of certainty. Therefore, the basis for the calculations could be reconsidered in a future project with a more significant amount of empirical, quantitative and qualitative data. If this is completed the overall estimated possibilities for a dangerous and a critical situation should be established at the size of 10^{-3} , as the estimations in this project has been calculated on the base of a worst case scenario.

It can be difficult to gather quantitative data as there is a political agenda that has an interest in suppressing the fact that it can be dangerous to navigate ships in the waters of Greenland, and the maritime sector and public of Greenland are a close knit society which, at times, appear hesitant to share this knowledge. As a result hereof, the Danish Maritime Accident Incident Board has never received a single report about an incident in the waters of Greenland. The Arctic Command under the Danish Defence Command who assists in emergency situations in Greenland have information and could be willing to share some information but they have no detailed information going back more than 10 years.

In the future, it is expected that marine traffic will increase in the arctic areas. Therefore, it is desired to minimise impact of the hazardous situations. This will be done by upgrading the legislation, as this has been lagging behind. In 2017 The International Maritime Organization (IMO) plans to adopt the International Code for Ships Operating in Polar Waters (Polar Code) to SOLAS. This will implement changes to the design, construction, equipment, operational, training, search and rescue and environmental protection. When the Polar Code has been adopted it is acknowledged that Bayesian model created in this project should be updated. This holds true primarily in relation to the estimated possibilities as these should diminish if the Polar Code achieves the desired effect.

8 **Thank you**

In the making of this project many different current and former sailors with experience sailing in the waters of Greenland have contributed with information, guidance and estimations. I would especially like to give a very big thank you to:

John Mogensen - Assistant Professor at SIMAC, Former technical officer, Danish Royal navy

Bjarne Rasmussen - Former master mariner Royal Arctic Line

Mads Winter - Master mariner Royal Arctic Line

Niels-Peter Albrechtsen - Master mariner Royal Arctic Line

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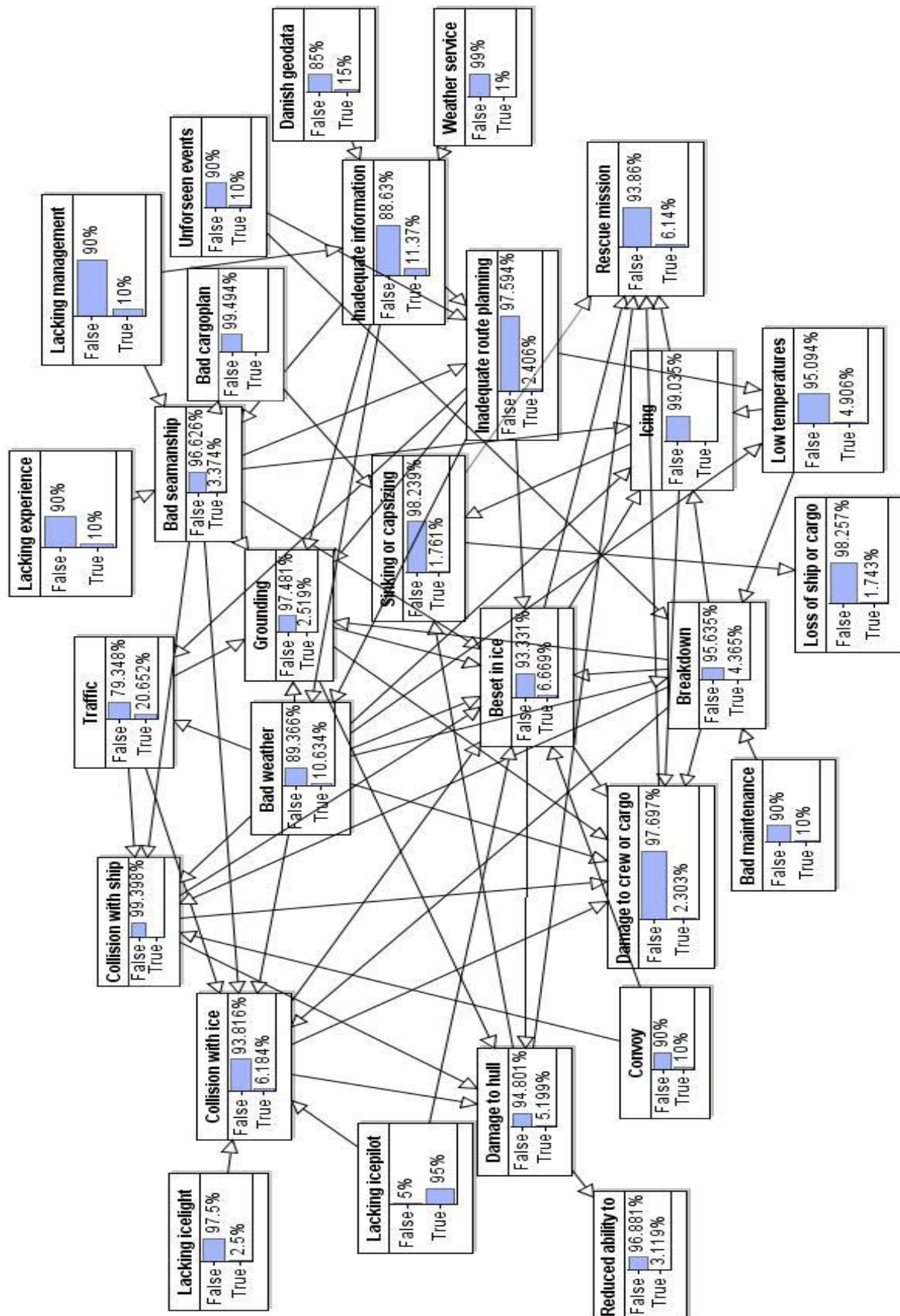
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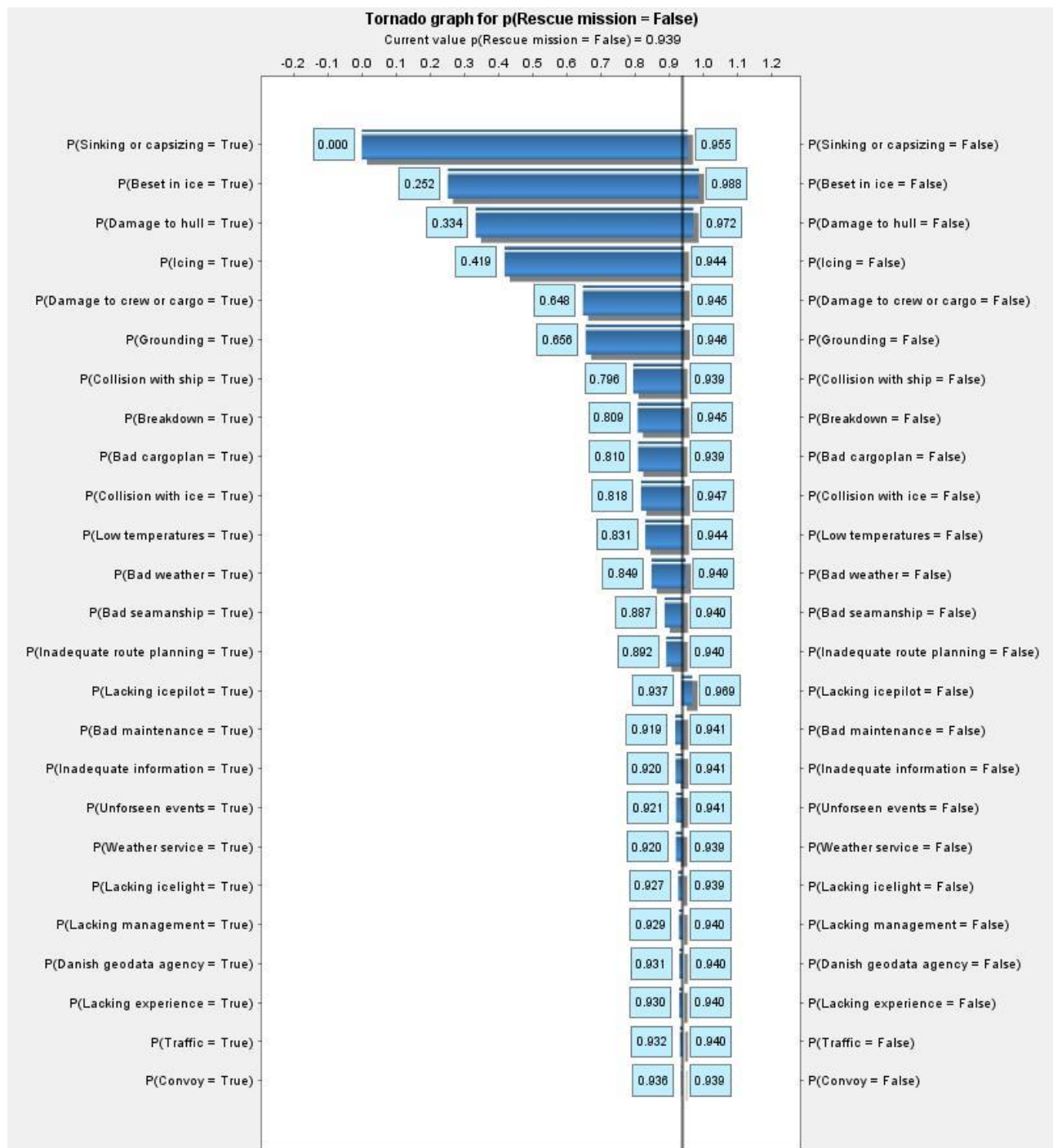
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The diagram is a complex causal network with numerous nodes and directed edges. The nodes are arranged in a roughly circular fashion, with arrows indicating the direction of causality. Key nodes include 'Bad seamanship', 'Inadequate information', 'Icing', 'Breakdown', 'Collision with ice', 'Damage to hull', 'Reduced ability to sail', 'Bad maintenance', 'Low temperatures', 'Loss of ship or cargo', 'Rescue mission', 'Inadequate route plan', 'Sinking or capsizing', 'Beset in ice', 'Damage to crew or cargo', 'Convoy', 'Lacking ice pilot', 'Collision with ice', 'Lacking ice light', 'Collision with ship', 'Traffic', 'Bad weather', 'Grounding', 'Bad cargo plan', 'Lacking management', 'Unforeseen events', 'Danish geodata agency', 'Weather service', 'Inadequate information', 'Rescue mission', 'Icing', 'Low temperatures', 'Loss of ship or cargo', 'Breakdown', 'Damage to crew or cargo', 'Convoy', 'Damage to hull', 'Reduced ability to sail', 'Bad maintenance', 'Beset in ice', 'Sinking or capsizing', 'Inadequate route plan', 'Inadequate information', 'Weather service', 'Danish geodata agency', 'Unforeseen events', 'Lacking management', 'Bad cargo plan', 'Lacking experience', 'Lacking ice pilot', 'Collision with ice', 'Collision with ship', 'Traffic', 'Bad weather', 'Grounding', 'Bad seamanship'.

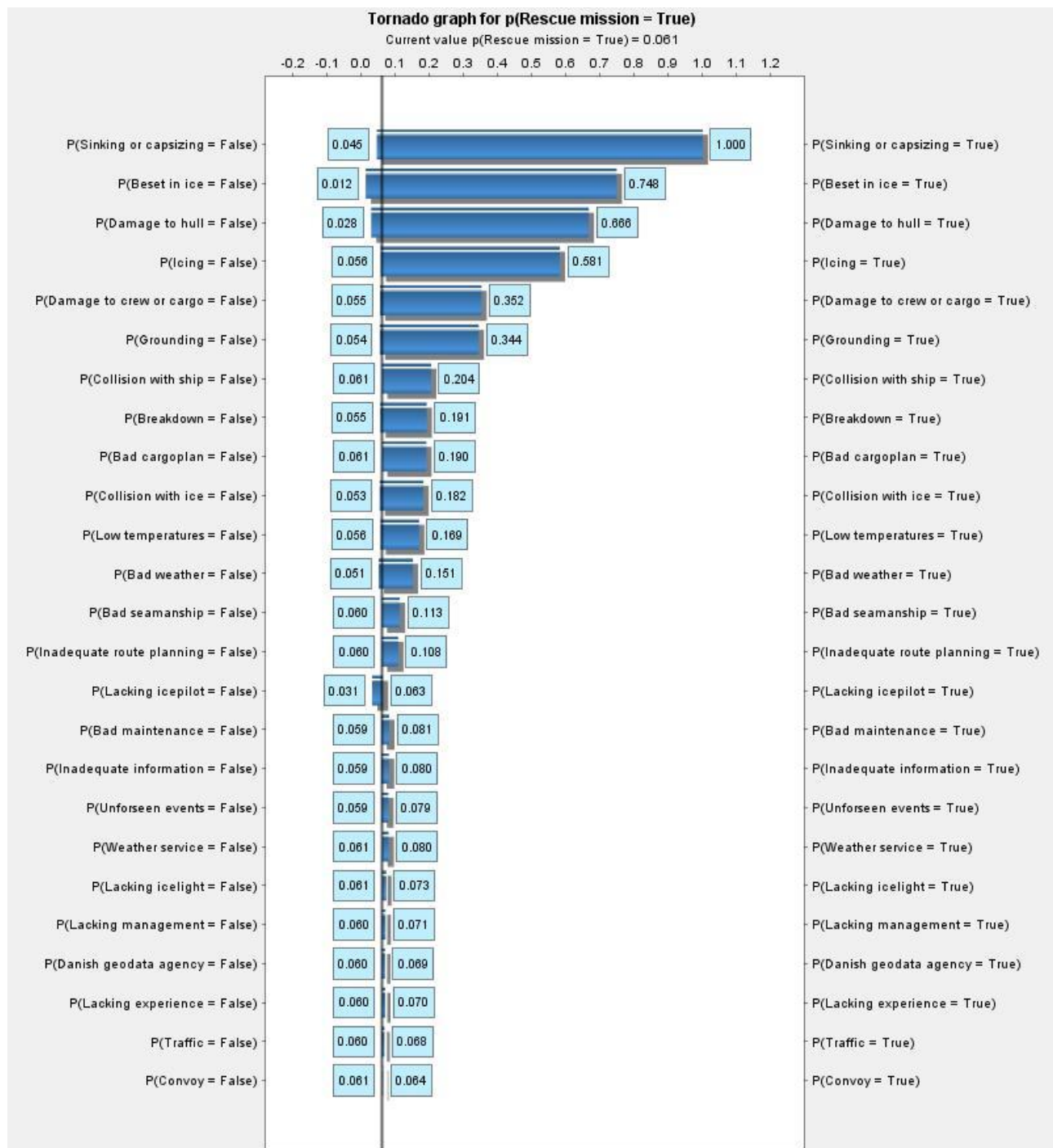
12 Appendix 2 – Total Bayesian network with %



13 Appendix 3 – Tornado graph sensitivity analyse False



14 Appendix 4 – Tornado graph sensitivity analyse True





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