



CHALLENGES WITH BRINGING COLLISION RISK MODELS USED IN THE NORTH SEA AND NORWEGIAN SEA TO THE BARENTS SEA

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ABSTRACT:

Norwegian offshore oil and gas exploration and production is moving into new and previously unexplored areas further north, such as the Barents Sea. This poses multiple new challenges in design, development and operation. Some challenges are due to the harsh arctic climate and conditions, others because this area is remote and undeveloped compared to the offshore fields further south. The distance between installations will be much greater and the overall infrastructure is far less developed.

The industry standard risk model for ship-installation impacts (COLLIDE) relies heavily on operational elements and risk reducing measures commonly found throughout the North Sea and Norwegian Sea. These are presently not available in the Barents Sea. This implies that risk assessments will have to adapt the current methodology to account for the lack of data, quality of available data, and overall “modus operandi” as offshore operations in the Barents Sea may prove to be different from comparable operations in more established areas of the Norwegian Continental Shelf.

The main operational barrier and risk reducing measure against ship-installation impacts in Southern Norway are two control centers that operates an integrated network of radars, VHF stations and AIS base stations. The same level of emergency resources, surveillance and communication coverage is not available in the Barents Sea. The lack of infrastructure and available resources affect core assumptions in collision risk assessment models and may cause otherwise minor incidents to have a significantly more serious outcome in such a remote area.

This paper discusses the main challenges of using existing risk assessment tools and models in an area with significantly less infrastructure and available resources, and proposes alternatives to overcome these issues.

Keywords:

Automatic Identification System (AIS), Ship Collision, Risk Model, Collision Risk, COLLIDE

1. INTRODUCTION

The Arctic is a vast area that may be defined in many ways depending on context and purpose. Generally speaking it is usually defined as the geographical area north of the arctic circle (at 66° 33' N) (Petroleum Safety Authority 2014). As there is (currently) no active petroleum activity along the coast from the arctic circle and up to about 70° N, there is a natural gap helping to define the areas of petroleum activity generally thought of as being in arctic regions.

The infrastructure and urban centers become smaller and further apart the further north you go in Norway, and there is significantly less petroleum activity offshore Finnmark compared to the Norwegian Sea and North Sea. The supporting infrastructure onshore in Finnmark is usually at a minimum, as petroleum operators tend to already have established headquarters and support bases in southern Norway. Supporting public services such as SAR (search and rescue) helicopters, hospital capacity, ambulances and other resources that may be needed in an emergency are also scarce north of Tromsø, with the exception of the national SAR helicopter base for Northern Norway located at Banak.

The oil and gas prices have declined significantly lately, and the USA is shifting from a major oil and gas importer to potentially becoming an exporter due to its new shale gas fields being developed (Teknisk Ukeblad 2013). Combined with indications that OPEC (Organization of the Petroleum Exporting Countries) may wish to keep oil prices low for an extended period to maintain market share, the interest in arctic petroleum exploration may decline. The speed of arctic field development is closely tied to oil prices, as the combined costs of constructing the necessary local support-infrastructure, equipment capable to deal with harsh weather conditions and new environmental challenges requires a fairly high oil and gas price to make new field developments profitable. Many believe that hard-core arctic petroleum exploration simply will not become a reality. But the Norwegian Continental Shelf in the Barents Sea is perhaps the least "arctic" area in the arctic, making field developments here more agreeable than going any further north. One field, Snøhvit (subsea), is already in operation, with one more on the way in the near future (Goliat – surface installation) and another in the pipeline (Johan Castberg – surface installation).

When the petroleum industry enters new areas, they usually bring with them people, equipment, experience and models previously used in other locations, sometimes with a very different operating environment. Practically all the areas open for petroleum exploration in the Barents Sea is free from ice most of the year, and there are fewer shipping lanes crisscrossing the Barents Sea, compared to the Norwegian Sea and North Sea. Most of the shipping traffic follows the big shipping lanes along the coast (one inner and one outer shipping lane, the outer one having two distinct "lanes") while some offshore related traffic goes from the base at Hammerfest out to the newly developed fields and other fields under exploration. Additionally quite a bit of fishing activity can be found in the area, but fishing vessels generally do not conform to shipping lanes or regular routes, but is more irregular and "random" in their activity, which is spread out across the whole Barents Sea. Although the Barents Sea has less traffic and a bigger portion of the merchant traffic adheres to known shipping lanes, it is still enough to warrant the same level of traffic surveillance that is found on installations in the Norwegian Sea and North Sea, see Figure 1. (The lines in Figure 1 are AIS tracks, with the different colors representing different ship types.)

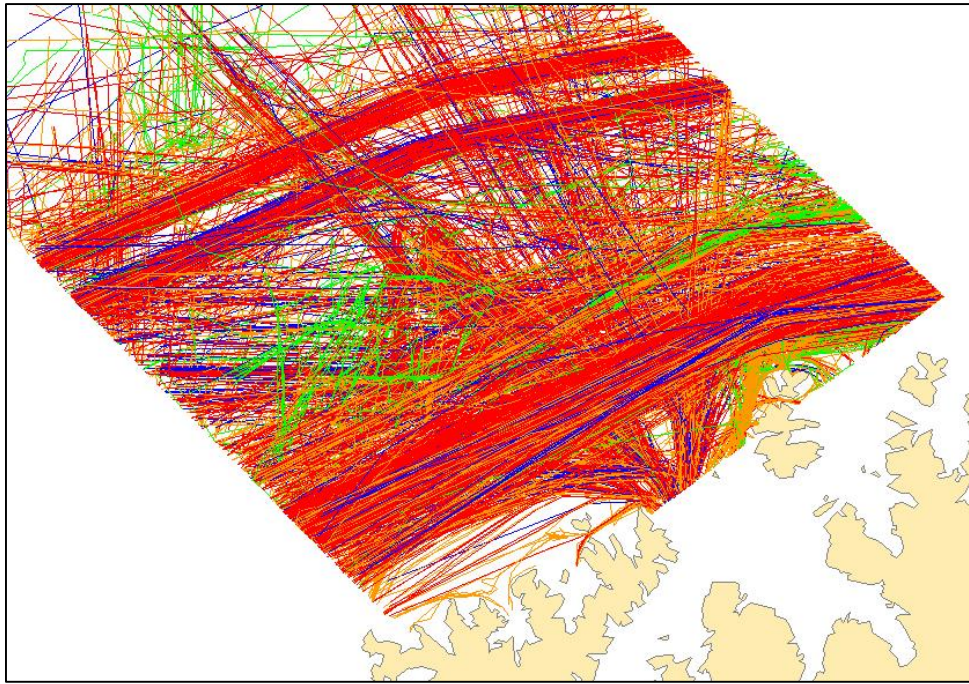


Figure 1 - AIS (Automatic Identification System) data showing shipping traffic north of Hammerfest (12 months of aggregated data) (Norwegian Coastal Administration)

This paper addresses the following research questions: (i) should more demanding arctic exploration and operation become relevant, for areas such as the north Barents Sea or the Arctic Ocean, how would the current collision risk assessment models cope with these aspects?, (ii) will arctic- and ice-related challenges necessitate the development of a brand new collision risk model, or could we simply modify the current model?

2. THE INDUSTRY STANDARD RISK MODEL

The COLLIDE risk model (Hassel et al. 2014) is used to calculate the risk of a ship-installation impact and it has quite a lot of emphasis on detection and notification for vessels on a collision course. The primary means of detection is assumed to be radar and AIS (Automatic Identification System), usually from an array of receivers spread along the coast and on collaborating installations, resulting in a cumulative coverage that is fed back to the maritime control center at Sandsli, operated by Statoil. Here traffic is monitored by experienced navigators and traffic controllers, who contact vessels, should they behave erratically or be on a collision course towards an installation. Contact is made easier by AIS, showing ship information and enabling more specific and targeted hailing. Traffic surveillance by a VTS (Vessel Traffic Service), such as Statoil Marin, combined with AIS on both the installation and incoming vessels are rewarded with a risk reduction factor of up to 96% in the current risk model. By comparison, having the installation perform its own traffic surveillance is only given a 38% risk reduction factor. A significant risk reduction factor has become the rule rather than the exception for most installations in the Norwegian Sea and North Sea.

Having a dedicated standby vessel (SBV) is quite common, and from a risk assessment perspective a very useful risk reducing measure in many ways. First of all, it enables physical interception and targeted hailing of errant ships, and it is staffed by navigators and maritime crew trained and experienced in vessel traffic detection and management. The current risk model rewards the presence of a dedicated standby vessel with a risk reduction factor of about 80%.

Traffic composition is an important aspect of the risk picture, not only because larger and faster vessels have a bigger energy potential, but also because of assumptions about the vessels behavior and inherent risk contribution. This aspect is often tied to a vessel's flag state, or ship type. In the Norwegian Sea and North Sea it is normal to see a wide range of flag states and vessel types, but in the Barents Sea, the composition is usually less diverse, as most of the shipping passing through is to and from Russia.

Notification of regular runners (vessels with regular and multiple passings through the area of interest) is another risk reducing tool in the current risk model. However, the effect of notification to vessel operators are highly variable, depending on the professionalism and available means of communication with the operators. Many Russian ship operators are hard to reach, and even harder to engage in dialogue, implying that the effect of notification of regular runners in the Barents Sea may be lower than for the Norwegian Sea and North Sea.

Many aspects of the current risk model is virtually unaffected by a new location, as weather data and operational variables will simply be entered into the model and calculated without any problem. The issues with blindly accepting certain input variables arises when underlying assumptions or fixed parameter values may be of questionable validity for the scenario/area in question.

Recently, the risk model for ship-installation impacts has been extended to also include probability of successful evacuation and the probability of structural collapse immediately after impact. Looking beyond simply the loss of main safety function (MSF), it becomes apparent that a major accident scenario in the Barents Sea is quite different from a similar scenario off the coast of western Norway. Another issue relevant in waters with sea ice, is that the current model of estimating absorbed collision energy is markedly different in areas where the majority of ships are ice-classed and/or have reinforced bow/hull. Impacts with ice-classed vessels will mean that the offshore installation will receive a much larger portion of the total kinetic energy of a collision. This issue has been described in more detail by Storheim and Amdahl (2014).

The COLLIDE risk model used in collision risk assessments in the Norwegian Sea and North Sea is heavily based on static factors and fault trees (Haugen and Vollen 1989). It is difficult to incorporate more elements or have a bigger focus on human and organizational factors (HOFs) without starting from scratch. As discussed by Chen et al (2013) and Uğurlua et al. (2013) HOFs play important roles in many marine accidents and should be incorporated in risk models for marine casualties. Fault trees are still a common methodology in accident analysis, and work well for certain subsets. Collision and grounding scenarios are often modelled by fault trees, as seen in Kuma and Sahin (2015). A Bayesian Network (BN) is an alternative method that that is less hierarchical than fault trees and more feasible for inclusion of HOFs (Trucco et al. 2008)(Ahktar and Utne 2014).

3. CONDITIONS IN THE BARENTS SEA

3.1. Vessel Traffic Surveillance

Vardø VTS (NOR VTS) (Norwegian Coastal Administration) is the only vessel traffic surveillance station in northern Norway, and is tasked with monitoring a vast geographical area. It does so through self-reporting to the online portal SafeSeaNet (Norwegian Coastal Administration), military coastal radar stations, and AIS. Long Range Identification and Tracking (LRIT) is another system used for vessel surveillance, but it is a closed system only

available to maritime authorities and government agencies, and only updates data points every 6 hours, so for the purpose of anti-collision the system is practically unusable. It is not discussed further in this paper.

The national coastal radar chain, which is part of NATO's (North Atlantic Treaty Organization) early warning system, is also used by the civilian-military coastal surveillance of merchant traffic along the coast (Forsvarets Forum 2003). These large radars are usually situated on top of mountains, giving them excellent range, typically 40-50 nm (Forsvarets Forum 2012). The closest stations to the Barents Sea are located at Sørvær, Magerøya, Berlevåg and Holmfjellet. But even these stations do not cover the Goliat or Snøhvit fields, let alone other areas further away from the coast.

3.2. *Automatic Identification System (AIS)*

AIS uses VHF (Very High Frequency) communication to transmit a small information package containing some basic ship information, as well as position, course and speed. The coastal radios have VHF transmitters (also typically on top of mountains) along the length of the Norwegian coast, providing VHF and AIS coverage up to 40-50 nm from the coast (Miljeteig 2011). Additionally, Norway launched its AISSAT-1 in 2010, and increased its AIS detection coverage to include virtually all Norwegian waters, including the whole Barents Sea and the areas around Svalbard and Jan Mayen. Data from 2010 to 2012 are shown in Figure 2. However, AISSAT-1 was only intended to operate 1-3 years, so a new satellite (AISSAT-2) was launched in 2014 to replace it when its lifetime ends (Moen 2014). A third and fourth AIS satellite are planned, so it seems AIS coverage of the northern regions is secured for the foreseeable future. However, the AIS data from these satellites are sent to the Coastal Administration, NOR VTS and the military, and are not openly accessible by regular vessels and AIS operators. Ship-ship detection is still limited by line of sight.

3.3. *RADAR and VHF range (line-of-sight)*

Both RADAR and VHF are line-of-sight, meaning the radio waves travel in a straight line, and can detect or interact with receivers and/or objects as far away as the horizon, or in the case of objects with it's own height above sea-level, beyond the distance to the horizon. Assuming a perfect sphere with no terrain irregularity, the theoretical distance to horizon (line-of-sight) from a transmitter can be calculated by the Pythagorean theorem. A radar or VHF interact with other units with their own height above sea level. Theoretical range for a radar or VHF is thus line-of-sight to the horizon for both the transmitting and receiving unit: (h_i is the height in meters, d_{nm} is the distance between the units in nautical miles)

$$d_{nm} \approx 1.93 \times (\sqrt{h_1} + \sqrt{h_2}) \quad (1)$$

This means an installation with a transmitter at 50 meters, trying to communicate with a vessel with transmitter/receiver at 20 meters, will have a theoretical range of about 22 nm. Radar, VHF and AIS range is typically 20-25 nm between installations and vessels. Typical vessel speeds are usually between 10 and 18 knots, resulting in a TCPA (time to closest point of approach) of 75 – 120 minutes, assuming that the vessel is heading straight towards the installation. This means that the typical time available from detection to (potential) impact will in most cases be between 1 to 2,5 hours, which in theory should be sufficient according to the current regulations stating that vessels on collision course must be detected at a distance of at least 1 hour prior to impact.

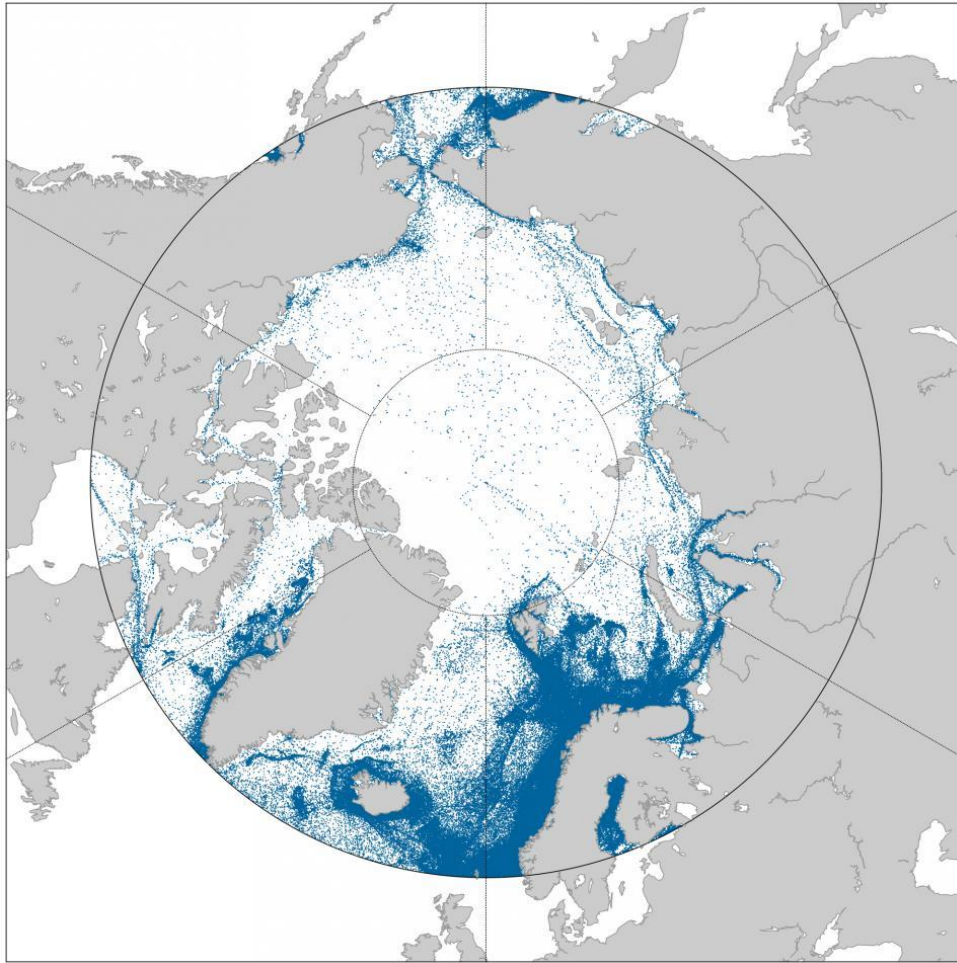


Figure 2 - AIS data from AISAT-1 from September 2010 to September 2012 (Moen 2014)

3.4. *Ice classed vessels*

Many vessels operating in the Barents Sea are likely to have some form of ice-class, and as previously mentioned, this has a negative effect on the energy distribution in case of an impact with offshore structures. This issue does not directly affect collision risk assessments, as they focus on the probability of impact, but it is worth mentioning that consequence assessments will need to be modified to account for vessels with ice class or otherwise reinforced bow/hull.

3.5. *Evacuation to shore and/or medical facilities*

In the Norwegian Sea and North Sea, evacuation is the standard solution in order to remove people from harm's way. It is assumed that further evacuation to shore, nearby installations or ships in the vicinity is unproblematic. In the Barents Sea, such "secondary evacuation" may not be so easy. The distance to shore is significantly greater, nearby installations are significantly fewer and much further apart, helicopter and ship resources are more limited and with a longer reaction time due to the greater distance and weather conditions may be more extreme, making prolonged exposure even more critical. Another issue is that proper hospital capacity and medical resources are even further away, and not necessarily equipped to handle mass trauma on the scale a potential major accident involving an offshore installation can produce.

3.6. *Arctic conditions*

In the north Barents Sea and Arctic Ocean one can find "true" arctic conditions, with drifting ice, polar lows and solid ice parts of the year. Such conditions are significantly different from

sailing in open waters with the possibility of encountering an occasional growler or sea ice. Although there are currently little petroleum activity in such areas, it could very well become an issue in the not so distant future.

Arctic conditions involving significant ice mean that some form of ice-management must be implemented. Such activities involve one or several vessels and constant monitoring of ice conditions and movement. Ice-management operations and navigation in icy waters are very different from the typical open water navigation and rig operations in the Norwegian Sea and North Sea.

4. ADAPTABILITY OF THE COLLISION RISK MODEL TO ARCTIC CONDITIONS

4.1. Current challenges with adapting the COLLIDE risk model

The COLLIDE risk model can easily be used in the south Barents Sea, where conditions are not too different from those found in other places on the Norwegian Continental Shelf. Several factors and parameters will have to use values that may be quite different from a typical scenario in the North Sea, but that is to be expected and nothing extraordinary. Some factors could be modified due to the new geographical and physical conditions in the Barents Sea, but this is still within the flexibility of the model, and the core methodology is unaffected by such adjustments.

If the COLLIDE risk model should be applied for the north Barents Sea, or the Arctic Ocean, where conditions are significantly different, with ice-conditions and even more limited satellite coverage, certain underlying assumptions and core methodology of the model are difficult to use. The current risk model is not really malleable enough to easily incorporate true arctic conditions. Adding ice-related challenges as an external component on top of the existing calculation framework may not be a good way to model how navigators and vessels respond to such conditions. Perhaps there is a need for a complete overhaul and/or alternative calculation methodology to better represent the challenges of operating in truly arctic conditions.

The current methodology is heavily based on fault trees and parallel or sequential barriers and risk reducing measures on top of assumptions of how things are done and common scenarios. If core elements of normal operations are changed, it could be more correct to change the methodology altogether, rather than trying to modify certain elements in the periphery. The biggest issue that the current models would be incapable of modelling well is sea ice. A situation where an installation is actively performing ice-management, or if the surrounding area contains a large amount of ice affecting navigation significantly (compared to open waters) is beyond the scope of what the collision risk assessments used in the Norwegian Sea and North Sea are capable of calculating with the current methodology. Farid et al. (2014) has proposed a hybrid risk model for ice management, where risk influencing factors (RIFs) for multiple branches of a fault tree are treated as individual BNs and the outcome of these are passed on to the conventional fault tree for final analysis. This might improve the current risk modelling, but will most likely not be optimal for COLLIDE, as discussed in Sections 4.2 and 5.

Other arctic conditions, such as extreme temperatures and limited satellite and communication coverage, are also elements that have not really been considered or quantified in the existing models. The impact of these factors on the final results of collision risk assessments remains unknown. New operational procedures and different modus operandi require new calculation

methods if the situation cannot be modelled in the same way with simple adjustments to certain factors. If a scenario is markedly different, simply adding more or less of certain parameters will not be sufficient. New and unforeseen challenges may also arise when analyzing operations in new locations, like the fact that navigation chart data quality is of a whole different level for certain areas of the arctic ocean. "Facts" that are taken for granted elsewhere, may no longer be valid when entering the Arctic.

4.2. *Bayesian networks (BN) – a promising approach to modeling collision risk under arctic conditions*

BNs are directed acyclic graphs (DAGs) where the model variables are represented by nodes, usually linked by directional conditional probability and dependencies. Using Bayes theorem of conditional probability (2), a BN is a good way to graphically represent a set of variables with a probability distribution.

$$P(A|B) = \frac{P(B|A) P(A)}{P(B)} \quad (2)$$

Sometimes BNs are called causal networks as the structure of BNs typically reflects causal relations, with directed arcs between the nodes to show influence. A directed acyclic graph means there cannot be any loops back to the same node. All the network nodes have a (finite) number of mutually exclusive states, each with a probability of occurrence depending on the state of the parent nodes (Darwiche 2009). Compared to other modelling techniques, BNs are often well adapted to combine expert knowledge data and handle lack of data, in addition to presenting causal relationships and a good graphical representation that enables easy comprehension of the overall network (Uusalito 2007). Some researchers believe the high number of probability parameters in even simple BN models is one of the major drawbacks (Chena and Pollino 2010).

In the current collision risk model, radar navigation is only relevant in case of restricted visibility, and the "radar error" part of the fault tree, shown in Figure 3, is relatively simple. It is arguably an overly simplistic model of radar navigation, which is a specialized form of navigation with a whole range of challenges and possible error modes. An example of how arctic factors may be integrated into the collision risk model looking more closely at radar navigation using a BN is shown in Figure 4. The graph itself is a visualization of causal links and how some factors may influence one or several other factors. A node may even have a positive effect on one node and a negative effect on another.

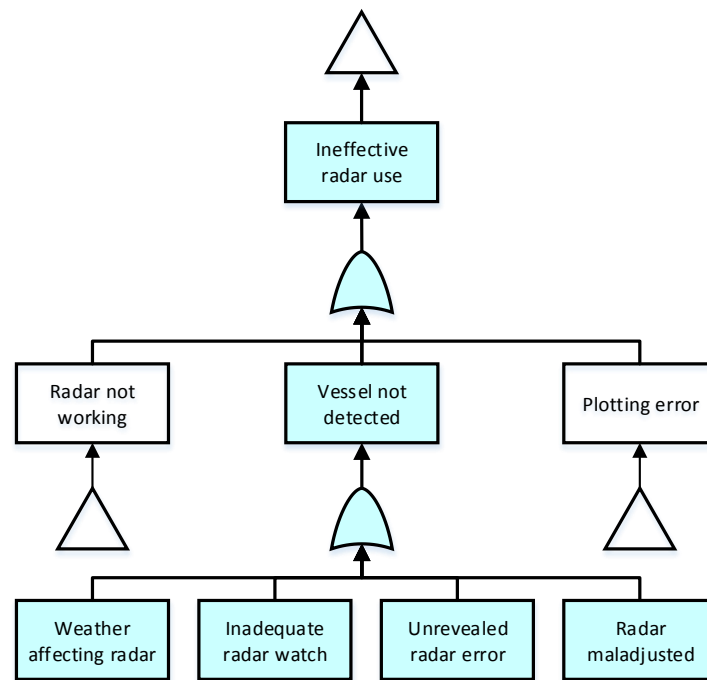


Figure 3 - Excerpt of COLLIDE fault tree for radar (navigation) performance

The fault tree shown in Figure 3 is only an excerpt of the COLLIDE collision risk model showing the section related to radar error. Only the section marked in light blue is intended for comparison with a similar BN model shown in Figure 4.

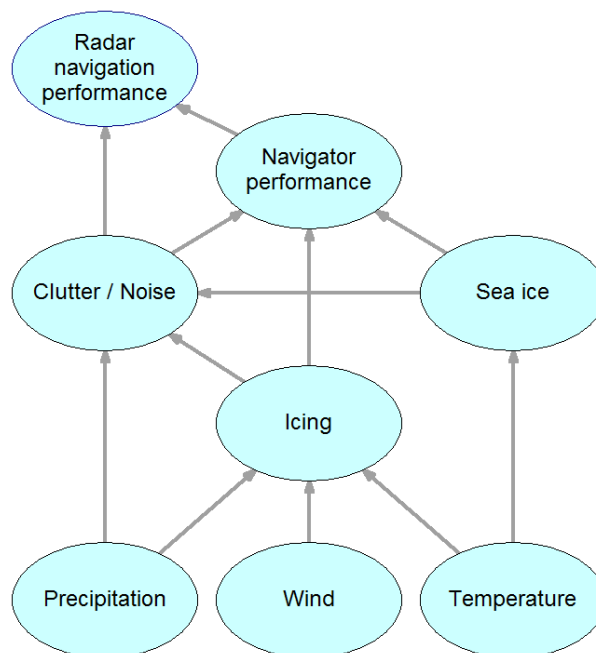


Figure 4 - Qualitative BN of some factors affecting radar (navigation) performance under arctic conditions

To use the BN shown above as an example: "Precipitation" affects both the level of "clutter/noise" directly, but also the level of "icing" on the vessel superstructure/instruments. "Temperature" affects both the level of "sea ice" and the level of "icing". The crew may not even know the level of "icing", so the effect on the radar is perhaps only experienced through increased "clutter/noise" on the display, which in turn may affect both the navigator performance and overall radar navigation. "Sea ice" will have a negative effect on

"clutter/noise" (meaning it will produce more clutter/noise), but potentially a positive effect on "navigator performance" as the navigator will most likely become more alert and cautious when navigating in waters with "sea ice". An increased attention to the conditions will most likely improve the quality of the radar navigation, but known and unknown levels of "clutter/noise" may ultimately negatively affect the radar navigation, despite the navigator's best efforts.

While the fault tree in Figure 3 simply uses AND/OR gates, the BN in Figure 4 uses conditional probability tables for each node. These tables very easily become very large, as a node with M parents (variables), each with N states, produces a conditional probability table with N^M cells. To illustrate this, a conditional probability table of "Clutter / Noise" is shown in Table 1.

Table 1 – Example of conditional probability table (CPT)

Precipitation	Icing	Clutter / Noise	
		True	False
True	True	0.99	0.01
True	False	0.9	0.1
False	True	0.8	0.2
False	False	0.0	1.0

5. DISCUSSION AND CONCLUSIONS

Several elements of the COLLIDE "radar fault tree", outside of what is shown in Figure 3, are overly simplistic, outdated and rigid. Adding new elements to such a fault tree to account for arctic conditions would not be optimal. Fault trees are great for many purposes, but a dynamic and non-linear activity, such as radar navigation, has many influencing factors at several levels, and is a complex interaction between the external weather conditions, the radar and the navigator. In the fault tree, there is a node for "adverse weather conditions". Weather is not good or bad; it is increasingly challenging and may at some point make effective (radar) navigation almost impossible. Modeling weather as a binary element of an "OR" gate makes such a model unsuitable for detailed analysis in the Arctic or harsh weather environments.

The BN in Figure 4 shows a much more complex network of interactions and causal links compared to the fault tree in Figure 3, without becoming significantly harder to understand or calculate. It would also be easier to add new factors to a model with higher fidelity and level of detail, such as the BN in Figure 4. The radar operator's role ("Navigator performance") and HOFs have not been elaborated in the BN-example in Figure 4; only (arctic) weather related factors have been included in order to illustrate the example.

BNs can have a tendency to become large and complex, but a large fault tree can be equally unwieldy if not even worse. The linearity and hierarchical nature of fault trees also tend to cause problems when models become large and complex, as the scenarios being modelled are rarely linear. BNs can be challenging to quantify/calculate if a node has too many parent nodes, as the conditional probability matrices quickly become very large. This can be mitigated by merging several nodes into larger "umbrella"-nodes, providing the nodes are relatively homogenous with respect to outgoing arcs and dependencies. In Figure 4 the three nodes "precipitation", "wind" and "temperature" could for example be merged into the node "weather". Such simplification of the BN should not be done unless necessary for calculation purposes, as one of the benefits and strengths of a BN model is the level of detail and transparency one can achieve. The primary

difference between arctic weather conditions and the weather in the North Sea could for example primarily be temperature, while wind and precipitation may be relatively similar. In such cases, it would be beneficial to have separate nodes for each data set, in order to accurately model differences between areas, such as the North Sea and the Arctic, due to weather conditions.

If petroleum exploration in the northern part of the Barents Sea should become relevant, it would be natural to have good collision risk models that incorporate the special circumstances and factors that separate the arctic from other more common areas with petroleum activity. Trying to modify existing fault tree models does not seem like a good alternative, as BNs can be developed that better represent the actual conditions and influencing factors with better fidelity without becoming overly complex.

Going forward, it should be investigated what types of marine operations or aspects of petroleum exploration would most likely be subject to arctic conditions and need specialized risk models adapted to handle the conditions only found in the arctic.

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