Towards a risk model for the Northern Baltic maritime winter navigation system

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Abstract - The implementation of the Finnish-Swedish winter navigation system has managed to increase the safe passage of merchant vessels in the Baltic Sea. However, there will always be risk associated with Baltic Sea winter navigation. Based upon IMO's Formal Safety Assessment; steps zero through two, this report will aim to provide a system description of the Finnish-Swedish winter navigation system outlining the main elements used to ensure safe passage for merchant vessels, and based upon a literature survey, discussion with Finnish icebreaker crew and the results of an exploratory hazard session this report will determine the hazards associated with Baltic Sea winter navigation, the preliminary results of a risk analysis and the icebreaking operations which are linked to the winter navigation accidents. This work will lay out the preliminary work towards a risk model for preventing oil spills in the Northern Baltic.

1. INTRODUCTION

The following report will focus on icebreaker operations; the risk related to these operations and will provide the framework for a risk model of the Northern Baltic maritime winter navigation system. The framework of this risk model is different than the risk models proposed by Jalonen and the International Maritime Organization, as we are introducing a structured framework to model risk and will define hazardous situations, hazards, hazardous events and the potential accidents which may lead to an oil spill and our focus area is that of the Northern Baltic Sea which only experiences first year ice unlike polar regions which experience multi-year ice.

2. System Description

A. BALTIC SEA TRAFFIC AND WONTER CLIMATE CONDITIONS

The Baltic Sea covers an area of 415,266 square kilometers and is bordered by nine countries with over 85 million people in the surrounding area (HELCOM, 2013). The area contains more than 500 functioning ports and can have more than 2000 vessels in its waters at any given time, making the Baltic Sea one of the world's busiest shipping areas and according to HELCOM, accounts for more than 15% of the worlds transported goods.

During the winter, navigating the Baltic Sea can prove to be challenging and dangerous to the many vessels within its waters due to its harsh ice conditions. The northernmost part of the Baltic Sea will normally begin to freeze in the middle of November and reaches its maximum extent in late February or early March with ice thicknesses greater than 70 centimeters in the most severe areas. On average the Baltic Seas ice covered area is 45% and in the winter of 2010/11 the Baltic Seas ice covered area was nearly 75% (Baltice). Combining a heavy volume of traffic with severe ice conditions can increase the possibility of an accident which can consequently lead to a loss of cargo / passengers, loss of the vessel, and environmental damage due to an oil spill. Moreover, the response to such an accident is very challenging due to harsh ice conditions

B. WINTER NAVIGATIONSYSTEM BREAKDOWN

The Finnish-Swedish winter navigation system is meant to increase the safety of Baltic Sea winter navigation by limiting the number of merchant vessels which are eligible for icebreaker assistance when they enter the Baltic Sea; Vessels which do not meet the requirements are not included in the icebreaking service (Liikennevirasto, 2012). Only the most capable vessels will be granted icebreaker assistance. The winter navigation system consists of four main elements which are used to increase safety:

- Ice class rules
- Traffic restrictions
- Icebreaker assistance
- ice services

Ice class rules specify the required structural strength and engine output for a vessel in order for it to be assigned a Finnish-Swedish ice class. Traffic restrictions determine the minimum ice class and deadweight of vessels permitted in a certain area of the Baltic Sea with icebreaker assistance. Only vessels which have an ice class suitable for the traffic restrictions are assigned for icebreaker assistance. Icebreakers will assist merchant vessels when they enter the ice field and safely escort these vessels to and from port. Ice services provide the merchant vessels with relevant ice charts and ice reports which will further aid the vessels to ensure safe winter navigation in the Baltic Sea. These elements are described in further detail in the following sections.

C. ICE CLASS RULES

The Finnish-Swedish ice class rules have been accepted by many classification societies, but some classification societies still have their own ice class rules in place. For these ice class rules an equivalency chart is used to determine which vessels that are classed with other classification societies can be permitted icebreaker assistance in the Baltic Sea (HELCOM, 2013). The Finnish-Swedish ice class rules are a set of rules which specify the minimum strength of hull, propulsion machinery, and rudder in order to operate in normal conditions. Hull strength is determined by the design ice pressure which is strongest at the bow and decreases moving towards the aft end of the ship. The propulsion machinery requirements are considered to be met when a vessel is capable of navigating under its own power behind an icebreaker in ice covered waters. Finnish-Swedish ice class rules are divided into six different ice classes based upon varying strength of hull, propulsion machinery and rudder. Ice classes in order of increasing strength are class III, II, IC, IB, IA, and IA Super. Classes II and III are viewed as open water vessels, they are vessels with no ice strengthening and are only capable of operating independently in very light ice conditions, while classes IC and IB are only designed for early winter and late spring ice navigation. IA can operate all year round but is restricted when ice conditions are severe. Class IA Super is the highest of the Finnish-Swedish ice classes and ships are designed to operate in heavy ice conditions mainly without icebreaker assistance (TraFi, 2010). The requirements of these ice classes are based upon the assumption of the presence of icebreaker assistance.

Ice Class	Ice Class Requirements
IA Super	Ships with such structure, engine output and other properties that they are normally capable of navigating in difficult ice conditions without the assistance of icebreakers.
IA	Ships with such structure, engine output and other properties that they are capable of navigating in difficult ice conditions, with the assistance of icebreakers when necessary.
IB	Ships with such structure, engine output and other properties that they are capable of navigating in moderate ice conditions, with the assistance of icebreakers when necessary.
IC	Ships with such structure, engine out and other properties that they are capable of navigating in light ice conditions, with the assistance of icebreakers when necessary.
II	Ships that have a steel hull and that are structurally fit for navigation in the open sea and that, despite not being strengthened for navigation in ice, are capable of navigating in very light ice conditions with their own propulsion machinery.
III	Ships that do not belong to the ice classes referred above.

Table 1 – Ice Class requirements (TraFi, 2010)

D. TRAFFIC RESTRICTIONS

When ice conditions in the Baltic Sea become severe, the Finnish and Swedish Maritime Administrations impose traffic restrictions to certain ports. Theses traffic restrictions are implemented to ensure the safety of merchant vessels, protect the environment and decrease waiting times for icebreaker assistance by limiting the number of vessels which are not suitable for severe ice conditions (Jalonen, Riska, and Hänninen). The Finnish and Swedish Maritime Administrations determine these restrictions based upon weather and ice conditions, as well as a vessels ice class and deadweight. Only vessels which meet the ice class and deadweight requirements can be granted icebreaker assistance. Along with the ice class and deadweight requirements a vessels engine output and amount of cargo on board may be taken into consideration in the most severe ice conditions. As winter advances and the ice conditions become more severe the traffic restrictions will also become more strict. The length of these traffic restrictions will be dependent upon how long and harsh the winter is. Traffic restrictions are issued five days before they will be enforced so visiting vessels can notify the maritime administration well in advance of their arrival in ice covered waters. In individual cases the Finnish and Swedish transportation agencies can grant a ship exemption from the traffic restrictions if ice conditions have temporarily eased, if there is a special transport, threat of a production shutdown in a factory, or if the vessel would otherwise be granted icebreaker assistance and its deadweight is no more than five percent below the required deadweight. However, exemptions cannot be granted to vessels older than twenty years, and exemptions are valid for only the one voyage (Liikennevirasto, 2012). Table 2 indicates the ice thickness which each ice class is limited to and table 3 shows the typical traffic restrictions for the ports of Tornio, Kemi, and Oulu as winter progresses. The table specifies the ice class and deadweight of the vessel restrictions.

Ice Conditions	Ice Class Restriction
Thickness of ice: 10 – 15 cm	Restriction II
Thickness of ice: 15 – 30 cm	Restriction IC
Thickness of ice: 30 – 50cm	Restriction IB
Thickness of ice: > 50 cm	Restriction IA

Table 2 – Basis of Traffic Restrictions (Finnish Maritime Administration)

Port	21 Dec	11 Jan	21 Jan	11 Feb	28 Feb	11 Mar	21 Mar	1 Apr	8 Apr	21 Apr	May 11
Tornio, Kemi, Oulu	I,II 2000	IA, IB 2000	IA 2000	IA 3000	IA 4000	IA 4000 2000 (t)	IA 4000 2000 (t)	IA 4000 2000 (t)	IA 4000 2000 (t)	IA 2000	I,II 2000

Table 3 – Typical Traffic Restrictions for ports of Tornio, Kemi, and Oulu. (Liikennevirasto, 2003-2011)

E. ICEBREAKER ASSISTANCE

Icebreaker	Built	Displacement (ton)	Speed (kn)	Power (MW)	LOA (m)	BWL (m)	Draft (m)
Finnish Icebreakers							
Voima	1954/79	5209	16	10.2	83.5	19.4	7.0
Urho	1975	7925	19	16.2	106.6	23.8	8.3
Sisu	1976	7925	19	16.2	106.6	23.8	8.3
Otso	1986	9130	18.5	15.0	99.0	24.2	8.0
Kontio	1987	9130	18.5	15.0	99.0	24.2	8.0
Fennica	1993	9700	16.5	15.0	116.0	25.2	7.0
Nordica	1994	9700	16.5	15.0	116.0	25.2	7.0
Zeus	1995			5.4		14.6	6.7
Swedish Icebreakers							
Ale	1973		14	3.5	49.0	13.0	5.0
Atle	1974	7900	18.5	16.2	104	23.8	7.3/8.3
Frej	1975	7900	18.5	16.2	104	23.8	7.3/8.3
Ymer	1977	7900	18.5	16.2	104	23.8	7.3/8.3
Oden	1989	13000	15	18.0	108	29.4	7.0/8.5
Tor Viking II	2000	5900	16	13.5	83.7	18	6.5
Balder Viking	2000	5900	16	13.5	83.7	18	6.5
Vidar Viking	2001	5900	16	13.5	83.7	18	6.5
Estonian Icebreakers							
Tarmo	1963		14.8	10.12	84	21.2	7.4
Eva-316	1980			5.151	60	12.2	3.8
Botnica	1998	7300	15	10.0	96.7	23.1	7.2

Table 4 – List of Northern Baltic Icebreakers (Jalonen, Riska, and Hänninen, 2004)

Once the Finnish-Swedish ice class rules and the traffic restrictions have been applied to a merchant vessel and all requirements are met, then that vessel is now considered eligible for icebreaker assistance for as long as it is in the ice-covered waters of the Baltic Sea. Merchant vessels which are bound for the Baltic Sea and require icebreaker assistance are to notify the Finnish or Swedish Maritime Administrations well in advance of entering ice-covered waters. Both maritime administrations control their own icebreakers operations and will therefore order the icebreakers to their operating areas according to ice conditions and traffic flow. Once in its operating area the icebreaker will have control of the traffic in that area and will make the decisions on the assistance operations and routes. Icebreakers will be in direct contact with the merchant vessels within its operating area and will provide them with information on the ice conditions and the easiest routes through the ice covered waters (Jalonen, Riska, and Hänninen, 2004). With this information merchant vessels are expected to proceed in the ice covered waters without icebreaker assistance for as long as possible. When a vessel can no longer proceed without direct assistance then the icebreaker will cut the vessel loose from the ice, open a channel and escort the merchant vessel to port. In cases of severe ice conditions the icebreaker will tow the vessel into port. In the case that several vessels require direct icebreaking assistance then the icebreaker controlling that operational area will likely arrange the vessels into a convoy. The vessel with the worst ability will be the first vessel to follow the icebreaker; if necessary it can be towed. The vessel with the best ability will be taken last in most cases (Kujala, Suominen, and Jalonen, 2007).

F: ICE SERVICES

Ice services is a service which is used to further aid merchant vessels while navigating the ice fields of the Baltic Sea and help to contribute to a safe voyage. Ice services are provided by the Meteorological Institute where they monitor ice conditions and ice developments on a daily basis. From the data which the institute collects it issues ice charts and ice reports that provide a description of the current ice conditions and information about the operational areas of the icebreakers. Information regarding traffic restrictions as well as shipping routes are also available. Ice charts, ice reports and ice forecasts can be ordered from the Meteorological Institute for a charge and ice charts and ice reports are available on the Baltic Ice website free of charge. Another aspect of ice services is IBNet. The IBNet system is a distributed traffic information system for icebreakers. IBNet takes the Baltic Sea traffic information and combines this with satellite images, weather and ice conditions and aids in the coordination of the icebreaking fleet, see figure 1.

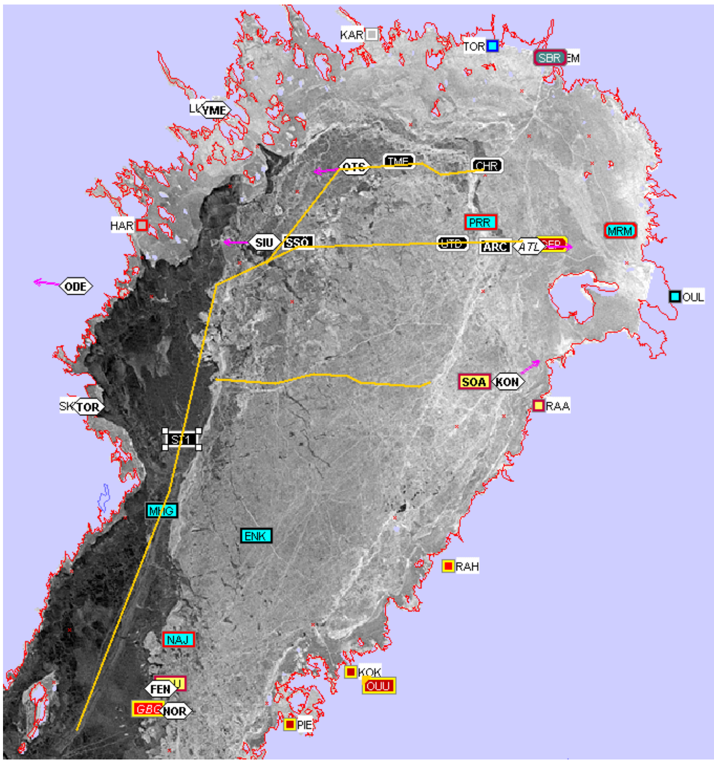

Figure 1 – Traffic situation view for April 18th, 2013 (VTT)

G. ADDITIONAL REQUIREMENTS FOR THE WINTER NAVIGATION SYSTEM

Both the Finnish and Swedish Maritime Administrations have outlined additional requirements which must be met by all merchant vessels when taking part in Baltic Sea winter navigation activities to further increase the safety of travelling in ice covered waters. The requirements are that when navigating in ice, the vessel is to always be loaded to the draft line required for its class. The propeller is to be completely submerged and if possible below the ice, the vessels have to use the maximum engine power specified by its ice class if it is required, and the cooling-water system is to be designed and used so that the supply of the cooling-water is ensured when navigating in ice (Liikennevirasto 2012).

3. RISK MODEL FRAMEWORK

A. OVERVIEW

Winter navigation in the Northern Baltic Sea can be a hazardous activity. Not only are there hazards involved with merchant vessels navigating in the Baltic Sea during winter months, there are also hazards involved with icebreaking operations while escorting these merchant vessels through the Baltic Seas ice covered waters. In the past the consequences of these activities have led to loss of life, environmental damage, material damage and loss of ship (TraFi Accident Statistics 2009-2012). The Finnish-Swedish winter navigation system was implemented to help reduce the occurrence of these hazards and mitigate the risks involved. This section focuses on defining a structured framework for expressing and modeling risk associated with Northern Baltic winter navigation operations which can potentially lead to an oil spill.

B: RISK MODEL HIERARCHY

Accident scenario identification for a maritime winter navigation system can be a challenging task, as there is a large number of influencing factors which can lead to the occurrence of an accident. For the purpose of identifying factors which may lead to Baltic Sea winter navigation accident, a hierarchy was created to more easily identify these factors which may lead to a winter navigation accident in the Baltic Sea. There were six stages for this risk model hierarchy; traffic / environment, hazardous situations, hazard, hazardous event, accident, and consequence. The hierarchy can be used by first determining the traffic, environmental and operational parameters of the merchant vessel. Next determine the source or object which can be considered a hazard and then determine an irregular event which occurs and can potentially lead to an accident. The hierarchy provides a systematic approach to this risk model by beginning with broad parameters (Traffic/Environment) and then gradually determining more specific parameters in the risk model hierarchy. Table 4 describes all stages of the risk model hierarchy which is developed around an idea of coherent knowledge and an understanding based risk perspective.

Stage	**Stage Description**
Traffic / Environment	Traffic and environmental parameters which the merchant vessel is operating in.
Hazardous Situation (HS)	Current operation of the vessel which can be considered hazardous. (eg. Towing, Convoy)
Hazard (H)	A source / object which can contribute to a hazardous event (eg. vessel, ice, ground)
Hazardous Event (HE)	An irregular event from the vessels operation which if occurs may lead to the occurrence of an accident (eg. Vessel slows significantly in heavy ice conditions)
Accident (A)	The accident which may occur due to the contributing factors. (Traffic / Environment, hazardous situation, hazard, hazardous event)
Consequence (C)	The outcome due to the accident.

Table 4 – Stages and Stage Description of Risk Model Hierarchy

C. ACCIDENT SCENARIO DIAGRAM

Figure 2 is a representation of the process to determining accident scenarios using the developed risk model hierarchy. The figure shows the relationship between all stages of the risk model hierarchy and illustrates that there are numerous possible paths which can lead to an accident. The traffic/environment is represented in the figure by the larger of the circles and shows that within those traffic/environmental parameters there can be multiple hazardous situations (HS). Within the multiple hazardous situations there are then hazards (H) which can lead to an accident. It is shown in the figure that a hazardous situation may have one hazard, multiple hazards and in some cases two different hazardous situations could have a similar hazard. Stemming from the hazard an irregular event in the vessels operation may occur, which is called a hazardous event (HE). This Hazardous event can then lead to a potential accident (A) and the resulting consequences (C) from the accident which occurred, all of which is illustrated in figure 2.

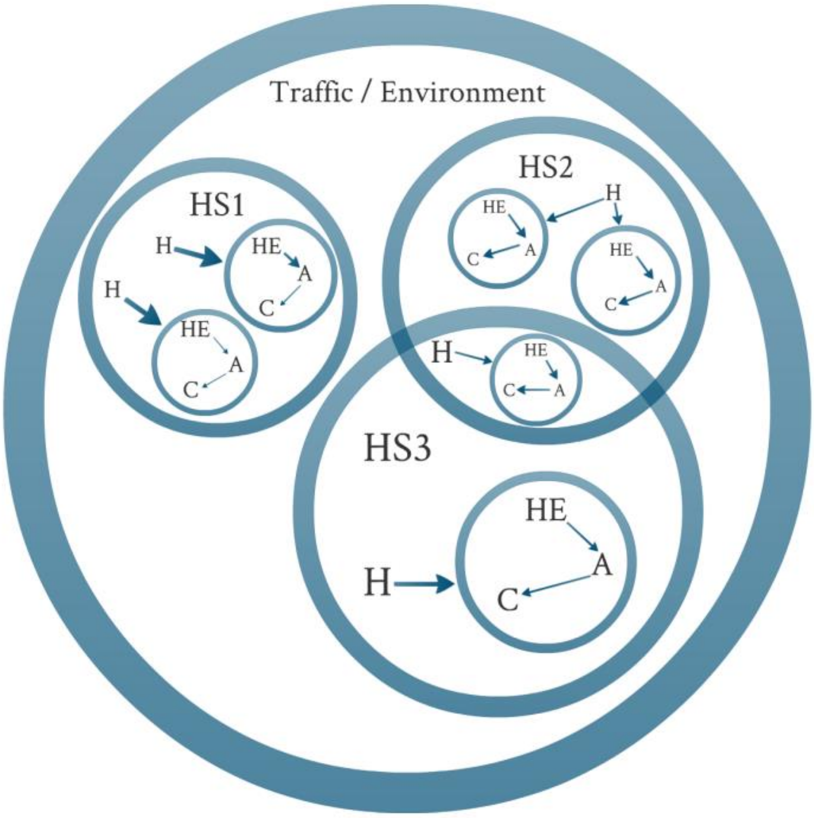

Figure 2 – Hazard Identification Diagram. HS: Hazardous Situation, H: Hazard, HE: Hazardous Event, A: Accident, C: Consequence(s)

D. PRELIMINARY RISK MODEL

D.1 OVERVIEW

The preliminary risk model was created from a qualitative analysis to effectively illustrate the hazards, hazardous events, and possible accidents associated with the identified hazardous situations of a merchant vessel which is navigating in the Baltic Sea. The diagrams show which operation a merchant vessel is performing and indicates which contributing hazard and hazardous event may lead to a certain accident. Both the hazard and hazardous event are dependent upon each other in order to lead to an accident, which is shown in each accident event chart. Through a hazard session with maritime industry experts, discussions with Finnish icebreaker crews and review of available literature the indicated hazards and hazardous events were determined to be the most notable factors which can lead to the listed potential accidents.

D.2 CONVOY

A convoy generally refers to two or more vessels. A convoy will be assembled in most cases so an icebreakers service can be most effectively utilized. Figure 3, shows the event chart for the convoy operation, which indicates the hazard (orange), the hazardous event (yellow), and the potential accident (red). The figure shows the relationship between the hazard and hazardous event, and how one is dependent upon the other in order for the outlined accident to occur. From the hazard session it was determined that the greatest hazards to the merchant vessel while in the convoy operation were the other merchant vessels, icebreaker, and any challenging ice conditions. The ground was not considered to be a factor because an icebreaker has the most up to date charts for its operating environment.

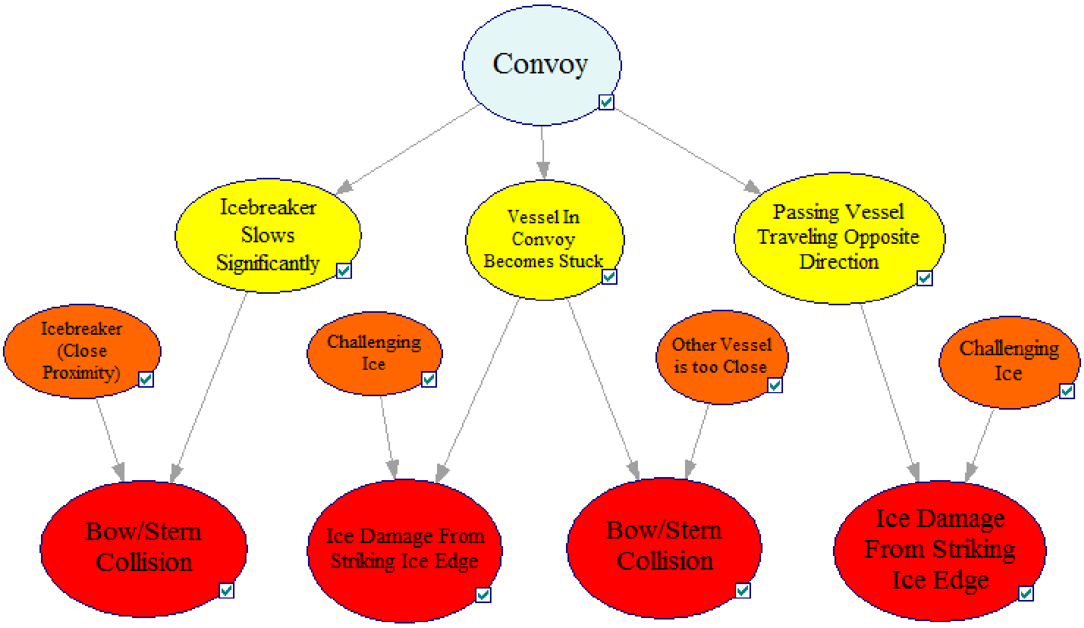

Figure 3 – Convoy Risk Model Diagram – Orange: Hazard, Yellow: Hazardous Event, Red: Accident

D.3 INDEPENDENT NAVIGATION

Independent navigation is when the merchant vessel is operating on its own in the Baltic Sea. A merchant vessel would likely be in an independent operation while in the Baltic Sea if it had one of the higher Finnish-Swedish ice classes or the wait for icebreaker assistance would be too long. Figure 4 indicates that the determined hazards for solo navigation are other vessels, challenging ice, and the ground. It also indicates the associated hazardous events with these hazards and the accidents which they can both lead to.

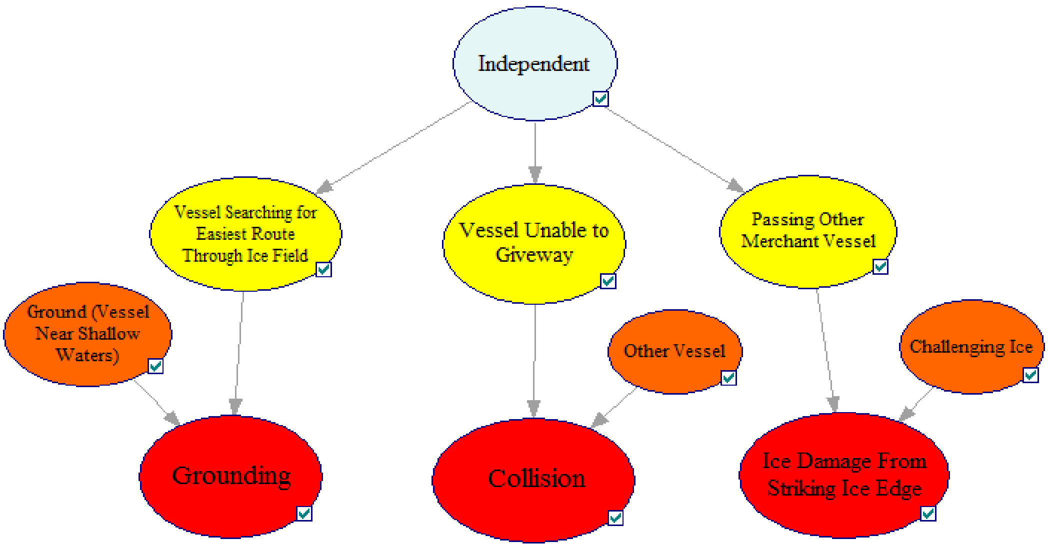

Figure 4 –Independent Navigation Risk Model Diagram – Orange: Hazard, Yellow: Hazardous Event, Red: Accident.

D.4 BESET IN ICE

A vessel which is beset is said to be stuck in ice and unable to free itself. A vessel can become beset in ice due a lack of machinery power to navigate the ice field or due to challenging ice conditions. Figure 5 shows the risk model for a merchant vessel which is beset in an ice field. The figure indicates that compressive and drifting ice fields can be the most dangerous for a beset ship. It also shows the hazards which can arise from becoming beset in these two ice fields and the potential, all of which were determined from the hazard session.

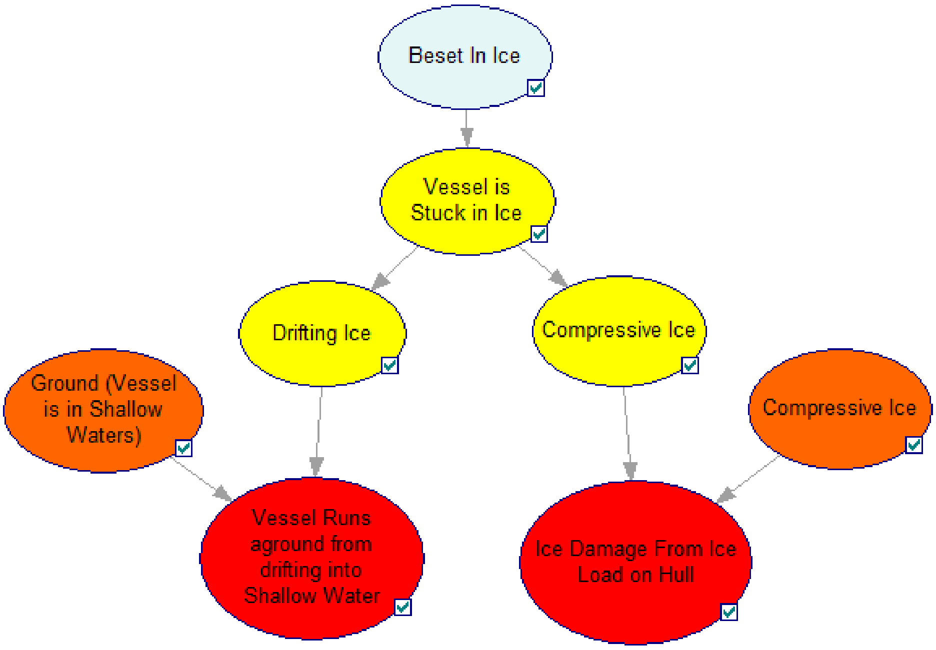

Figure 5 – Beset Risk Model Diagram - Orange: Hazard, Yellow: Hazardous Event, Red: Accident.

D.5 CUT LOOSE

A merchant vessel is to be cut loose when it has become beset in ice. A vessel is broken loose from ice with the help of an icebreaker. The icebreaker will pass alongside the merchant vessel at a very close distance of several meters, opening a channel beside the vessel which releases the ice pressure. From discussion with a Finnish icebreaker crew it was determined that compressive and drifting ice fields can prove to be challenging when cutting a beset vessel loose, see figure 6. When the ice pressure is released the compressive or drifting ice could force the merchant vessel in the direction which the pressure was released and potentially resulting in a side/side collision with the icebreaker.

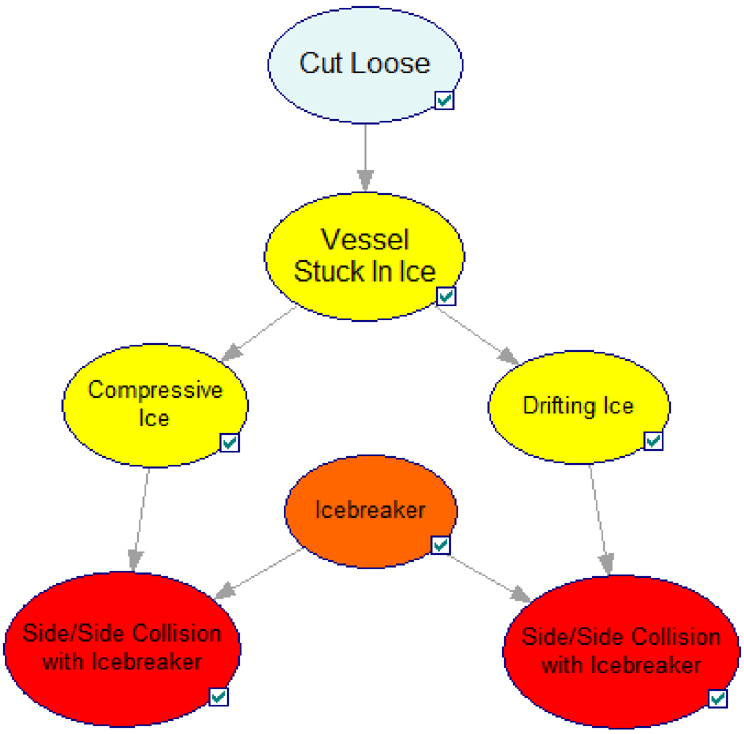

Figure 6 – Cut Loose Risk Model Diagram - Orange: Hazard, Yellow: Hazardous Event, Red: Accident.

D.6 TOW (SHORT TOW)

The short tow operation is when a merchant vessel is attached to an icebreaker by its towing rope and the bow of the merchant vessel is positioned in the icebreakers towing notch. After discussions with Finnish icebreaker crews it was determined that Finnish icebreakers most often use short tow as the preferred operation when escorting a merchant vessel. Short tow is the preferred operation because it provides the icebreakers with nearly full control over the merchant vessel. Providing the icebreaker with full control over the merchant vessel significantly limits the occurrence of encountering a hazard because icebreakers have superior strength, the most up to date navigational aids and are experienced with the operating environment which allows it to easily maneuver harsh ice conditions and avoid shallow waters.

4. DISCUSSION

In this report we outlined the weather and traffic conditions of the Baltic Sea, provided a system description of the Finnish-Swedish winter navigation system and identified the four main elements for that navigation system. The understanding which we gained from the winter navigation system allowed us to then develop the framework towards a risk model for the Northern Baltic maritime winter navigation system with a focus on oil spills. The preliminary framework involved creating a risk model hierarchy which would provide a structured approach to identifying accident scenarios which may lead to an oil spill. With the aid of the created hierarchy, available literature, Finnish icebreaker crews, TraFi accident statistics and a hazard session with industry experts we were able to develop the preliminary risk model for the main merchant vessel operations. The merchant vessel operations which we developed risk models for were convoy, independent navigation, beset in ice and cut loose. The created risk model for each operation outlines the hazardous situation (Vessels Operation), the potential hazard in the situation, the hazardous event (Irregular Event) and the possible accident which may occur due to the previously mentioned factors. After discussions with Finnish icebreaker crews a risk model was not created for the towing operation because short tow is most commonly used and limits the occurrence encountering a hazard due to the icebreaker having nearly full control over the merchant vessel.

5. CONCLUSION

The purpose of this report was to provide the preliminary framework for a risk model for the Northern Baltic winter navigation system. This was done so from a literature review, discussions with Finnish icebreaker crew as well as a hazard session with industry experts. From this a risk model hierarchy was created to provide a systematic approach to hazard identification for merchant vessels in the Northern Baltic Sea. The next phases for this risk model will be to provide a qualitative analysis of the determined accident scenarios and for the preliminary work to be presented to industry experts for approval so this project can then move towards the completion of a risk model for the Northern Baltic winter navigation system. This risk model differs from that created by Jalonen by developing a structured approach to determining accident scenarios with a focus on oil spills.

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