Activity 1.1

Study on future need of icebreaking capacity

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Abstract: This report is part of the WINMOS project that is co-funded by the European Union. The aim of this report is a desktop study for the subactivity 1.1, study on future need of icebreaking capacity. For this report previous studies made on winter navigation were studied. These studies were assessed from the perspective of the simulation model that will be the outcome of the WINMOS activity 1.3. The first part handles the traffic flows in the Baltic Sea, with focus on the future scenarios. The second part discusses the ice conditions in the Baltic Sea, again focusing on the future. The following chapters handle the icebreaking operations in the Baltic Sea. The last part focuses on the simulations made previously on the subject of winter navigation, especially in the Baltic Sea. Lastly, the report gives some suggestions on how the simulation model in the WINMOS-project should be carried out.

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1 Introduction

This report is a part of a larger WINMOS project that is co-financed by the European Union. The main objective of the WINMOS project is to ensure sustainable and efficient maritime transports all-year-around and diminish the barrier caused by the sea ice in the Baltic Sea. The project consists of a number of measures that are needed today and within the following years, but also measures that are needed in order to make strategic decision for the period 2020-2030. The project has therefore both short- and long-term goals, of which the long term goal would be to agree upon and formulate a joint “Baltic Sea Winter Navigation Strategy”.

This report is a part of the first activity of the WINMOS-project and is defined as a study on the future need for icebreaking capacity. This activity will result in a simulation model of the whole Baltic Sea winter traffic which in turn will form a base for the common winter navigation strategy mentioned above. The starting point for the activity is to carry out a desktop study on relevant previously performed studies in the area, which is the aim of this report. The findings that are described in the report will serve both as input data to the model and as an aid when deciding on how to actually define and construct the model.

In order for the study to form the basis of the simulation model, there are certain aspects of the winter navigation in the Baltic Sea that need to be covered. This includes estimating the future marine traffic in the Baltic Sea area, both in terms of number of vessels and the ice going capabilities of the fleet. The report highlights certain issues that might affect the composition of the fleet during the following years and presents several traffic estimations made both for the entire Baltic Sea area and for each of the participating countries. Furthermore the effects of for instance the new regulations on sulphur emissions are discussed.

Other important aspects to consider when analyzing the future need for icebreaking capacity are the future climate and ice conditions. This topic will be covered by discussing recent ice conditions, the estimated development of the ice conditions and overall the effect that ice has on navigation and the marine traffic.

The following chapter is dedicated to the current operations done, in order to make Baltic Sea winter navigation possible. These operations are undertaken by the authorities of each Baltic Sea country and include both actions to facilitate the winter navigation, such as providing icebreaker assistance, and inflicting restrictions on the vessels in order to assure that the required icebreaking service level will be reached. The last chapter of the report focuses on the actual simulation part of the study and presents six relevant, previously done simulation models. The reasoning behind the chosen simulation models, as well as their advantages/disadvantages, are also discussed.

At the end of each chapter the findings and how they should be taken into consideration when constructing the simulation model and defining the future Baltic Sea Winter Navigation Strategy are discussed. Moreover, at the end of the report a thorough discussion will bind all of these different parts together and lead the way to the next part of the activity.

2 Marine traffic in the Baltic Sea

Probably the most important aspect of the winter navigation in the Baltic Sea area is the seaborne traffic. Without cargo and passenger ships operating in the area, there would be no need for icebreaker assistance. For the creation of new winter navigation strategies, the amount and type of the customers has to be known. It is important to estimate the future traffic flows and what kind of ships are operating in the Baltic Sea. This chapter therefore analyses both the amounts and types of the Baltic Sea traffic.

2.1 Analysis of the current and future traffic flows

The Baltic Sea Region is described as a sea area with a dense port network. There are approximately 250 ports all together, ranging from local piers to major international ports. Sweden, Finland and Denmark have the highest number of ports due their long coastlines. Although there are numerous ports in the area, the traffic is generally concentrated to a few larger ports. In 2009 46% of the total cargo throughput was concentrated to 10 of the biggest Baltic Sea ports. In terms of cargo volumes the two biggest ports in the Baltic Sea region are Primorsk and St. Petersburg in Russia. (Petersen et al. 2011) The total amount of cargo handled in the ports bordering the Baltic Sea was about 839.4 million tons in year 2012. This means an increase of 0.1 % compared to that of year 2011. However, on country level most countries experienced a decline in cargo volumes. This was the case for Estonia (-10%), Finland (-9%), and Sweden (-2%), whereas volumes increased in Russia (+12%). Of all the different cargo types, liquid bulk and container traffic experienced the highest increase of volume, while other dry bulk cargo remained the same. More statistical information can be found from the Baltic Port List 2013, Baltic Port Insight 2013 and Baltic Port Barometer 2013, all published by the University of Turku.

Despite the current economic climate and the decreased cargo volumes during the previous years, there were no dramatic drops in cargo volumes in the Baltic Sea Region in 2012. Furthermore, the fifth Baltic Port Barometer survey, in which a total of 53 seaport authorities participated showed that half of the respondents expected a moderate economic growth for the year 2013. (Holma & Kajander, 2012)

When looking at transport scenarios for the Baltic Sea Region for 2030, it is clear that a significant increase in transport within the region is expected. Especially in the eastern parts, such as Russia, Estonia, Latvia, Lithuania and Poland, the general economic development and the increased trade between the countries will lead to an increase in their respective traffic volumes. In total, maritime freight transport is estimated to grow by 30 % between 2010 and 2030. This would amount to an increase of more than 220 million tons and an annual growth rate of 1.3%. The use of alternative fuels and the improved energy saving techniques in general are taken into consideration by including in the estimation a reduction of 7 % of liquid bulk, mainly crude oil. The largest increase is expected in the container market, where an increase of almost 140 % is estimated, meaning over 82 million tons. Dry bulk is expected to increase by 42 %, RoRo/trailers by 52 % and other freight by 32 %. These percentages apply to the total volumes to/from and within the Baltic Sea Region, not just between regions within the BSR. In Figure 1 can be seen how the growth is expected to be divided between the different coastal regions. (McDaniel & Kyster-Hansen, 2011)

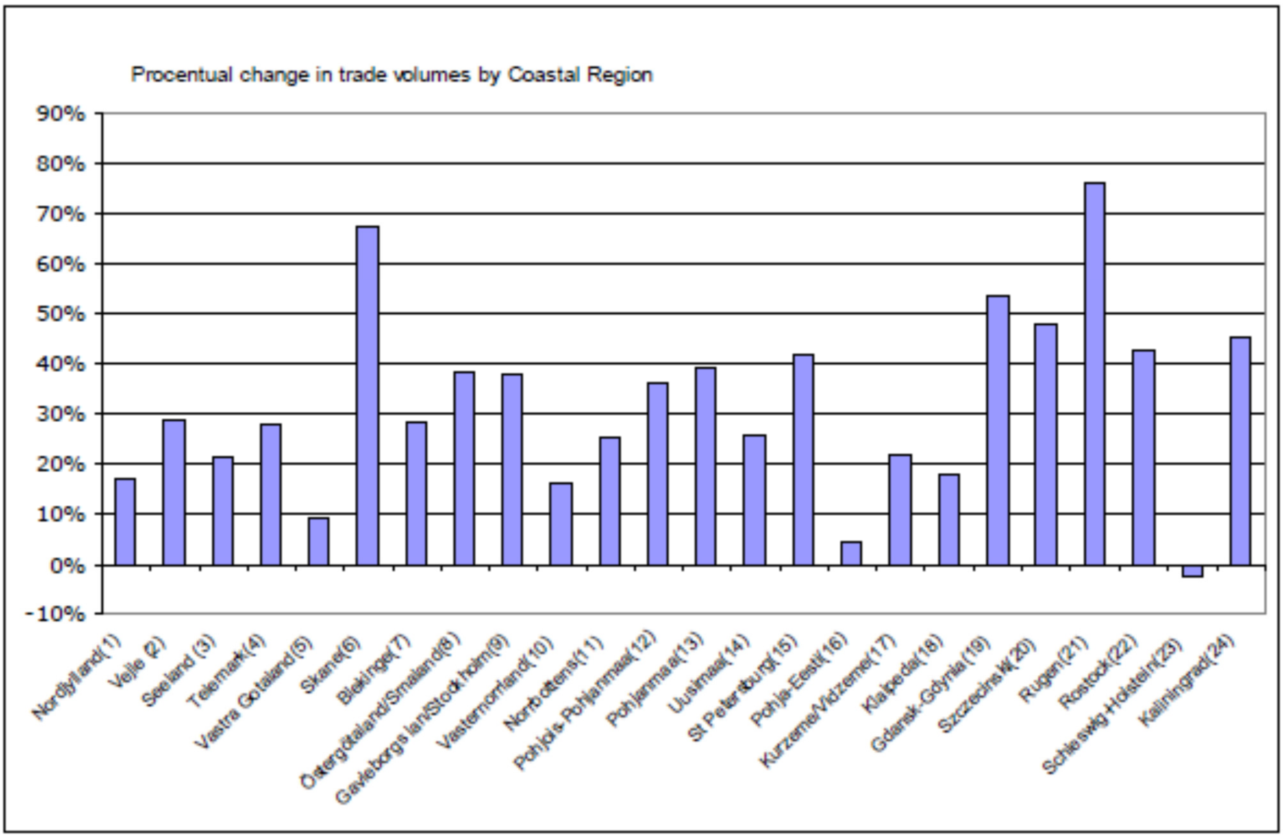


Figure 1 The expected changes in the cargo volumes divided by coastal region (McDaniel & Kyster-Hansen, 2011)

Both Finland and Sweden have made some estimates on how their marine traffic will develop in the future. In Finland the estimation is done for year 2030 and takes into consideration changes in population, activity rates, productivity, import/export share and production structure. It is however mentioned that the growth of the share of imports/exports in the overall economy is probably the biggest factor in maintaining the growth of seaborne transport. An estimated annual level of approximately 140 million tons of international seaborne transports is reached by combining an approximately 2,5 percent average long term GNP growth rate, a 10 million tone transit trade scenario and the "WAM" energy policy scenario. When fuels are excluded, the growth in imports is significantly larger than the growth in export. Two thirds of the 50 million ton growth in imports is significantly larger unitized cargo and almost a threefold increase in container transport is estimated. (Lehto et al., 2006)

The Swedish forecast for year 2020 was made by SIKA (Statens institut för kommunikationsanalys) and the traffic administrations. It is based on the official national economic forecast, where structural changes towards service and knowledge intensive sectors, existing taxes and fees as well as transport infrastructure that is assumed to be complete by year 2020, were assumed. With these assumptions a much faster growth in transported monetary values (84 %) than growth in transported weight volumes (17%) between 2001 and 2020 was forecasted. However, the number of tons loaded and unloaded in Swedish ports increased already by 16 percent between 2001 and 2005 to approximately 150 million tons yearly. The forecast in volumes for 2020 was either almost reached or exceeded in most ports already by 2005. (Vierth et al., 2007)

Another estimation done by the Swedish Transport Administration suggests that the seaborne traffic will increase between 1,48-1,61 % yearly between the years 2006-2030. It also estimates that the percentage of seaborne traffic compared with the total traffic (including road and railway traffic) will remain at the same level as year 2006. This means that the seaborne traffic will account for 37 % of the total traffic year 2030. The traffic estimation is based on an assumption of a 2,2 % yearly GDP increase during the period 2005-2030. The percentage used has been the average GDP growth between the years 1980-2005 and is therefore also chosen for this study. Other economical and societal issues that have been considered when making the traffic estimations for year 2030 include the population growth, forecasts for the value of goods, for transit traffic and for international trade, the increase of rail access charges and the sulphur regulations. (Wikström, 2013)

Furthermore the capacity of the port of Luleå is expected to increase from 6 million tons up to 20 million tons by the year 2020. This increase in the handled cargo is due to the increasing demand of iron ore. In the port of Luleå there is therefore an ongoing project on drenching a new deeper fairway, which would allow even larger cargo vessels to enter the port. If the estimated capacity increase will take place, it would mean that the port of Luleå would become one of the three largest ports of Sweden. The icebreaking capacity in the Baltic Sea should be adjusted accordingly, taking into consideration to the increased icebreaking need of the dry cargo vessels and AFRAMAX- size vessels exporting cargo from the port of Luleå. (Sjöfartsverket, 2013)

The future of maritime transportation in the Estonian ports is evaluated in for instance a study made on marine transportation in the Gulf of Finland. It is said that Estonia’s own import and export is only 27 % of the total tons handled in the Estonian ports. The rest is Russian transit traffic that consists mostly of petroleum products but also include coal and fertilizers. Russia is, however, officially aiming at transporting all petroleum products through its own ports by 2015. The Estonian ports are expected to experience an increase between 21,3 - 70,7 million tons between the years 2007-2015. (Kuronen et al., 2008)

All in all it appears that the traffic volumes in the Baltic Sea will keep on growing, despite the current economic situation. If the volumes keep increasing, there could be larger need for icebreaking assistance as well. The cargo import volumes will most likely be rather steady, whilst the export volumes can easily be affected by the closure of businesses in Finland. Furthermore, the traffic to Russia is of special importance and should not be ignored. If the traffic volumes on the Gulf of Finland keep on growing and the icebreaking co-operation with Russia would become more feasible, this could have a large impact on the need of both Finnish and Estonian icebreaking.

2.2 The effects of new sulphur regulations on the Baltic Sea traffic flows

The International Maritime Organization (IMO) adopted in 2008 a decision for new restrictions for the sulphur dioxide emissions in marine traffic. The restrictions include stricter regulations for the special sulphur emission control areas (SECAs). The Baltic Sea, along with the North Sea and the English Channel form a SECA-area. The maximum sulphur content of marine fuel will drop to 0,1% in 2015 in these areas. Ships have different options to fulfil these regulations. They can change their fuel to one that has low sulphur levels, such as marine gas oil, LNG or other alternative fuels. In addition to marine gas oil, a new low sulphur HFO has been developed. This fuel would be cheaper also compared to marine gas oil. The Swedish Maritime Administration is already contemplating using the fuel in their vessels. The installation of sulphur scrubbers is also possible. All these alternatives will cause higher expenses for the ships and these additional costs will be transferred to the freight costs. The rises of freight costs can then affect the amounts of ship traffic in the Baltic Sea as alternative transport methods could become more cost effective. (Mellin et al., 2013)

These changing traffic flows can have major impact on the need of icebreaking services in the Baltic Sea. Freight operators will try to minimize the costs incurring to them. If sea transport will become costly, the ship operators will aim for transport routes that minimize their costs. The longer the ship has to sail in the SECA-area, the higher the expenses will be. For example in Sweden this could mean more traffic to the west coast from where the goods would be taken by road or rail to the east coast, instead of straight ship traffic to the east coast. Also, in the north, shipping from Narvik can become more appealing than shipping from Luleå. In Finland the traffic could concentrate on the southern ports, from where the transport would go further via railway or truck. This would mean diminishing traffic volumes especially to the northern ports, where the need of icebreaking services is largest. Thus it is important to find accurate assessments of the effects of the sulphur regulations on the traffic flows of the Baltic Sea. Some studies have been conducted in Finland and in Sweden that assess the costs of the regulations as well as their impact on traffic volumes.

According to a study for the Finnish Ministry of Transport and Communications, the estimated costs of the SECA-regulations to ships paying fairway dues to Finland would be between 350 million and 560 million euros. These estimates were based on three different scenarios that varied the fuel consumption of the ships. The future fuel prices were estimated by member companies of the Finnish Oil and Gas Federation. The study did not estimate the effects on the traffic volumes. Also, the effects of using scrubbers was not studied. (Kalli et al. 2009)

Two different studies have been made in Sweden on this subject. The first analysis was conducted by VTI with the samgods model in 2009, and it was updated in 2013. This analysis had three different scenarios and it predicted decreases of 2,5% to 4,5% in the seaborne traffic to Sweden. The northern ports are of special interest in this study as in Sweden they are the ones that need icebreaking assistance. The study divided the ports in to sea traffic areas. For the Haparanda-Skellefteå area, the changes in seaborne traffic volumes were from one percent increase to one percent decrease. For the Umeå-Sundsvall area, the volume changes varied according to different scenarios from -8% to -19%. (Mellin et al. 2013)

The second analysis made by Trafikanalys was an update on the previous model by VTI. Trafikanalys wanted to perform a new investigation of the effects as it felt the first one done by VTI had issues with the scenarios for different ship types. This one estimated the increased transportation costs to be from 320 million euros to 570 million euros. The effect on the traffic volumes to Haparanda-Skellefteå area was estimated to be -1,4%. For the Umeå-Sundsvall area the figure is -1,3%. (Trafikanalys, 2013)

The studies show that there would be changes in the traffic volumes to the northern Swedish ports, but the figures are relatively small. In some scenarios, the traffic from Haparanda-Skellefteå-area was even estimated to increase, but there was no discussion on why this would happen. According to these studies it would seem that there would be no major effect on the winter navigation to Sweden. It is unfortunate that there were no figures available for Finland in regards of the traffic volumes. Still, it has been the general consensus amongst the ship owners that the new regulations will change the traffic patterns in the Baltic Sea. Thus it should be reasonable to take the scenario of diminished traffic flows in the northern Baltic Sea into consideration in this project. What would happen, if for example most of the traffic to Kemi/Tornio/Oulu/Luleå would transfer to road or rail? These effects could be assessed by analyzing the cargoes to these ports: would it be feasible to transport these via alternative routes. The cargo owners could be interviewed on their views on how they would see the situation to evolve in the case of increased freight costs. Would they transfer to alternative transport or in the worst case scenario, could it influence the existence of the business in that certain location?

2.3 Baltic Sea winter traffic

When looking at the import/export statistics for previous years, it can be said that the winter conditions of the Baltic Sea do not affect the cargo traffic on a large scale. Some comparative values from the cargo handled in Swedish ports can be seen in the Table 1 below, where it can be noted that the first quartiles for the mentioned years more or less have the same amount of cargo as does the quartiles for the rest of the year. However, it should be noted that Göteborg, which is not a port requiring icebreaker assistance, is the largest port in Sweden and for instance in year 2005 approximately a third of all Swedish goods passed through this port (Vierth et al., 2007).

Table 1 Handled cargo in Swedish ports, foreign and domestic traffic. Quantities given in 1,000 tons (Söderbaum, 2013)

	January-March	April-June	July-September	October- December
2010	43 763	46 354	44 062	45 400
2011	44 475	45 636	42 713	44 269
2012	43 166	44 554	43 096	42 331

To get a better view on how the ice conditions in the Baltic Sea affect the seaborne traffic we can look at statistical data from Finland, where all of the port areas are frozen during a typical winter. The information in the Table 2 is compiled from different statistics published by the Finnish Transport Agency. Unfortunately data was only available for the two years mentioned below. Based on these two years it can be said that the effect of winter conditions on the amount of handled cargo is barely noticeable. The amount of cargo handled yearly by the ports is more or less equally distributed along the year. This is nevertheless statistical data on a country level and some ports may be more affected than others by the ice cover.

Table 2 Handled cargo in Finnish ports, foreign traffic. Quantities given in 1,000 tons. (Liikennevirasto, 2013)

	January-March	April-June	July-September	October- December
2011	21 743	25 879	25 605	25 144
2012	22 509	23 357	23 144	24 248

2.4 Fleet

The Baltic Sea is a densely trafficked sea area. The total number of vessels sailing in the Baltic is 3,500 – 5000 each month, slightly depending on the season. In order to study shipping patterns in the Baltic Sea, in a study by Kalli et al, AIS data from March 1st 2006 to February 28th 2007 was analyzed. Below you can see Table 3, Table 4 and Table 5 that show the distribution of different ship types, size classes of ships and the age of ships respectively for March 2006. (Stipa et al. 2007)

Table 3 Number of ships and their proportion in total number of ships sailing in the Baltic Sea region in March 2006 (Stipa et al. 2007)

Ship type	Number of ship	Percentage, ships
Passenger	201	5,8 %
RoRo Cargo	121	3,5 %
Container cargo	103	3,0 %
Oil / Chemical tanker	539	15,5 %
General cargo	1152	33,1 %
Vehicle Carrier	68	2,0 %
Refrigerated Cargo	115	3,3 %
Bulk Cargo	247	7,1 %
Icebreaker	29	0,8 %
Barge	4	0,1 %
Other	89	2,6 %
Tug, Dredger, Pilot	81	23,3 %
Total	3480	100 %

Table 4 The age of the ships sailing in the Baltic Sea region in March 2006 (Stipa et al. 2007)

Build year	Number of vessels
2000 -	654
1990 - 1999	753
1980 - 1989	745
1970 - 1979	553
1960 – 1969	97
- 1959	33
Unknown	645
Total	3480

Table 5 The size classes of the ships sailing in the Baltic Sea region in March 2006 (Stipa et al. 2007)

Vessel size, GRT	Number of vessels	2 – stroke	4 – stroke
- 300	76	5	71
301 – 999	293	24	269
1 000 – 2 499	661	13	648
2 500 – 4 499	566	18	548
4 500 – 7 999	328	224	104
8 000 – 11 999	209	185	24
12 000 – 20 999	279	243	3
21 000 – 49 999	313	267	46
50 000 -	108	100	0
Unknown	647		
Total	3480		

As can be seen from the tables above, more than 40 % of the ships trading in the Baltic Sea can be classified as general cargo ships. Oil and chemical tanker, bulk carriers and passenger ferries are other major ship types operating in the Baltic Sea. The age structure is fairly evenly distributed from new builds to about 40 year old ships. This means that there is a continuous replacement of old vessels and it takes approximately ten years to replace 25 % of the fleet.

The vessels sailing in the Baltic Sea are mainly relatively old, small general cargo ships and tankers. This poses several issues for the winter navigation operations in the area. If the vessels are old, they are less likely to have all the machine power that has been stated when the ice class was given, and they could have troubles navigating in ice or keeping up with the icebreaker. Small vessels also will more often need icebreaker assistance than larger vessels. General cargo ships often run on smaller profit margins and might not be that well-adjusted to winter conditions as for example tankers or Ro-Ro-vessels. Thus, it could be beneficial to more study how the old, small general cargo ships burden the icebreaking services of the Baltic Sea.

2.4.1 Performance in ice

When an ice cover starts to develop on the Baltic Sea, different restrictions and requirements are put on the vessels that are allowed to navigate in the sea area. When analyzing the winter 2003, it can be noticed that the imposed traffic restrictions do not really change the fleet on the Baltic Sea during a normal winter. This means that the ships that normally tend to operate in the Baltic Sea have already adjusted themselves according the winter navigation requirements and are among other things ice strengthened. Of the Finnish maritime traffic more than half of the fleet measured by dwt are ships classified as IA Super or IA vessels. (Riska et al., 2003) From Table 6 can be seen the total number of vessels that have needed assistance during the winters between year 2007 to 2012. The statistics are compiled from information published by the Baltic Icebreaking Management.

Table 6 Number of assisted vessels in the Baltic Sea, given per winter season (Baltic Icebreaking Management, 2007/2008 – 2011/2012)

Winter	Bay of Bothnia	Sea of Bothnia	Gulf of Finland	Central Baltic	Gulf of Riga	Total
2007-2008	691	5	654		18	1368
2008-2009	1464	5	945		20	2434
2009-2010	2327	2173	2839		39	7708
2010-2011	4277	1255	4604	190	423	10749
2011-2012	1328	71	2510		71	3980
Total	10087	3509	11552	190	901	26239
Percentage	39 %	13 %	44 %	1 %	3 %	

A study made by the Finnish Maritime Administration has analyzed statistics from year 1999 to 2007 and estimates that during this period approximately 24 % of the ships have needed ice breaking assistance during the time that winter traffic restrictions have been employed. The biggest need of ice breaking assistance is in the Bothnian Bay, where the percentage of the ships that need assistance has been approximately 70 %. In the Bothnian Sea the percentage has been approximately 5 % and in the Gulf of Finland roughly 8 %. (Ikkanen & Mukula, 2008)

The fleet that operates in the Baltic Sea during the winter traffic restrictions consists mostly of vessels that belong to ice class IAS, IA and IB. Of the ships that actually have been assisted by an icebreaker during the winter traffic restrictions 77 % belong to ice class IA, 13 % to IB and 3 % to IC and II. (Ikkanen & Mukula, 2008)

Of all the different ship types that need icebreaker assistance, the conventional dry cargo ships are the most typical one and their share of the total assistance time is approximately 70 %. In the Bothnian Bay a noticeable share of the assistance time also goes to tankers and dry bulk ships. Of the assisted vessels the majority (83 %) have belonged to the size category of 4 000 dwt, 16 % to the size category 2 000-4 000 dwt and only 1 % are less than 2 000 dwt. Some 66 % of all the vessels that require icebreaker assistance during the winter season have an engine power of 4 000 kW or less. 30 % of the assisted vessels have an engine power between 4 000 – 10 000 kW and only 4% have an engine power larger than 10 000 kW. (Ikkanen & Mukula, 2008) It has been noted though that ships having the same ice class but for example smaller size, can have more difficulties in navigating in ice than larger ships within the same ice class.

It has furthermore, been criticized that ship operators seem to be using fleet that has an adequate ice class, but that still goes poorly in ice. The export industry has traditionally used better fleet than the import industry. The threat is that in the future when the traffic volumes increase, there would be even more poor ships in the traffic, with no resources for their assistance. (LVM, 2010)

IMO has developed the Energy Efficiency Design Index (EEDI) as a method to control CO2 emissions from ships. The regulations are mandatory from January 1, 2013 and apply to new ships above 400GT. Reference lines have been developed for different ship types and are based on reference values and the DWT of the ship. The attained EEDI is calculated for each ship and it should fall under the values of the reference lines. The factors that affect the attained EEDI values are mainly engine power and transport work (capacity). (Lloyd's Register, 2012) Thus the easiest way to attain the reference values is to cut down the engine power of the vessel. Also fuel selection and the use of energy saving technologies can help with reducing the attained EEDI. The calculation includes a reduction factor, if the ship has an ice class. Still, it can be argued that even with the corrections, the ice-going capabilities of the fleet can be compromised as the most important feature in winter navigation is the engine power of the ship. If the ships have to reduce their power, this would mean that the vessels would be less equipped for winter navigation.

Although most of the ships of the Baltic Sea fleet fulfill the winter navigation requirements, a good performance is not guaranteed. There are for instance cases where the Swedish-Finnish ice class rules cannot be applied to a specific vessel due to its main dimensions. If that is the case, the necessary engine power has to be defined by model tests. There has been discussions about especially the larger tankers and their engine power not being powerful enough compared to the ice class that they were given. A study on the AFRAMAX vessels suggests that especially the performance of vessels in the ice class category IA is lower than expected. Based on AIS data for winter 2006 it is hard to make assumptions other than the conclusion that if the ice conditions would be more severe than the ice conditions of winter 2006, it is clear that the ice performance of IA ice class tankers is not sufficient. Furthermore, it was noticed that there was little difference between the power of a class IA and IC vessel. This by itself already suggests that the engine power of a vessel of ice class IA is not at the level that it should be. (Niemelä, 2010)

During the time between December 2010 to April 2011, data was collected on ships that were reported to have less than good ice performance in the Gulf of Finland, the Bothnian Sea and the Bothnian Bay. The common reason for poor ice performance was shown to be weak engine power. In some cases this was a result of not using the maximum potential of the engine. Sometimes the problems were due to an inexperienced crew or because of language problems between the icebreakers and the vessel. In other cases there were even direct disobedience when the crew chose not to follow the orders from the icebreakers. (Leisti, 2011) A similar conclusion was made in a publication where the performance of ice navigating vessels in the Northern Baltic in winter 1992 was studied. The author concluded that based on the observations one of the more important factors that have a significant effect on the ship ice navigation capability is the competence of the personnel. Besides the crew, the influence and the skills of the pilot is important especially when navigating in the coastal ice channels. The use of engine power and the maneuvers at channel bends do make a significant difference. As the study points out, the ice channel resistance increases by 20 – 30 % if the centerline of a vessel lies two meters beside the centerline of the channel. (Pöntynen, 1992)

The fleet operating in the Baltic Sea is at least on paper well equipped for navigating in ice. Most of the ships in regular traffic here are already ice-classed. However, even though the vessel might be well-equipped for winter navigation, the human side of operations has to be taken into consideration also. A good crew can operate their vessel better in ice and in this way save icebreaker resources.

Excluding Russia, the biggest need of icebreaking in the Baltic Sea is in the Bothnian Bay. Thus it is clear that in this project special attention has to be paid for this area of operations. The numbers of assisted vessels are clearly affected by the severity of the winter. The total volume of assistance can range from a bit over 1000 ships to slightly over 10000 ships. This means that the service levels have to be considered well when planning for the future strategies. The most important cost factor is to decide how well assistance is wanted to be given during harder winters.

3 Baltic Sea ice season

The ice season in the Baltic Sea usually begins in November with ice first forming in the shallow water areas of the Bothnian Bay. On average, the maximum ice extent on the Baltic Sea occurs in March. By that time the ice normally covers about 40 % of the total sea area. Typically the ice edge will be located in the northern Baltic Proper and the Bothnian Bay, the Gulf of Finland and the Gulf of Riga are covered with ice. During extremely severe winters, almost the entire Baltic Sea has been covered with ice. Nevertheless, in very mild winter ice might only be formed in the Bothnian Bay and the eastern Gulf of Finland. The ice extent naturally depends on the climate of the winter in question and as can be seen it varies quite much. On an average it can be said that the length of the ice season is 130 to 200 days in the Bothnian Bay, 80 to 100 days in the Gulf of Finland and 0 to 60 days in the southern Baltic Sea. (HELCOM, 2013)

The severity of the winter season in the Baltic Sea has up to year 2011 been classified into 5 different groups depending on the observed ice extent. The classification can be seen in Table 7 below. This classification was based on observed data from the years 1720 – 1996 (Luomaranta et al., 2010).

Table 7 Severity classification based on ice extent (Luomaranta et al., 2010)

Severity of winter season	Ice extent (km^2)
Extremely mild	52 000 – 81 000
Mild	81 001 – 139 000
Average	139 001 – 279 000
Severe	279 001 – 383 000
Extremely severe	383 001 – 420 000

There has however, been a significant decreasing trend in the ice extent of the Baltic Sea. Altogether the ice extent has decreased some 20 % over the past 100 years up to 2011. The length of the ice seasons has also changed during the past century. In the Bothnian Bay the trend is -18 days/century. In the eastern Gulf of Finland respectively 41 days/century and during the last 50 years the rate has decreased up to -62 days/century. It is mentioned that these changed in the Baltic Sea ice conditions are consistent with observed increase in temperature, but could also to some extent be caused by shipping. Ship-induced waves are known to prevent the formation of permanent ice cover in the autumn as well as enhance the break-up of the ice cover during spring. (Helcom, 2013)

Since both the ice extent and the length of the ice season have experienced some changes, the old winter season severity classification did not properly reflect the ice conditions and how they were perceived. Some winters were classified as average based on the ice extent, but they were nevertheless perceived as challenging from the point of view of the marine traffic. Therefore the Baltic Sea countries agreed upon changing the severity classification year 2011. The new classification is based on the ice seasons 1961 – 2010. These ice seasons were arranged accordingly to the maximum ice extent and the 13 smallest ice extents were classified as mild and the 13 largest as severe. The extent that was left in the middle between these two extremes was classified as an average ice season. The obtained severity limits were 115 000 km^2 and 230 000 km^2. If the ice extent exceeds 345 000 km^2, it can be classified as an extremely severe winter. (Vainio, 2011)

Between the years 1993 to 2007, 7 winters have been classified as average winters and 7 as mild winters based on the ice extent (Ikkanen & Mukula, 2008). In the Table 8 below you can find statistical data on the severity of the winter season and the largest number of icebreakers that have been simultaneously in use. The information has been compiled from yearly statistics published by the Baltic Icebreaking Management and the Finnish Meteorological Institute. As can be seen from the table, the number of icebreakers engaged in icebreaking activities simultaneously has varied from 6 to 24 icebreakers. This would mean a calculated average of 17 icebreakers.

Table 8 Severity of different winters and the responding number of icebreakers needed. (Baltic Icebreaking Management, FMI)

Winter season	Severity	Max nr of icebreakers engaged
2005 - 2006	Average	21
2006 - 2007	Mild	19
2007 - 2008	Extremely mild	6
2008 - 2009	Mild	10
2009 - 2010	Average	21
2010 - 2011	Severe	24
2011 - 2012	Average*	18

* Severity classification changed year 2011

The maximum ice extent for two ice seasons can be seen in Figure 2 below. The ice extent on the left side is for winter season 2002/2003, which was classified as an average winter based on the extent of the ice cover. However, the season in question was exceptional since the winter arrived earlier, lasted longer and brought along a thicker ice cover in the Gulf of Finland than average. The ice extent shown on the right side is for winter season 2007/2008 and was a short and very mild winter. (FMI)

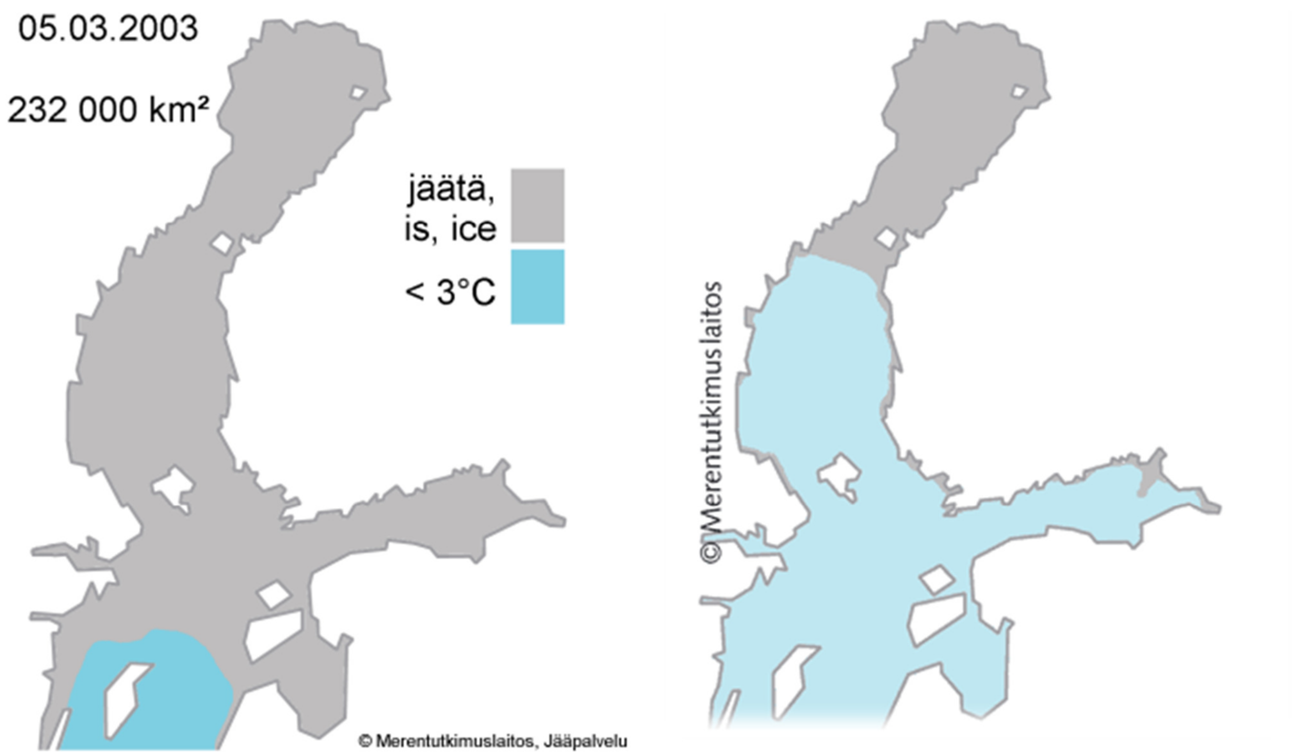


Figure 2 The maximum ice extension for winter seasons 2002/2003 and 2007/2008 (FMI)

3.1 Future ice scenarios

There are two main factors affecting the ice conditions in the Baltic Sea, namely the frost sum and the prevailing westerly winds (Tuominen et al., 2010). As has been discussed above, the Baltic Sea winter seasons and ice conditions are constantly changing. The future reductions of the sea-ice cover depend mainly on the projected changes in the winter air temperature. Other factors such as the wind conditions are less important. (Helcom, 2013) It should however, be noted that wind and currents also do affect the need for icebreaking assistance as for instance strong winds may facilitate the formation of ice ridges (Luomaranta et al., 2010). The future projections made by Helcom (2013) depend on a variety of different variables such as the greenhouse gas emission scenario, the general circulation models and the Baltic Sea model used; all new simulated scenarios indicate that there will be a drastic decrease in the sea-ice cover in the Baltic Sea in the future.

The Finnish Meteorological Institute has estimated the future extent of the ice coverage of the Baltic Sea up to year 2050. The results are based on observations as well as the use of 19 different global climate models. A regression model was fitted between the observed maximum ice cover extent and coastal winter temperatures. Using this result, the distribution for maximum sea-ice extent for four future decades was estimated. According to the results, both the maximum ice cover extent and the probability of severe winter will decrease. During the period 2011-2020 the probability that a severe winter will occur is less than 10 %. The following period 2021-2030 the probability has decreased to 5 % and in the period 2041-2050 there is not expected to be any severe winters at all. Consequently the mild and extremely mild winters are increasing. It should be noted that the study made by the Finnish Meteorological Institute use the old categorization of the severity of a winter season and therefore the estimations should be slightly adjusted in order to fit the new categories. (Luomaranta et al., 2010)

The average maximum fast ice thickness for each decade was calculated using Stefan's law and the winter-frost sum. This was assessed only in coastal sea areas. The fast ice thickness is expected to decrease every decade. During the period 2011-2020 the maximum ice thickness in the Bothnian Bay is estimated to be 90 cm, in the eastern parts of the Baltic Sea 0-20 cm and in the Gulf of Finland between 20 to60 cm. The following decade (2021-2030) the maximum ice thickness in the Bothnian Bay will still be slightly over 80 cm, while the eastern part of the coastal regions of the Baltic Sea will be partly ice free. During the last two decades analyzed (2031-2040 and 2041-2050) there will no longer be ice thicker than 80 cm in the Bothnian Bay and in the coastal regions of the Gulf of Finland the maximum ice thickness will be approximately 10-40 cm. The eastern parts of the Baltic Sea will be ice free during an average winter. The method used in this analyze does not however, take into account the snow layer on top of the ice cover. Snow acts as an insulator and slows down the growth of ice thickness. Therefore the calculated ice thickness is about 10-20 cm too large. (Luomaranta et al., 2010)

The report made by the Finish Meteorological Institution also states that there will be some changes in the wind during the next decades and the largest changes will occur during the winter months. In the southern parts of the Baltic Sea and in the Gulf of Finland the monthly average wind could increase as much as 2-6 %. How the changing wind will affect the ice conditions is a topic that has not yet been researched. The report mentioned that it will most likely affect the movement of ice fields and increase ridging during the late winter months. Nevertheless, the estimated change is quite small and will most likely not have a big impact on the amount of ridges. Neither will the ice pressure on ships increase due to the wind during mild winters. (Luomaranta et al., 2010)

3.2 Effect of ice on winter navigation

The severity of a winter is, as mentioned, usually measured by the maximum ice extent. This type of simplicity in the classification of winters creates a conflict between the authorities' definition and how the winter is perceived by those whom actually operate in the ice conditions in question. A winter and its ice conditions might look quite different when looking at it from the point of view of navigation in ice or merely seaborne traffic in general. It is said that those winters that are classified as average, in reality tend to be the worst ones. This is explained by the typical sequence of events occurring during an average winter. Between the frosty periods there are most likely some periods of mild ice conditions with strong winds. These conditions in turn produce movement in the ice which leads to pack ice and compression conditions on the navigating vessels. The following frosty periods increase the amount of ice, which then again during the next mild period will reach the edges of a drift ice field or the fast ice field at the shorelines and together they produce a slush belt (Tuominen et al., 2010)

The most difficult conditions in ice navigation are often considered to be a heavy wind, a continuous frost or snowfall. Here the continuous frost affects the actual categorization of the severity of the ice season, while the wind moves the ice and may even result in a vessel getting stuck in an ice field and/or drifting aground. A heavy snowfall in turn decreases the visibility and may even affect the radars. The authorities point out that the positive thing about a severe winter is actually the fact that it makes it easy to anticipate and plan the operations. If the weather constantly changes and it is windy, there might be some sudden changes in both the operations of merchant vessels and the icebreakers. A mild winter also has the side effect that it facilitates the disappearance of the winter navigation know-how. (Tuominen et al., 2010)

The ice cover in the Baltic Sea also reaches port areas and affects harbor operations. During a severe winter the share amount of ice in a port might make it difficult for vessels to reach the docks. The harbor basin of a part is an area where the ice accumulation generally is severe because tugboats and icebreakers operate frequently in this limited area. Every time a vessel passes through a channel the amount of ice in the channel increases due to the ice accumulation process. Experiences from the harbors in the Gulf of Finland imply that the total time of arrival and departure from a port, including maneuvers to take and leave the pilot increases by roughly two hours on an average during the winter. (Kvaerner Masa-Yards Inc) Some ports have been able to resolve this problem by having industry close by that can lead their condensation water to the harbor basin (Tuominen et al., 2010).

Generally the risks of winter navigation can be defined as the risk of delays and/or cancellations and the risk of obtaining structural damages. The delays can either be a direct result of the ice conditions that make the vessels operate at a lower speed or they can be indirect if the ship for instance has to wait for an icebreaker or a pilot (Tuominen et al., 2010). The indirect waiting times also include the time that a ship spends waiting in order to later be able to navigate directly to a vacant terminal quay. When studying the AFRAMAX oil tankers sailing to Primorsk, it has been found that more than half of the total time spend on a roundtrip transit is spent inbound. Almost 2/3 of this inbound time is spent waiting which means that the waiting time inbound contributes for 1/3 of the roundtrip transit time. (Berg, 2010) The delays also affect the efficiency of the ports since the port operators can't predict when the ships arrive. This then crowds the port area. The port are can also be crowded when a convoy reaches the port, when many vessels need the loading docks.

Marine traffic accidents are statistically infrequently spread out during the year. However, it is more common for collisions to take place during winter while drifting aground is more common for the open water season. The collisions that occur in the winter months usually take place in a convoy of an icebreaker or when two ships pass each other in an ice channel. Fortunately the damages are usually not severe since the speed is low. Many of these small damages are not even reported although the lead to increased costs for different operators. Some typical damages on the vessels include rudder damages, shaft seal damages and dents on the outer plating. Another extra cost caused by a long ice season is the increased fuel cost which might even be doubled for both commercial vessels and icebreakers (Tuominen et al., 2010)

3.3 Discussion

When estimating the future need of icebreaking capacity in the Baltic Sea, climate changes such as the global warming and how it will affect the northern conditions are quite essential. There have also been some signs that extreme weather conditions would be occurring more often in the future and how this will show in the Baltic Sea is unknown. As mentioned, there exist several different climate models and a number of them have been used in the studies referred to above. Although some estimates on the future ice cover extent and severity of ice conditions are presented, it should be remembered that these are just estimates based on uncertain climate predictions. Therefore the reliability is quite low; especially the further away in time the predictions are made for.

The question is how these predictions should be used in order to prepare a functional common Baltic Sea Winter Strategy. Would it be better to count on the ice conditions getting milder and the winters shorter and optimize the icebreaking costs by minimizing the number of icebreakers? Or should the number of icebreakers be decided accordingly to the strategy of always preparing for the worst and the possibility of severe winter conditions taking place against the odds?

Deciding on the optimal number of icebreakers is nevertheless not only a problem of the future. At the moment several of the icebreakers operating in the Baltic Sea are quite old and it will soon be necessary to decide on when and how they will be upgraded. As showed by the statistics above, the number of icebreakers that have been simultaneously in operation during the previous years has varied from 6 to 24, with a calculated average of 17 icebreakers. If the average number of icebreakers needed would be the deciding factor, the Baltic Sea countries would have a total of 17 icebreakers. This would mean that during a mild winter there would be 11 idle icebreakers, generating costs for the countries just by being in a state of readiness. On the other hand if the winter would be severe, it would mean that there would not be a sufficient number of icebreakers to guarantee the wanted service levels. There is always the possibility of renting or contracting the needed extra icebreakers, but if done in the last minute during a severe winter it might be difficult to find and an expensive solution. When deciding the optimal icebreaking strategy it would be important to define whether it is more important to secure a sufficient icebreaking service level independent of the ice conditions or to be cost efficient.

4 Icebreaker assistance

The winter navigation system has three main pillars that are the icebreakers, the merchant fleet and the winter navigation regulations. The nations around the Baltic Sea regulate the winter navigation by offering assistance and imposing regulations. The fleet was discussed earlier, but this chapter will concentrate more on the icebreakers and the winter navigation regulations.

In Finland the Finnish Transport Agency is responsible for the winter navigation assistance, but outsources the actual icebreaking services from Arctia Shipping. In Sweden, the Swedish Maritime Agency is responsible also for the operation of the icebreakers. In Estonia, the Estonian Maritime Administration handles the winter navigation assistance. Finland and Sweden operate especially in the Bay of Bothnia in integrated icebreaker assistance.

4.1 Icebreaker fleet

Finnish icebreaking operations are currently handled with 5 traditional icebreakers (Voima, Urho, Sisu, Otso and Kontio), 2 multipurpose icebreakers (Fennica and Nordica) and one icebreaking tug (Zeus). The icebreakers and multipurpose icebreakers are owned and operated by Arctia Shipping; the icebreaking tug is owned and operated by Alfons Håkans Oy. Table 9 presents the Finnish icebreaker fleet. (Baltic Icebreaking Management, 2011)

Table 9 The Finnish icebreaker fleet (Baltic Icebreaking Management, 2011)

Ship	Year	Lwl	Bwl	P [MW]
Voima	1954	83,5	18,7	10,2
Urho	1975	96	22,5	16,2
Sisu	1976	96	22,5	16,2
Otso	1986	90	23,4	15
Kontio	1987	90	23,4	15
Fennica	1993	96,7	25,2	15
Nordica	1994	96,7	25,2	15
Zeus	1995	42	14	5,4

Sweden operates 5 icebreakers (Ale, Atle, Frej, Ymer and Oden) and charters two icebreakers/AHTS vessels (Tor Viking II and Balder Viking) from Viking Supply Ships. The charter agreement for Tor Viking II ends in 2014 and the charter for Balder Viking in 2015. Table 10 presents the Swedish icebreakers.

Table 10 The Swedish icebreaker fleet (Baltic Icebreaking Management, 2011)

Ship	Year	Lwl	Bwl	P [MW]
Ale	1973	47	13	3,5
Atle	1974	96	22,5	16,2
Frej	1975	96	22,5	16,2
Ymer	1977	96	22,5	16,2
Oden	1989	100,2	31,2	17,7
Tor Viking II	2000	75,2	18	13,4
Balder Viking	2000	75,2	18	13,4

Estonia has currently three icebreakers (Tarmo, EVA-316 and MSV Botnica). The main parameters of the Estonian icebreakers are presented in Table 11 .

Table 11 The Estonian icebreaker fleet (Baltic Icebreaking Management, 2011)

Ship	Year	Lpp	Bwl	P [MW]
Tarmo	1963	82	21,2	8,8
EVA-316	1980	48,6	12,2	4,4
Botnica	1998	77,9	23,1	10

The icebreaker fleet in the Baltic Sea is slowly aging and one of the reasons for this project is also to assess the need for new icebreakers. One new icebreaker has been commissioned by the Finnish government that is supposed to be in operation for the winter 2016. This new icebreaker will be owned by the Finnish Transport Agency. The new icebreaker is of the traditional type but discussions are intense on the views of whether the new investments should be of the traditional or multipurpose type. It has been questioned whether the multipurpose icebreakers are adequate for the Baltic Sea icebreaking purposes. These vessels are only deployed for icebreaking purposes on hard winters but have also faced some performance issues in difficult ice conditions. One of the aims of WINMOS project is to assess the amount and type of icebreaker fleet the Baltic Sea countries need in the future.

4.2 Icebreaker assistance

Finland, Sweden and Estonia operate in icebreaker assistance in fairly similar methods. Icebreaker assistance is offered to those ships that fulfil the ice-class and traffic regulations. Icebreaker assistance can be denied by the icebreaker captain (in Finland) or the head of icebreaking division (in Sweden), if it can be assumed that the vessel does not fulfil these regulations or that ice navigation can pose a threat to the vessel. The assisted vessels are not prioritized in Finland or in Sweden, except when it can be assumed that they are in danger. (Liikennevirasto, 2013). In Estonia, liners are prioritized and also other ships according to their confirmed schedule. (Estonian Ministry of Economic Affairs and Communications, 2003)

During mild winters, Finland usually has 5 to 7 icebreakers in operation, in an average winter 8-9 icebreakers and during a severe winter, all of the icebreakers are in operation. In the winters 1993-2007, the average sum of Finnish icebreaker operation days was 710 days per winter. Of these days 72% were in the Bay of Bothnia, 24% in the Gulf of Finland and 4% in the Sea of Bothnia. It is important to notice that in the Bay of Bothnia, the sum of operation days is not much affected by the hardness of the winter. The hardness or the mildness of the ice winter is more reflected in the assistance amounts in the Gulf of Finland. (Ikkanen & Mukula, 2008)

Finland and Sweden operate the IBNet system that is used in the daily communication between the authorities and the icebreakers and between the icebreakers. The IBNET system offers also ice-, weather- and satellite imagery data that helps the icebreaker crews in daily operations planning. The icebreakers also report on IBNet their operations and assistance.

Icebreakers assist ships when the ship is either stuck in ice or in the need of assistance due to drop in her speed. Usually the ships are assisted to and from the fairway entrance. The ship should be able to sail to the port on her own, but at times smaller ships have to be escorted into the port. (Trafi, 2011) The port icebreaking is handled by icebreaking tugs and is offered by the port operators independently. For instance in the Swedish Gävle area in the ports of Skutskär and Norrsundet, the icebreaking is until the year 2015/2016 operated by AB Isbjörn Oy and in the port of Skellefteå the icebreaking is operated by the port itself (Sjöström,2013; Skellefteå Hamn, 2013). In Finland the icebreaking tugs are operated by for instance Alfons Håkans and its subsidiary Finntugs Ltd and Arctia Karhu Oy (Alfons Håkans, 2013). Arctia Karhu Oy is currently buying a new generation port icebreaker, which is expected to be delivered in autumn 2014 and is already contracted by the ports of Kemi, Tornio and Oulu (Arctia, 2012). It should also be mentioned that the icebreaking tugs sometimes are also responsible for breaking the ice in fairways that are too narrow or shallow for the state icebreakers to enter, which is the case in the Veitsiluoto fairway where the icebreaking is taken care by M/S Jääsalo. (Keminsatama, 2013)

Ships can be assisted individually or they can be collected into convoys of several ships that are then assisted at the same time. The convoy method is applicable when the traffic volumes are high, but the convoys for example in the Bay of Bothnia often form of maximum three vessels. The convoy method can be especially slow for better ice-going vessels if there are ships with poorer ice capabilities in the convoy.

The main methods with which icebreakers assist ships are escorting and towage. Towage is used in difficult ice conditions when the assisted vessel is suited for towage. According to statistics from IBNET collected by the SAFEICE project, during the icebreaking season 2002-2003, the Swedish and Finnish icebreakers assisted 2040 times by escorting and 145 times by towing. In 2003-2004, the corresponding numbers were 642 times and 21 times. In 2004-2005, Swedish and Finnish icebreakers assisted 568 times by escorting and 13 times by towing. (Safeice, 2006) The average assistance speed of icebreakers is approximately 9-10 knots, whilst the normal open water speed for the vessels is 12-15 knots. A study by Ramboll states that they did not find remarkable changes in assistance speed when comparing different winters. (Ikkanen, 2008)

Nordic countries have smooth cooperation in the icebreaking services. By natural reasons, this cooperation takes usually place in the northern Baltic Sea, between Sweden and Finland. The ships are assisted in the fairways going north independent of the destination port. The division of labour can be done for example by dividing the legs of the fairway between different icebreakers. The Swedish icebreakers can assist the vessels from the Quarken to Raahe latitudes, from where Finnish icebreakers escort them to the Finnish ports. In the Gulf of Finland there is no smooth cooperation between Finland and Russia. It has been calculated for example in the Catrin-project that cooperation is always the cheaper option in icebreaking services than strict national operations. Negotiations are ongoing regarding the cooperation with Russia. The agreement will mostly likely be contracted soon, but the actual legislation will take some time to come into force. The agreement would allow Finnish icebreakers to assist in the Russian waters. (YLE, 2013)

The Finnish and Swedish authorities have set service levels for the icebreaker assistance. The average waiting time for assistance should not exceed 4 hours and the percentage of vessels that would not have to wait should be between 90% and 95%. The average percentage of ships that have had to wait for Finnish icebreaker assistance has varied from 26 to 54%. There have been major differences in these percentages according to the different parts of the sea. Although in 2003, which was a difficult ice winter, the percentage was roughly the same 55% in all of the sea areas. (Ikkanen & Mukula, 2008)

4.3 Icebreaking costs

The costs for icebreaking are, as you would expect, dependent of the severity of the winter and its ice conditions. During a severe winter costs such as fuel costs can even be tripled compared to that of a mild winter. Then again during a mild winter over half of the icebreaking costs are fixed costs that are not dependant on the number of operating days of the icebreakers. These costs will occur even though the icebreaker is not operating, since it is necessary for the vessel to be in readiness in case the ice conditions change. (Ikkanen & Mukula, 2008)

The actual icebreaking costs are rarely discussed in public and especially the breakdown of the total cost into smaller cost units is often unknown. According to the Baltic Sea Icebreaking report the cost of the Finnish icebreaking services vary from 22 to 50 million euros, depending on the severity of the winter. The total costs for the Swedish icebreaking services, including external costs, vary from 11 to 40 million euros while the Estonian costs tend to be significantly lower. In the Table 12 below some more precise yearly estimates are given. It would, however, be important for each of the Baltic Sea countries to carefully estimate the optimal solutions, from a cost perspective, for producing the icebreaking services. Interesting questions include whether it is more cost efficient to privatize and outsource the icebreaking operations or to produce them yourself and how could the different countries benefit from cooperating with each other either by sharing the icebreakers or simply handling the procurement processes together.

Table 12 Yearly costs for icebreaking per country (Baltic Icebreaking Management)

Winter season	Finland (M€)	Sweden (M€)	Estonia (M€)	Severity of winter
2007-2008	20,9	11,5	1,5	Extremely mild
2008-2009	26	20,2	0,75	Mild
2009-2010	39	24	1,66	Average (but long)
2010-2011	45	30,5	5,9	Severe
2011-2012	34	20,7	*	Average

* No reliable information available

The costs that arise from the icebreaking operations are usually covered by some type of fees collected from the vessels. The Baltic Sea countries Finland, Sweden and Estonia more or less follow the same general model of fairway dues. In Finland the fairway dues are applied on most vessels entering and engaging in maritime trade, with a few exceptions such as passenger vessels with a net tonnage lower than 300. The amount of the fairway dues depend on the net tonnage of the vessel and the ice class in way that encourages the vessels to have a higher ice class. Recurrent traffic is also encouraged and for vessels that enter the Finnish ports frequently a reduction system of the fairway dues is applied. Some vessels such as cruise lines and high speed vessels have a fairway due that is independent of their ice class. In Sweden the fairway dues are divided into three categories, which all have different unit costs. The first category is defined by the gross tonnage of the vessel, while the second part is defined by the amount of cargo that will be unloaded /offloaded in the port. The third category covers the environmental costs and is related to the nitrogen oxide and sulphur emissions of the vessel. Estonia in turn has defined its fairway dues as lighthouse and navigation fees. The lighthouse fees are paid for a safety reason and covers the costs for maintaining the fairway signs while the navigation fees cover costs for the fairway maintenance, icebreaking services and other marine traffic information services. The Estonian fee system gives certain discounts, for instance for vessels of ice class IA and IA Super, who get a 50 % discount. Otherwise the fee is based on the gross tonnage of the vessel. The bases of the fairway dues for the Baltic Sea countries is a recurring issue and for instance in Finland the authorities are preparing a new fairway due system. (Tervonen, 2013)

4.4 Winter navigation regulations

The winter navigation regulations in the Baltic Sea are the ice-class rules and the national traffic restrictions. Finland and Sweden have developed their own Finnish-Swedish ice class rules and Russia has their own ice-class system. The national traffic restrictions are imposed by the national maritime authorities for safety and efficiency reasons when the ice conditions become such that regulation on the traffic is needed.

The traffic restrictions are based on the Helcom recommendations. The recommendations state that when the ice thickness is between 15 and 30 cm, the minimum ice class required should be IC. For 30-50 cm, it is IB and for over 50 cm of ice, the restriction should be ice class IA or above. It has been discussed whether the level ice thickness is an adequate form of setting the restrictions, or should the basis be some sort of an equivalent ice thickness measure. This was studied in the SAFEICE project and it was noted that for example ridging is difficult to model, the maximum level ice thickness would serve as well in the setting of the restrictions. (Liljeström & Riska, 2006)

The restrictions enter into force five days after their date of issue, except for relaxations which enter into force immediately. The ice-class and tonnage-size requirements can vary with the severity of the winter conditions. The ice class requirements usually guarantee that the ship's structural design is ice proof and that the machine power of the ship is adequate for icebreaker assistance. The size requirements guarantee not only safety, but also that there are enough icebreakers for all ships as the ones with larger cargo volumes are only operating.

The average times of the restriction are as follows:

Bay of Bothnia: The first restrictions – ice class I and II, deadweight 2,000 dwt – for the ports in the northern Bay of Bothnia are normally imposed in December. The maximum restriction IA 4,000 dwt has been applied in combination with the cargo restriction of 2,000 tonnes.

Sea of Bothnia: The first restrictions – ice class I and II and deadweight 2,000 dwt – are normally imposed in January-February. During an average winter the maximum restriction is IA, IB 2,000 dwt.

In the Archipelago Sea: The first restrictions I, II 2,000 dwt have been imposed somewhat later than in the Sea of Bothnia although the restrictions are about the same. The strictest restriction during a normal winter is IA, IB 2,000 dwt.

Gulf of Finland: The first restrictions – I, II 2,000 dwt . Have normally been imposed at the end of January. The maximum restriction during an average winter is IA 2,999 dwt.

The maritime authorities can also issue additional traffic restrictions if conditions require. For example in the cases of forecasted severe compression, the traffic in certain areas can be completely stopped or rerouted to coastal routes. This happened for example in winter 2011, when the traffic and icebreaker assistance in the Quarken area was stopped due to hard winds and compression. Also, at times in the northern Bay of Bothnia, the traffic can be rerouted to the coastal fairways between Oulu and Kemi.

4.4.1 Ice class rules

The Finnish-Swedish ice class rules (FSICR) were given in order to guarantee structural and operational capabilities of ships for winter navigation. The rules include regulations for the minimum engine power required to navigate in ice as well as the different requirements for the hull structural integrity. The latest amendments to the ice class rules were given in 2010. The FSICR are intended for ships that operate in first year ice conditions for part of the year. A certain minimum engine power has been set for the ships with an ice class: the ships must be able to sail at least 5 knot speed in a brash ice channel of the thickness defined for each ice class. This requirement is set so that ships should be able to follow icebreakers at a reasonable speed and also proceed independently in old ice channels. The hull structural strength has no general requirements, but it should endure ice loads with a minimum safety margin. The minimum safety margin is due to economic reasons, as excessive ice strengthening is costly. (Trafi, 2011) In the SAFEICE project, the ice class rules were discussed. It was suggested that maneuvering requirements would be included in the rules. These could include for example turning circle diameter and breaking out from an old channel. (Liljeström & Riska, 2006)

There has been also discussion about a new ice class of IA Super +. The idea of this ice class would be that these ships would be able to navigate independently in ice, rarely or never needing icebreaker escort in the Baltic Sea. This ship would bring cost savings to the winter navigation system as it would need no icebreaker resources. Building and operating a ship that can navigate independently in ice is costly, but incentives for this operation could be offered by the state. These ships could have lower fairway dues and funding from the winter navigation budget could be offered to compensate the icebreaker service that is not needed. The cost of the operation of an icebreaker for two months in the same route is roughly equivalent to the extra investment costs needed for the IA Super + class ship. (This takes only into consideration the extra capital costs and not the extra operational costs.) Still, there are often several ships on fairways and having one ship with independent ice going capabilities does not take away the need of icebreaker assistance on that particular route. (Riska, 2008)

There are still more questions regarding the IA Super + class than straight answers. Not including icebreakers, the cargo ships with the best ice-going capabilities, such as big Ro-Ro vessels and double-acting ships still have difficulties in severe ice conditions. What would happen if these vessels actually got stuck, who would pay for the icebreaker assistance? The operation of these ships is still fairly expensive for the ship owners and giving incentives is also not cost efficient for the state either.

The problems of winter navigation in Finland have traditionally been caused by ships with poor ice going capabilities, small cargo amounts and the large number of ports. In this project and the following simulation, these issues and their effect on the overall model can be assessed. Do the poor ships actually have a large effect on the overall operation of the icebreaker assistance? Would it be useful to implement stricter rules for the ships that visit the Baltic ports or is it better to give assistance to those that fulfil the current requirements? It could also be simulated that what happens if in the future the icebreaker services are inadequate compared to the need. Could there be prioritization amongst ships or ports, or would all traffic be deemed equally important?

5 Simulations

In this chapter seven different simulation tools or methods to simulate maritime traffic in ice are presented. Some of these are the end result of extensive projects, such as the IceWin or CATRIN project where as others are smaller independent studies. Each of these will then be briefly discussed and their benefits, restrictions and simplifications will be compared.

5.1 The IceWin simulation tool

In the IceWin project a simulation tool was completed to model the winter time ship traffic in the Gulf of Finland and the associated icebreaking service. The model can be used to investigate the effects of different factors (route and port network, increasing traffic, technical characteristics of ships, number of icebreakers, ice and wind conditions and agreement concepts of icebreaking) on the level of service of icebreaking, as well as on the use of resources and emission levels.

5.1.1 Route network and ship performance

In the fifth work package of the project, the performance of merchant vessels and a route network were modelled based on ship speed and positions AIS data of winter 2010. The IceWin simulation tool is based on a simplified route network which is designed based on previous work, namely the ICOMOB-project, and on actual routes used by ships. The AIS data of actual ship routes was collected from the Finnish Traffic Administration server. The data was pre-analysed and by combining it with the data obtained from ice charts, the route networks correlation with ice was obtained.

Before analysing the data any further, a calculation in SQL query language was performed, where each interpolated point was completed with information about closest fix point, ship and icebreaker. The database consists of 5 tables, which for instance contain the interpolated points at 10 minute intervals. Also, it includes ship data gathered from the IBNet including up-to-date information on all ships that have visited Finnish or Swedish ports in wintertime up to end of May 2010.

In order to determine the performance of different ships, their states with respect to other ships and icebreakers have to be determined. Therefore the following ship states were identified:

> **In port**: The ship is in a port or in the vicinity of a port. The ship behaviour and speed are more dependent on other factors than ice conditions. The extent of this area is based on detailed regional statistics, e.g. pilot boarding positions were included.
>
> **Assisted**: The ship is under icebreaker assistance. Icebreakers always report to the IBNet when they are assisting. Therefore the rules based on distances as well as relative speed and angle can be determined by comparing IBNet data with the AIS data. Here a ship is being assisted if

the distance to closest icebreaker is less than 4km and the icebreaker is seen at an angle of +/- 20 degrees.

Towed: The ship is being towed by an icebreaker. Towing state can be determined based on distance and same speed. This means that a ship is being towed if the distance to the icebreaker is less than 0.21 km and the angle in which the icebreaker is seen is +/- 20 degrees and speed difference is +/- 0.8 knots.

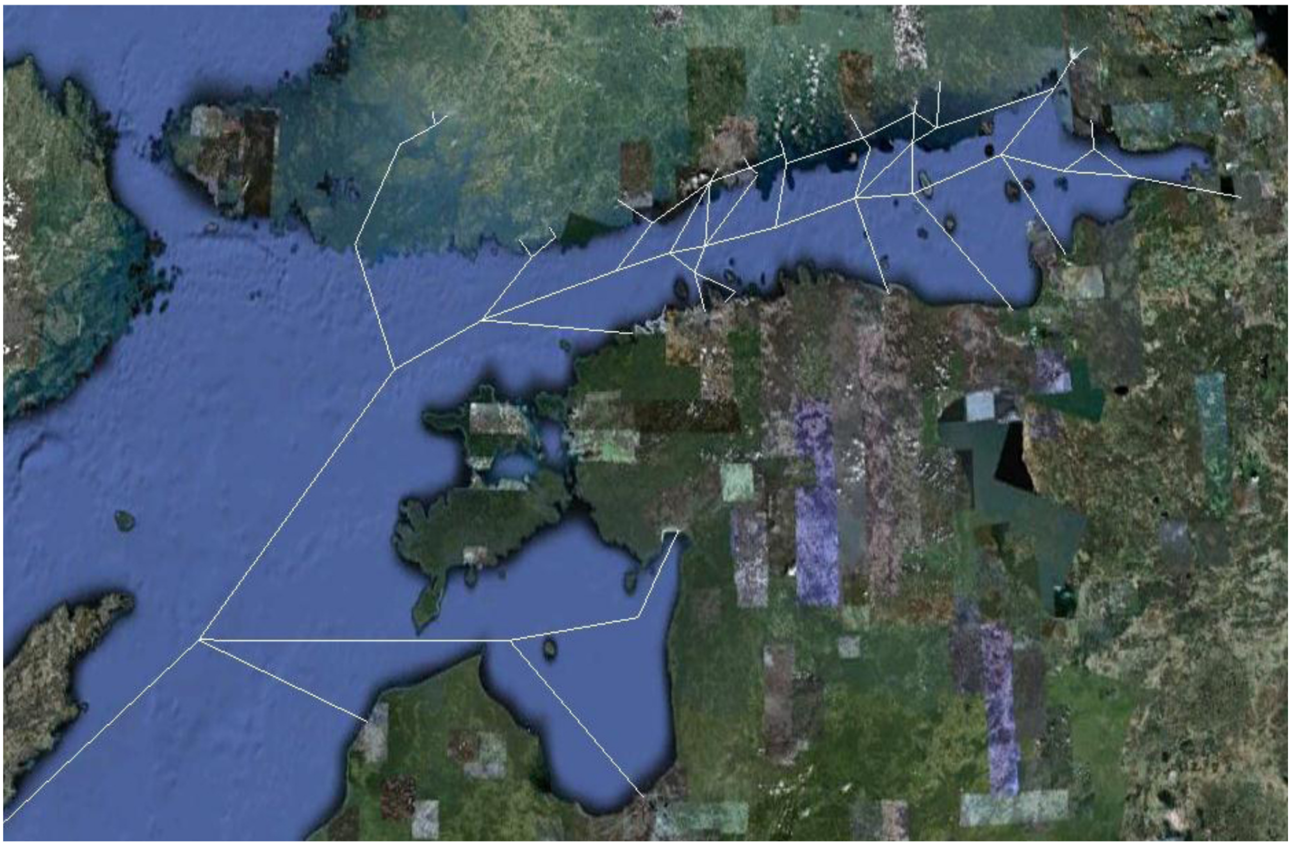
After ship near (SH2): The ship moves behind another ship, which is not an icebreaker, seen in an angle of +/- 20 degrees at a distance less than 2km. This rule is based on statistical data for ships moving in channel.

After ship far (SH4): The ship moves behind another ship, which is not an icebreaker, seen in an angle of +/- 20 degrees at a distance less than 4km but more than 2 km. This rule is based on statistical data for ships moving in channel.

Freely moving: The ship is considered to be moving freely if it has a speed of 1 knot or more and is not in any of the states listed above.

Waiting: The ship has a speed less than 1 knot and is freely moving or after another ship, not in port. The problem is to infer the reason for waiting since it is important to know if the ship is waiting for icebreaker escort or waiting for other things, such as berth which is not of interest here.

The data was aggregated in 10 day periods, starting from 30.12.2009 to the 18.4.2010. The observations were mapped to the route network legs using the rule of closest route point. Usually a leg is assigned one leg point, which is the midpoint of the route. The legs are also grouped into nine subareas. In the picture below you can see the route network of the model.



The simulation model is also provided with the following functions implemented as look-up tables.

1) Ship speed as a function of ice conditions. The ship speed is expressed relative to the open water speed.

$$v = v_r(G(s_i), h_{ice}) * v_{ow}(s_i)$$

where

v_r = relative ship speed (speed relative to open water speed)

G = parameter vector of the ship group of the individual ship. This parameter vector consists of ship type (passenger ship, cargo ship or tanker), machine power class (<5000kW, 5000-10000 kW, 10000-20000 kW, 20000-40000 kW and >40000 kW) and ice class (II, IC, IB, IA, IAS)

s_i = individual ship

h_{ice} = ice thickness class (0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and over 50 cm)

v_{ow} = open water speed of the ship; from the AIS data as the average ship speed when the ship is not in ice and moving faster than 5 kn.

2) Estimate of probability of needing ice breaker assistance as a function of region and time period. The basis for the estimate is the ratio between distances in different states per total distance. This estimate tells that on average, during the period, the ship has been assisted *a* miles on the leg, where *a* is *l * p* and *l* is the total length the ship has travelled *on that leg* during the period.

$$p_{ass10} = p_{ass10}(G(s_i), R, T)$$

where

p_{ass10} = ratio of icebreaking assistance distance as measured during winter 2010

G = as above

s_i = individual ship

R = region (Western, Middle, Eastern part of the Gulf of Finland). The region is based on longitudinal limits. OR other suitable criteria.

T = Time period. The winter is divided into 10 day periods, starting from 30.12.2009 to 18.4.2010.

3) Estimate of probability of needing convoy assistance as a function of region and time period.

$$p_{conv10} = p_{conv10}(G(s_i), R, T)$$

where

p_{conv10} = Ratio: (icebreaking assistance or being after another ship at a distance less than 4km) / total distance as measured during winter 2010.

G = as above

s_i = individual ship

R = region as above

T = Time period as above

4) Estimate of probability of needing icebreaker assistance as a function of ship group and ice thickness. Thus this estimate tells that on average, the ship has been assisted *a* miles, where *a* is *l * p* and *l* is the total length the ship has travelled *in the given ice thickness*

$$p_{assice} = p_{assice}(G(s_i), h_{ice})$$

where

p_{assice} = ratio of icebreaking assistance distance to total distance

G = as above

s_i = individual ship

h_{ice} = ice thickness class (0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and over 50 cm)

5) Estimate of probability of needing convoy assistance as a function of ship group and ice thickness

$$p_{convice} = p_{convice}(G(s_i), h_{ice})$$

where

$p_{convice}$ = Ratio: (icebreaking assistance or being after another ship at a distance less than 4km) / total distance

G = as above

s_i = individual ship

h_{ice} = ice thickness class (0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and over 50 cm)

6) For validation of the model, the waiting times of the ships are also measured. To remove waiting times caused by other factors than ice condition dependent reasons, average waiting time values from ice free periods can be subtracted from the times measured during other times. This then assumes that the (average) waiting times can be expressed as a sum of waiting due to ice conditions and waiting due to other reasons

$$w = w10(G(s_i), R, T)$$

where

w10 = waiting time ratio, i.e. waiting time per total time in open sea areas (ice or open water)

G = as above

s_i = individual ship

R = region as above

T = Time period as above

7) Average ice conditions per route leg and period during winter 2010

$$h_{ice} = h_{ice}(L,T)$$

where

h_{ice} = ice thickness class (0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and over 50 cm)

L = Leg number

T = Time period as above

5.1.2 Simulation tools and results

The ship traffic in the model is based on the real traffic during the winter 2009-2010. Acquired from Finnish, Estonian and Russian maritime administrations and port authorities, port calls are the basic traffic for the simulation model. Every observation contains at least the name, arrival date, previous port, port of the port call and next port, which makes it possible to assign an actual ship to enter the model at the right time and to an actual destination. To Baltic Sea and from Baltic Sea is used as an entry/exit point as well as the other ports in the Gulf of Finland.

During the winter in question the real ice season started in the beginning of January and due to the harbour strike in March the simulation period was chosen to end already in the end of February. The ice conditions on a leg are represented by its ice thickness and the ice data was received from the Finnish Meteorological Institute and processed by VTT. The ideal way of simulating different ice conditions would be to measure the performance during several winters of varying severity and then applying these values to the simulation model. The approach used in this simulation is to use different parts of the Gulf of Finland as measured during the winter 2010 as representative samples of the conditions during winters of varying severity. Thus applying the conditions in the Eastern part to the whole sea area indicate conditions during a severe winter. This means however, that conditions in the eastern part would not be changed during simulation of a severe winter.

This mean that additional modelling is required. As the speed and assistance probabilities have been estimated as a function of ice thickness, a suggestion is to increase the average thickness on all legs by one step to simulate more severe conditions. The average thickness per leg during the most severe period in a severe winter could also be estimated using statistical data from the Ice Service regarding ice conditions in the Gulf of Finland during a severe winter.

Data from different locations and different points in time was mapped to the nearest leg in ten day periods. For each leg and ten day period an average ice thickness and standard deviation of the thickness measurements was received. The ice conditions were randomised each day in the model in order to represent compressed ice and ridges. Each day one sample from the N (0,1) distribution was drawn and used for calculating the randomised ice thickness on each leg using their respective means and standard deviations. This means that if a high number is drawn, there will be more severe than average ice conditions on all legs during that day.

When a ship arrives to the beginning of a leg, the simulation determines:

- Does the ship need icebreaker assistance?
  - Yes: Are there icebreakers available?
    - Yes: reserve the icebreaker and continue in icebreaker assistance travelling with a constant speed SOG_{ass} =8.5 kn.
    - No: Wait for an icebreaker to be available
  - Continue on the leg using a speed determined by the SOG function (SOG = Speed Over Ground in open water)

The assistance need probability for a ship is a function of the ice thickness on the leg, the machine power of the ship and its ice class:

$$P_{ass} = -power * p_{dep}(iceclass) - icethick * i_{dep}(iceclass)$$

where p_{dep} and i_{dep} are ice class specific parameters estimated by using ice and AIS data. Using the probability P_{ass}, the assistance need (yes/no) is drawn for each ship in the beginning of each leg. When a ship is travelling without IB assistance, its speed in ice is determined by a function of ice thickness, its machine power, ice class, breadth and SOG in open water:

$$SOG = SOG_{ow}\left[1 - \left(\frac{c_1 iceclass * breadth}{power} + c_2(iceclass) * icethick\right)\right]$$

where c_1 and c_2 are ice class specific parameters estimated using ice and AIS data.

The icebreakers are modelled as resources that can be taken in use by the ship entities, i.e. whenever an icebreaker is free it is available for any ship anywhere in the model. When a ship in assistance is no longer in need of an icebreaker, it releases it. The icebreaker will then be available for other ships after a quarantine time (90 min), which represents the average time required for the icebreaker to travel from one assistance task to another. If the ship is in assistance, other ships can also join the convoy. The model can be run taken into account only traffic from and to one country (Finland, Russia, Estonia) or for all traffic altogether.

For each test setting, the model can be run with different number of icebreakers to examine the effects of different icebreaking fleets, both for one individual country and for the whole Gulf of Finland. The model has also the possibility to assume that ships exceeding a certain breadth would need two icebreakers or an extra wide one.

As mentioned earlier, different winters can be represented by altering the ice thickness input data. In this simulation, a severe winter was represented by manipulating the 2010 ice data using the formula:

$$Heavy\_ice = 0.1 + 1.4ice$$

where *ice* is the original ice in meters.

The effects of other traffic volumes can be simulated by altering the traffic data input, for instance to represent the forecast for 2015.

New icebreaking concepts can be examined with the new model. In the concept of a ship deviating from its own route to assist others, the ship is temporarily suspended while assisting. In this scenario, all ships with ice class IAS except tankers and passenger ships would be assisting other if needed. When such a ship meets a waiting ship, its journey is temporarily suspended and starts to assist the other ship. The assistance task ends when an icebreaker becomes available, the assisted ship does not anymore need assistance or when the assistance has continued over 2 hours. The assisting ship can then continue its journey after the same amount of time has passed as spent assisting. It is assumed that the ship has to return to its original position before continuing the journey.

The results of the simulations show that there is a potential advantage to be gained from icebreaking cooperation between Finland, Russia and Estonia in the Gulf of Finland. From the point of view of the simulated results, there are also potential advantages from the new icebreaking concepts, where ships assist others in ice.

5.2 The CATRIN optimization model

The purpose of this part of the CATRIN-project was to analyze potentials in co-operation within the icebreaking services in the Baltic Sea. Two basic scenarios are addressed. The first is a base-scenario where the states have individual icebreaking arrangements, but have some mechanisms to share excess capacity and co-operate when it comes to strategies and individual operations. The second scenario is a full-fledged joint icebreaking management where all icebreakers are managed by a single organization. For these two scenarios the possible alternative forms of cost allocation are also discussed. (Eriksson et al., 2009)

For the purpose of modelling the demand for icebreaking services in the Baltic Sea, a traffic scenario based on the traffic for winter 2007/2008 was developed as well as two different ice scenarios (normal/severe winter). The data used in the traffic scenario was taken from the AIS database, the Baltic Port List and the IBNet. The two latter ones are used as a source for traffic in port regions, while the AIS data describes the open sea traffic. AIS-data was retrieved for a period that answers to the ice scenario of a severe winter, suggesting that the weeks 50 to 22 are of importance. The most recent data was used and since the traffic patterns at the Baltic Sea are stable from one year to another, it can be seen as a reasonable estimation for the traffic pattern for the following years. Port statistics were used to allocate the traffic volumes retrieved from the AIS-data.

The two different ice scenarios developed for this study have to describe the ice extent, ice thickness as well as existence and location of ice walls, ice ridges and open water. The scenarios are described by standard ice maps produced by the Ice Services at SMHI. After a consultation with FMI, the winter 1986/87 was to represent a severe winter. The same winter was used to describe a normal winter, except that the high season from mid January to mid April has been cut off. There the normal winter is only 11 weeks while the severe winter is 25 weeks. The ice restrictions used during the winter in question are directly transferred to the ice scenarios.

Based on these scenarios, the need for icebreaking services was estimated by making a theoretical allocation of the icebreaking resources. This was done by the best professional judgement of the Swedish icebreaking management, who were given the traffic scenario and two different ice charts (normal/severe winter) with the task to allocate icebreaking resources according to the methods regularly applied. This was done for the whole Baltic Sea according to the two parallel rationales that were previously mentioned, i.e. the national approach and the international co-operation approach.

When the need for icebreakers in the different parts of the Baltic Sea is summarized, it can be seen that the existing fleet is more or less sufficient to keep up with traffic even during a severe winter. However, in the non-co-operation alternative, there is a considerable lack of capacity. All in all 12 additional icebreakers would be needed and the investment need would be some 1 140 million €.

To model the optimal utilization of the icebreakers an optimization model has been developed. Based on the estimated costs for all the individual icebreakers the least costly set of icebreakers are engaged. The model is run both for the cooperation alternative and the non-cooperation alternative. The annual operation costs in cooperation mode gives us a saving of 67 million € during a severe winter, in comparison to applying the national approach.

5.2.1 The used optimization model and icebreaker costs

For an optimal cost allocation, the icebreakers have been classified according to their potential as icebreakers (engine power, length and beam) into four groups as can be seen in the table below.

Table 13 Categorisation of the icebreakers

Category	Engine power, kW	Length, m	Beam, m	Nr in category
A	>15 000	> 100	>= 24	12 – 14
B	13 000	83	18	3
C	6 500 – 10 000	76 – 100	15 – 24	10
D	< 5 500	< 75	< 18	13

Icebreakers tend to be individual and built as unique vessels or in short series and private owners such as Finstaship are hesitant to share cost information. The costs used in this study are therefore given by SMA and is first hand information on the costs of the Swedish icebreakers.

The investments in existing icebreakers are seen as a sunk cost since it is not a realistic scenario that the vessels in question would be employed in other operations and their alternative value is limited. Thus the concept of investment cost is here only relevant for potential new buildings. Since icebreakers are rarely built, there are no list prices for this type of vessels. The price depends among other things on the ship specific design and technologies. Based on recent concepts and pre-studies the estimated investment costs for the respective icebreaker categories are 140 million € for vessels of category, 80 million € for vessels of category B, 60 million € for vessels of category C and the category D vessels cost 50 million €. These investment costs are assumed to be written off over a period of 30 years. Multipurpose vessels however, do have an alternative value that depends on the respective market, i.e. whether it is an offshore vessel or research vessel.

Running costs are divided into fixed and variable costs. The fixed part represents costs that have to be invested just to have the vessel fit and in stand-by for icebreaking. These are mainly costs for crew and maintenance not related to hours of operation. For the Swedish category A icebreakers, the annual fixed cost amounts to 2 400 000 €, of which 1 800 000 is crew and 600 000€ is fixed maintenance costs. The costs for the category B icebreakers are defined in the contract with the ship owner as 750 000 € per year. The fixed maintenance costs for the Finnish icebreakers are assumed to be equal, except the cost related to crew which is estimated to be some 30 % higher due to larger crew. The annual fixed running costs for the Finnish icebreakers are estimated to be 3 000 000 €. For the Finnish multipurpose icebreakers one fourth of that cost is allocated to icebreaking and the rest to offshore activities. As for the category C icebreakers, six out of ten are classified as old vessels and are 40 years or older, which implies higher fixed annual maintenance costs estimated to be of the same magnitude as the corresponding cost for category A icebreakers i.e. some 600 000 € a year. Two of the icebreakers are medium aged, with maintenance costs that are some 80 % of the respective category A costs, while the modern class C icebreakers have maintenance costs that are 60 % of the category A costs. The costs for the category D icebreakers are estimated in a similar manner as those for category C vessels, except that the percentages are 80, 60 and 40 % of that of category A.

The variable costs are made up of fuel costs and costs for maintenance related to the icebreaking operation, fuel being the dominating part. The category A icebreakers have a fuel consumption of up to 80 ton per day. With a crude oil price of about 420 € per ton, the maximum daily fuel cost for a Swedish category A icebreaker is about 34 000€ / day. The average consumption is however, much lower and during a severe winter it is between 30-35 % of the maximum level. The variable running costs are therefore between 0 when the vessel is not used and 34 000 €/day when its full engine power is used for 24 hours of a day. The A category icebreaker Atle, is equipped with catalytic converter and its operation demands use of urea which means that the daily cost is estimated to be max 3 000 / day. The variable costs for a Swedish category B icebreaker is up to a maximum of 39 000€ a day. Due to the lack of information, the Russian icebreakers are assumed to have the same operation costs as the Swedish ones whereas the Finnish category A icebreakers use diesel fuel instead of crude oil, which means that the price taken in autumn 2008 is about 60 % higher. Therefore their estimated maximum daily cost is 58 000€.

The cost for crew for category C and D icebreakers is estimated to be about half of that of category A icebreakers, that is 900 000 €. This is nevertheless not an accurate estimate, since for instance the Danish icebreaker currently has no dedicated crew. A number of these icebreakers are also employed as tugboats or for instance Baltica's and Scandica's main employment is fairway maintenance. Therefore it is suggested in the article that a part of these annual costs should be allocated to other activities than icebreaking. The variable running costs for the category C and D icebreakers are estimated in relation to the different vessel engine power and age. The Swedish category A vessel Frej (1975) was used as a reference vessel and the variable costs are ain the article assumed to be linear to the engine power, given in kW, at a cost level represented by Frej and her sister vessel Ymer.

The efficiency of icebreakers is judged to improve by 0.75 % per year. By this the authors refer to the energy efficiency, but theoretically the same applies also for variable maintenance. As an example is mentioned that an icebreaker that is 30 years younger than Frej, is 15 % more effective per kW. According to this formula the maximum variable daily costs for category C icebreakers varies in the range of 24 500€ a day to 13 900€ a day. For the category D icebreakers the interval is 12 900€ a day – 5 100 € a day.

The icebreakers listed in Enclosure 1 (Baltic icebreakers and icebreaker costs) of the report written by Eriksson et al. 2009 are indexed by *i*= Oden, Atle,…Newb-in-D and the categories by *k*= A, B, C, D and the following sets are introduced:

> I^E = the set of existing icebreakers, I^N = the set of new icebreakers
>
> I^E_K= the set of existing icebreakers of category *k*,
>
> I^R_A= {Russia_1, Russia_2}

The new icebreaker of category *k*, is noted by i_k.

The cost parameters listed in Enclosure 1 are c^{inv}_i = investment cost of new icebreaker *i,* c^{fix}_i = fixed running cost of using icebreaker *i,* c^{var}_i = variable cost for icebreaker *i*. The need for icebreakers of category *k* in week *t* is denoted by d_{kt},where *t* takes the values of the set T = {50, 51, 52, 1, 2, …, 22}. Observe that d_{kt} takes different values for two cases “Cooperation” and “No Cooperation”.

For the existing and new icebreakers, the following variables are introduced:

> y_{it} =1 if existing icebreaker *i* is used in week*t*, 0 otherwise,
>
> z_i = 1 if existing icebreaker *i* is used in any week, 0 otherwise,
>
> x_{it} = number of new icebreakers of category *k* that are used in week t,
>
> w_i = maximum number of new icebreakers of category *k* that are used over all weeks.

Finally, the following parameters are defined: *n* = no. of working days in a week (here 7), *l* = work level (here 0.35) and *a* = depreciation time (here 30 years).

By these notations the optimization model can be defined as (P1)

$$\min \sum_{i\in I^E}(\sum_{t\in T} nlc_i^{\text{var}} y_{it} + c_i^{fix} z_i) + \sum_{i\in I^N}(\sum_{t\in T} nlc_i^{\text{var}} x_{it} + (c_i^{inv} / a + c_i^{fix}) w_i)$$

$$\text{s.t.} \sum_{i\in I_k^e} y_{it} + x_{it} = d_{kt}, k \in K, t \in T$$

$$|T| z_i \geq \sum_{t\in T} y_{it}, i \in I^E \, (2)$$

$$w_i \geq x_{it}, i \in I^n, t \in T \, (3)$$

$$y_{it} \leq y_{jt}, i \in I_A^R, j \in I_A^E \setminus \mathrm{I}_\mathrm{A}^\mathrm{R}, t \in T \, (4)$$

w_i, x_{it} integer, y_{it}, z_i binary $\forall i, t$

The two terms in the objective function express the costs of using existing and new icebreakers, respectively. The first constraints ensure that the need for icebreakers is satisfied. The subsequent constraints are coupling constraints, assessing that the values of the variables z_i and w_i are correct, according to the values of y_{it} and x_{it}, respectively. Finally the last constraints allow the Russian icebreakers in the set I^r_A to be used only if all other icebreakers of category *A* are used in that week.

5.3 A simulation tool for the future need of icebreakers, FMA

The strength of simulation models based on current maritime traffic conditions and actions is that it is possible to make comparisons and analyze different scenarios just by changing the studied variables, such as the number of icebreakers or commercial vessels, their performance and ice conditions. The model developed by the Finnish Maritime Administration, is specifically designed for the improvement of the winter traffic in the Baltic Sea. The studied sea area was divided into three smaller operative divisions, which are the Bay of Bothnia, the Sea of Bothnia and the Gulf of Finland.

For the simulation model a route network was modelled, along which the simulated ships navigate. The route network includes all the winter ports and fairways and some other important traffic nodes are also added. When the route network was defined, the next step was to set ice conditions for each of the route segments. These were defined in periods of ten days and for each of the segment the following parameters were defined: ice thickness, ice coverage, ridging parameters, ice bending strength and the thickness of the channel. The ice conditions were defined based on ice charts by the FIMR and the Climatological Ice Atlas for the Baltic Sea.

In the model commissioned by FMA, one voyage is considered to include both the journey to and from the port. In order to model the traffic, the entire fleet of ships that navigate to and from Finland was divided into 36 categories according to their capabilities of navigating in ice. From these categories 35 typical ships were chosen to represent the fleet coming to Finland in winter time. When the ships were categorized the ice class regulations were followed strictly, but otherwise the ships were referred to a specific category of ship type based on their engine power, breadth and deadweight. Each of the 35 typical ships was then given the technical parameters necessary to define their performance both in open water and different ice conditions. This made it possible to calculate the ship speed for the different route segments, which in turn allowed the model to decide, based on the given limit values, whether or not the ship was in need of assistance.

The ice-going capabilities for the different ships were calculated with a programme developed by Kvaerner Masa-Yards /MARC and it takes into consideration level ice, the ice extent, channel ice and ice ridges as well as the performance of the ship in open water and the net thrust. The transit in ice for one ship is in the model calculated by using the equation below giving us the acceleration and speed as function of time. Some of the parameters needed for the calculations were unknown and in that case they were estimated by the authors of the study.

$$F_{inertia} = M*a = T_{net} - R_{ow} - R_{level} - R_{channel} - R_{ridge}$$

where,

T_{net}	Net thrust of the propulsion system
R_{ow}	Open water resistance, calculated using the Holtrop method
R_{level}	Level ice resistance, calculated by the Poznyak and Ionov method
$R_{channel}$	Ice channel resistance, based on the methods used in the ice class rules
R_{ridge}	Ice ridge resistance, based on the Malmberg method with improvements and modifications made by MARC

As mentioned the traffic in the simulation model is simulated by ships going through different route segments or legs in the designed route network. They arrive to the entry point of the route network accordingly to the time information given in the input data of the model and continue their journey one leg at a time, where the ship speed always depends on the ship type and the ruling ice conditions of the leg in question. If the ice going capabilities of the ship do not exceed the critical limit for the respective ice conditions, the ship will stop at the beginning of the leg in question and wait there for icebreaker assistance. When an icebreaker arrives, it will escort the ship as well as any other ships that are waiting at the same node. If assistance is not anymore needed at the beginning of the next leg, the ship will leave the convoy and navigate alone to its destination port; otherwise the ship will stay in the convoy. If there are any other vessels waiting for icebreaker assistance, those will join the convoy. When the icebreaker is not needed anymore by any of the ships in the convoy, it is set free and it can move on to other routes and it can be used again for assistance after a transition period. If the icebreaker is set free at the same node where a ship happens to be waiting for assistance there will not be a transition period. Once arriving to the port, the ship will stay there for a specific amount of time, which is set in the model and can be changed, after which the ship will start is journey back to its port of origin using the same principles of icebreaking assistance. The simulation model registers for instance the following: time of independent journey, time being assisted by an icebreaker, waiting time for icebreaker assistance and the time spent in a port.

Some important values that are used in the model are listed below:

Limit for the need of IB assistance	All models:	5,0 knots
The speed of the IB assistance	Bay of Bothnia:	10,8 knots
	Sea of Bothnia:	8,8 knots
	Gulf of Finland:	8,2 knots
Period of simulation	All models:	1.11 - 31.5
The longitudinal traffic	Bay of Bothnia:	2136 port calls
	Sea of Bothnia:	3225 + 2136 port calls
	Gulf of Finland:	5673 port calls
The transverse traffic	Bay of Bothnia:	Vaasa – Umeå, 14 weekly voyages
		Raahe – Luleå, 4 weekly voyages
	Sea of Bothnia:	Turku –Stockholm, 40 weekly voyages
	Gulf of Finland:	Hki- Stockholm, 14 weekly voyages
		Hki – Tallinn, 49 weekly voyages
Time spent in port	All models:	Longitudinal traffic: 8 hours
		Transverse traffic according to schedules
Compression of ice	Bay of Bothnia:	5 days, the speed is decreased by 50%
	Sea of Bothnia:	11 days, the speed is decreased by 25%
	Gulf of Finland:	11 days, the speed is decreased by 50 %

The simulated results are mentioned to include mainly the time that the ships need assistance, their waiting time and the actual number of ships that need assistance. The user is also able to study what effects factors like the number of winter ports, an ice class based assistance or possible speed limits would have on the service level. The criteria for the FMA have been that the waiting times would not exceed 4 hours and that 90 % of the ships should not have to wait for icebreaker assistance.

All of the three models are defined separately and they use statistical data from different years. The model for the Bay of Bothnia is calibrated based on the statistical information on icebreaker assistance from winter 2000/2001. The Sea of Bothnia model in turn studies the effects of winter conditions from the years 2002/2003 and 1986/1987 on the traffic, which is taken based on the realized port calls year 2002/2003. The model is calibrated based on statistics on icebreaker assistance from year 2002/2003. In the model for the traffic in the Gulf of Finland, the ice conditions are taken from years 2002/2003 and 1986/1987 and the traffic data is equal to the realized port calls winter 2002/2003. The model is calibrated according the data for year 2002/2003. The validity for all of the above models can be considered good.

From the Bay of Bothnia model the authors mention that they have drawn the conclusion that the winter traffic up to Kaskinen can be assured by using five ice breakers. To maintain the required service level during a severe winter, six ice breakers would be needed. However, traffic to the Swedish ports is not included in the models, except for the regular transverse traffic. The simulations for the Sea of Bothnia show that for a winter like that of year 2002/2003 an average of two icebreakers was needed. If the ice conditions are those of winter 1986/1987 and the traffic is set to current level, four icebreakers would be needed to assure a waiting time of 4,5 hours. When simulating the traffic as a whole from a Finnish point of view, the current fleet of nine icebreakers would not even be sufficient to guarantee a waiting time of six hours if the winter is severe. In the Bay of Bothnia severe ice conditions would lead to waiting times between 9-13 hours.

The simulations done in the study for a normal winter in the Bay of Bothnia tells us that a decrease in the assistance speed and specifically when the speed drops below 10 knots has a large effect on the waiting times. If the assistance speed decreases from 11 to 9 knots, the waiting time almost doubles. Furthermore it can be said that if the ship sailing between Raahe and Luleå would be replaced by a vessel that is independent in ice, the waiting time would drop by two hours during a normal winter. The author points out that this is more or less equivalent to being able to remove one icebreaker from service and being able to place it elsewhere. On a general note, based on the results can be said that the need for icebreaker assistance is not evenly distributed among the different ship types. For instance in the Gulf of Finland the simulations show that 3 of the 33 typical ships that were used stood for half of the total assistance time of the icebreakers. This kind of information, as well as the other results that can be obtained from the simulations is by the authors suggested to be very useful in supporting decision making and choosing what infrastructure to develop further.

5.4 The transit simulation model

The transit simulation program for ice covered waters was developed at the Ship laboratory at Helsinki University of Technology with the aim of facilitating the investigations of the effects of different ice conditions on the performance of a ship. The main purpose of the program is to provide means of roughly determining ship's suitability for transiting a route of various ice conditions. The simulated route can have sections of open water, level ice, channel ice, floe ice fields of various concentrations and segments of ridged ice. (Patey & Riska, 1999) The program can for instance be used in the early design stages as it measures ship's suitability to ice navigation in terms of speed and energy expenditure (La Prairie et al., 1995).

The main output of the program is a speed profile along the route, the power consumed by the ship and the total voyage time of the journey. These results are obtained by comparing the total net thrust available for the ship in question to the resistance of the ice. The difference of these two values is the resulting acceleration of the vessel. The total net thrust is estimated based on the bollard pull and the effect of open water resistance is taken into account by a speed factor. (Patey & Riska, 1999) However, it is important to remember that the ship's speed and energy expenditure calculations are based on ice resistance formulae developed mainly for the Baltic Sea (La Prairie et al., 1995)

When running the simulation program, the user inserts various ship and ice parameters, which are constant during the simulations. If the user does not want to insert ship specific parameters, he can choose to use the pre-set parameters for a ship of the Norilsk-class. Ridged ice and pack ice properties cannot be considered constant and are therefore impossible for the user to insert. If the user decides to use his own ship specific parameters they will later have to choose whether to insert or let the program calculate the following parameters:

Ship's geometric coefficients, C_b, C_m, C_p and C_{wp} (Schneekluth 1987)

- L_{bow}
- L_{par}
- LCB

Other ship parameters needed by the program's resistance formulae, such as displacement, bollard pull and wet surface area always calculated by the program based on the values listed above. (La Prairie et al., 1995)

The actual simulations are mentioned to be run varying the following ice parameters:

- level ice thickness
- average ridge spacing
- floe ice coverage
- average ridge sail height
- average floe size and
- mean channel depth.

The user has to define the following parameters:

- the distances of all the respective ice conditions along the planned route
- the thickness H_c of the ice channel
- the expected level ice thickness H_i
- the mean ridge height H_s
- the expected ratio of keel depth to sail height
- the mean number of ridges per kilometre
- the speed of the converging ice field and
- the pack ice coverage in percent.

Furthermore there are the ice parameters that are common to all ice conditions (such as ice density, bending strength etc) and the program gives the user the option to wither accepting the default values or inputting new ones. (La Prairie et al., 1995)

The evaluation of the total ice resistance is done using separate resistance equations for open water, channel ice, level ice, floe ice and ridged ice. The channel ice resistance is evaluated using the formula by Malmberg, later modified by Riska (1995). The used open water resistance equations are proposed by Holtrop and Mennen. (La Prairie et al., 1995) The level ice resistance is calculated using the Lindqvist formula and the ridged ice resistance is obtained using the Malmberg equations. The computed algorithm then considers the route in five different segments, with each section having its particular ice condition as mentioned above. (Patey & Riska, 1999)

Both in the simulation of floe ice and ridged ice, the Monte Carlo probability distributions are used to model the spacing and size of ridges and the size of ice floes. The ridge field is generated using the probability distributions for ridge spacing and ridge sail height as mentioned in Lensu et al. 1996. The floe ice transit consists of individual ice floes separated by stretches of open water and the ice floes have a thickness equal to that of the level ice section of the route. (Patey & Riska, 1999) The user inputs the ice coverage and the program generates random sized ice floes until their sum in length is equal or bigger than the ice coverage of the total pack ice field length input by the user. After this the program generates an equal number of randomly sized open water gaps between the pack ice floes. In simulating the plates of ice and open water gaps, statistical information has not been used as a guide, due to the lack of information. The Monte Carlo method simply generates random pan sizes between 10 and 120 meters in diameter and gaps are randomly chosen from 0 to 30 metres wide. (La Prairie et al., 1995) Because probability distributions are used in the formulation of floe ice and ridged ice, the authors suggest that the user of the simulation model would run multiple simulations with identical input parameters to effectively capture the statistical nature of the ship's average speed when transiting a route having sections of ridged and/or floe ice. (Patey & Riska, 1999)

Should the ship speed go to zero, indicating that the vessel has stopped because the ice resistance is too high, the subroutine RAM, which simulates the ship attempting to ram its way through heavy ice, is invoked. This routine uses the equation of motion with the force terms reversed to simulate the ship thrusting astern until the reverse speed reaches roughly 4 knots. This assumes that any vessel simulated will be capable of achieving this speed in reverse and once it has achieved it, it will maintain it. If the resistance is greater than the available net thrust and the ship is unable to move, the program provides two options. The user may temporarily reduce the ship/ice coefficient of friction for the duration of the ramming routine or choose to end the simulation. The net thrust and ice resistance will appear on the screen to indicate how big the difference between them is, letting the user estimate the real chances of freeing the ship. Reducing the coefficient of friction is meant to simulate the ship's actions to free it, using heeling tanks or bubbling systems. If the ship is able to reverse, the program has the ship back up for a distance of one and a half ship lengths. When the ship has reversed this far the forward equation for motion will once again be used to simulate the ship engines shifting to forward thrust. (La Prairie et al., 1995)

It can be said from the results of simulations done using the transit simulation program that it works rather well for level ice conditions, but for instance in cases of floe ice the program tends to predict the ship speed too low (Patey & Riska, 1999). Some suggested improvements for the program are to include the effect of snow cover, compression and mechanics of the interaction between the ship and floe ice. At the moment the article was written, compressive ice was only applied to the segment of ridged ice and in this segment only for the level ice between the ridges. The method applied only to ships with vertical sides as the resistance caused by compressive ice is smaller for ships with inclined sides. (La Prairie et al., 1995)

5.5 The ARCDEV project

The main goal of the ARCDEV project was to demonstrate the viability of Arctic marine transportation in the Arctic Russia. The objective was to develop technical and logistical know-how to enable safe, year-round traffic in the Northern Sea Route. The project itself included a demonstration voyage during which for instance ice conditions were recorded both by visual observation and using technologies such as EM-measurements and satellite image analysis. Ice loads to the ship's hull were also measured.

From the ice condition data acquired from the demonstration voyage, the authors calculated an equivalent ice thickness for each leg of the route. Parameters such as the level ice thickness, ice concentration, ice floe size, ridge or hummock occurrence and the ice pressure were used in the equations. Ship specific correction functions are used for each of these parameters in order to calculate the equivalent ice thickness. With this ice thickness the resistance was then calculated by the Lindqvist method and the open water resistance was obtained according Holtrop-Mennen. The open water resistance was then added to the ice resistance. The delivered power and thrust were calculated with the help of empirical formulae.

The simulation program gives the following results: distance and course for the leg and average speed. Furthermore there are two cases that can be studied. The first case is when the ship is operating with maximum power and/or maximum allowable speed, which gives the resulting speed and propulsion power for the leg. The second case is the ARCDEV voyage, using the average measured power of icebreaker and the result is the speed and time required for the leg. The difference between the time measured for a leg during the ARCDEV voyage and the calculated time for the same leg is mentioned to be an indicator for the reliability of the calculations. The distribution scatters in a wide range from -100% to 100% and above. This is suggested to be an indication that the ice observations and/or the program for calculating the time and speed have some shortcomings. Therefore improvements would be necessary both in making ice observations and in the calculation of the ship's speed. Reducing the number of legs was shown to improve the error distribution and when using only some of the legs in the simulation the error was reduced to almost zero. It was also shown that by using only EM thickness data the error was smaller and that data can therefore be said to be more accurate than the observed ice data. When the actual ice charts of the National Ice Center (USA) were used as an input the error distribution scattered in an even wider range. One explanation for this is mentioned to be that difficult hummocked and ridged ice is not identified in the egg-code. However, both hummocks and ridges do affect the ship's speed significantly. The authors suggest that these charts can be used as a basis for pre-calculating the duration of a voyage. Nevertheless it would have been useful to get better information about the ice conditions along the proposed route. This would have made it easier to calculate a more accurate estimate of the expected time of arrival and it would also have helped to improve further the simulation program.

5.6 Ship operation in ice, simulation tool

The project done at the Helsinki University of Technology studies the ice going capabilities of different vessels and the aim is to develop a model which could calculate the ice performance of vessel in different ice conditions. This information could then further be used to calculate the performance of said ship at a specific route at a given time.

The year is in this study divided into smaller units, i.e. months and each of them are given a respective ice profile. In an ice profile the route that the ship takes is then divided into smaller parts. These short legs represent a typical ice condition for the region in question. When analyzing only one short journey there can be a large error in the calculations since the ice conditions naturally change for instance due to the prevailing weather conditions and are not homogenous.

The progression of the ship itself is calculated by taking into account the different forces resisting the movement of the ship and the ship propulsion power. The open water resistance is calculated by the Holtrop method and the level ice resistance by the Poznyak-Ionov method. The resistance of drift ice is obtained by using the equations for level ice and then removing a part of it to reflect the ice coverage and the size of the ice floes. It is assumed in this study that the level ice resistance is directly proportional to the ice coverage and the size is proportional to an exponential function so that compared to level ice an ice floe of the size of one kilometer would reduce the resistance by one percent and ice floes of 50 meters by 25%. The resistance of ridges and the channel resistance are both calculated by using the Malmberg method.

5.7 Discussion

All these simulations had somewhat different approaches for the analysis of winter navigation. For the uses of the model that will be created in this project, it is useful to analyse the methods used in previous simulations.

The basis of these simulation is either a statistical or scientific. The statistical method use statistical data, for example historical AIS-data and build the model based on the actual data. The scientific approaches base their model on different ice resistance calculation models. The use of statistical data, like AIS-data, can produce a model that more reflects the complex reality of ice navigation. Still, this approach is fairly heavy and in order to create a model using statistical data, a wide range of data should be used. For example in the Icewin-project, the data was limited to only certain area and certain months/year. This makes the validity of the model questionable. In the Catrin-model, the AIS-data was used to model the traffic patterns, whilst the actual placement of icebreakers was done by expert opinions. This approach, in a refined way, could integrate well the statistical side and the human element of winter navigation and icebreaker assistance.

The scientific methods in calculating ice resistance are fairly good and certain methods have been used for decades already. There are several methods available for the calculation of ice resistance, such as the Lindqvist formulas or Riska’s method. The ice resistance calculations the method usually needs a lot of input regarding the ship in question. Often this information, such as the hull angles of the ship, is hard to find. The downside of the ice resistance calculations is that at the moment these formulas often only analyse the transit in level ice, whilst the effect of ridges and compression has to be simulated in some other way. Also, this approach usually is aimed for the modeling of an individual ship's journey on ice, like in the Transit-model and computing this to represent an entire winter navigation system can be demanding.

There are also differences in the areas for which the simulations are applicable. For example the Icewin-model was based only on the traffic of the Gulf of Finland and the ARCDEV on the other hand handled the traffic on the Northern Sea Route. As the project handles the entire winter navigation system of the Baltic Sea, it is crucial to create a model that actually reflects the entire Baltic Sea. If easier for the operation of the model, it could be divided into different sea areas, such as in the FMA simulation tool. These areas could be for example the Bay of Bothnia, the Sea of Bothnia, the Gulf of Finland and the Gulf of Riga. As these different areas have different traffic patterns and ice patterns and their traffic is most often completely separate, the division could be feasible.

When deciding different scenarios for the model, different types of ice winters have to be used. The variation of ice winters is wide and simulating only one winter with certain ice conditions is not in any way reasonable. The simulations that were presented in this report have used different methods to represent winters of different ice severities. The milder winters could have been represented by certain months of the ice winter, such as January and February, whilst the harder winters would have been represented by March. This approach does not represent the actual conditions as ice conditions have special features for each month and each year especially. As there have been severe, average and mild winters in the previous years, it is reasonable to use ice condition data from these years in the simulation calculations.

6 Discussion and conclusions

The aim of this report was to make a desktop study on previous studies on the field of winter navigation, with special emphasis on the simulation models. This report will form as a guide for the creation of the simulation model in the following activities of WINMOS-project. The focus on this report was mostly in the issues that were seen important for the premises of the simulation model. These biggest parameters in winter navigation are the traffic, the ice conditions and the icebreaker operations.

This report firstly concentrated on the traffic flows in the Baltic Sea. For the purposes of the model it was important to analyse the current and future traffic flows to the Baltic Sea harbors, as the winter navigation needs straight correlate to the amount of seaborne traffic. It was found that the traffic flows in the Baltic Sea are estimated to be growing fairly much in the future also. To the future scenarios, the effect of the new environmental legislations, especially the sulphur regulations, has to be taken into consideration as it could have major impact on the traffic flows. Studies presented in this report do show that the effect of the SECA areas may not be as major for all the traffic areas as it has been suspected. The composition and the ice performance of the fleet that operates in the Baltic Sea are important when considering the entire winter navigation system. It would seem that the fleet operating in the Baltic Sea is already fairly accommodated to the winter navigation needs, as ships that operate here independent of the time of the year already have an ice class. Still, the ships operating especially to Finland are often small, old general cargo ships that can pose problems for the efficiency of the winter navigation system. Poor ships cause delays on the icebreaker assistance and increase the costs for the operations.

In the same way that it is necessary to know the future traffic flows, it is necessary to know how the future winters will be like. If the climate warming will diminish the extent of the ice winters, will there be need for icebreaking in the future? It was shown in this report that climate change models show that the ice extent might diminish relevantly due to the climate change in the following decades. However, it was also noted that milder winters can be more difficult for the winter navigation operations that harder winters, as during the mild winters the ice cover tends to move with the wind and cause compression and ridging.

Icebreaker operations are the third major issue handled in this report. The icebreaker fleets of the Baltic Sea and the icebreaker assistance operations were presented. As the simulation model for WINMOS project aims to identify also the financial costs related to winter navigation operations, the costs of icebreaking were also discussed. For example for Finland, the icebreaking costs are very much corresponding to the severity of the winter, ranging from 20 to 50 million euros per winter. With the aging icebreaker fleet, the costs of the icebreaker operations have to be carefully estimated. With the icebreaker assistance, other important feature of winter navigation are the regulations. These mean the ice class rules and the national traffic restrictions.

The last chapter of the report handled the different simulations made on winter navigation analysis before. The models all had different premises, but can provide good insight on how the simulation model in this project should be built. Of these models presented, the one that best reflects the needs of this project was the one carried out by FMA, on the simulation of the needs of the icebreakers.

From the premises of this project and based on previous discussions within the WINMOS partners, some propositions on the model are presented. The idea of the model as a three part simulation could be very feasible. One part would be reflect the individual ship's journey in ice. This most likely could be done with ice resistance calculation approach. As it would be difficult to simulate the ice travels of each individual ship in the Baltic Sea, typical ship categories could be identified. This could be done by analyzing the traffic to the most important winter ports and identifying certain characteristics of these vessels. Different ice scenarios would be part of this model also. This model would create the input for the operational simulation.

The second part would then take into consideration the costs of the different options. This model would act two ways with the operational model. It could be more useful to not only have the cost model to calculate the costs of different operational scenarios, but also to have the cost model to give input to the operational model also.

The operational model would then simulate the entire operations in the Baltic Sea. It would take into consideration the routing, the fleet, and the icebreakers. When this model runs, it would show how the operations would be affected by different inputs. For the premises of the model, different outputs from the model have to be identified, meaning what is the result that is needed from the simulation; what are the actual parameters that the model should give as a result?

The reliability of the premises always determines the reliability of the result. As a simulation model is always based on assumptions, forecasts and a selection of facts, the end results cannot be seen as the most important result of the model. What running different scenarios through the model can give is the sensitivity and the relations of different factors affecting the model. Often the connections of different parts can be seen to affect each other, but the magnitudes can be often exaggerated or undermined. What a good simulation does is to give the operator the issues that are the most important in terms of this particular system. This way the most important features can be prioritized, which is crucial in an operation such as winter navigation.

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