

Copernicus Sentinels' Products Economic Value: A Case Study

of
Winter Navigation in the Baltic

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Case Study of Winter Navigation in the Baltic

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Case Study of Winter Navigation in the Baltic

Table of Contents:

1	Introduction and Scope.....	6
2	Overview.....	8
3	Description of the Case	10
4	Ice Breaking in Finland	13
4.1	“Finland is an Island”	13
4.2	A Short History of the Ice Services	13
4.3	The Different Actors	15
4.4	Co-operation in the Baltic	16
4.5	IBNet information system	17
4.6	The WinMOS project.....	18
4.7	Operating charging Policy	19
5	The Value Chain	20
5.1	Description of the Value Chain.....	20
5.2	Tier 1: The Icebreakers.....	23
5.3	Tier 2: The Ships.....	24
5.4	Tier 3: The Ports.....	25
5.5	Tier 4: The Factories.....	25
5.6	Tier 5: The Citizens and Local Economy	26
6	The use of Satellite Imagery.....	27
7	Linking Economics to Reality.....	30
8	The Economic Assessment.....	33
8.1	The economic Impacts	33
8.2	Tier 1: Icebreakers.....	33
8.3	Tier 2: Ships.....	36
8.4	Tier 3: Ports and logistics	42
8.5	Tier 4: Factories and the local economy.....	47
8.6	Tier 5: Consumer Benefits.....	49
8.7	Total Economic Return.....	50
9	Summary of Findings.....	51
9.1	General Approach & Methodology	51
9.2	Economic Benefit to Winter Navigation in the Baltic	51
9.3	The Impact of the Imagery	53
9.4	Conclusions	54
	Annex 1: About the Authors	55
	Annex 2: Sources	56
	Annex 3: List of abbreviations.....	61

Case Study of Winter Navigation in the Baltic

List of Figures:

Figure 2-1: Sea transportation of goods. Finnish Imports, exports and goods in transit and the destination countries in 2013. Transit goods 7.5m tonnes.	9
Figure 3-1: Finnish Ice Service and FMI.	11
Figure 3-2: Finnish icebreaker URHO in operation.	12
Figure 4-1: Early ice chart	14
Figure 4-2: Number of icebreakers in operation each week during winter 2013-14	17
Figure 4-3: Ice images within IBNet.	17
Figure 5-1: Value chain for “Winter Navigation in the Baltic”	20
Figure 5-2: Model of the use and impact of satellite imagery	22
Figure 5-3: Number of Icebreakers used through certain winters.	23
Figure 5-4: Numbers of ships assisted in Finnish waters.	24
Figure 6-1 : SAR Image (Radarsat) and associated ice chart (FMI).	28
Figure 7-1: Distribution of ship arrival times.	31
Figure 8-1: Maximum ice extent and number of accidents in the Baltic Sea for 2003-2014.	41
Figure 9-1: Economic value of the satellite imagery for each tier of the value chain	52
Figure 9-2: Cumulative economic value at each tier of the value chain per annum	52
Figure 9-3: Reducing impact (relative value) of satellite imagery down the value chain.	54

List of Tables:

Table 4-1: Finnish customs trade statistics: Imports and exports by sea (mtonnes).	13
Table 5-1: Traffic through the main ports in Finland	25
Table 6-1: Number of downloads of the ice charts per year	29
Table 8-1: overview fuel costs savings Finnish icebreakers in the period 2004 - 2014	35
Table 8-2: Assisted Ships fuel savings.	37
Table 8-3: Ice related damages incurred by a sample of Finnish ships for the years 1984-1987.	40
Table 8-4: Potential loss of revenue by the ports in 2014 in the absence of icebreaking services.	44
Table 8-5: Total potential port revenue loss over last 8 years.	45
Table 8-6: Value of the local economies	47
Table 8-7: Assessments of the benefits resulting from the usage of the imagery by the icebreakers	50

Case Study of Winter Navigation in the Baltic

Executive Summary

At the same time as the merchant ship entered the Gulf of Bothnia, Sentinel 1A passed overhead; its Synthetic Aperture Radar imaging the ice-covered sea below. Within a short time (around 1.5hours) the picture taken will be on the screen of the icebreakers clearing the way for the merchant ships to pass through on their way to the Northern Finnish ports.

¹ *The ship, carrying a cargo of stainless-steel waste for recycling by the works in Tornio, follows the instructions received from the lead icebreaker, the Voima, and sets sail for the first designated waypoint marking the Dirway (the directed way). The captain is satisfied because he has had to wait less than 1 hour for the instructions. Given a fair wind (because the wind is one of the main factors determining and changing the ice conditions) he should be able to arrive at the port on time. He steams ahead at a steady 10knots and should be able to arrive in Tornio in time to berth in the morning.*

He radios ahead to the port to confirm his arrival time. The iron ore will feed the furnaces of Outokumpu without delay. The factory will keep working and the ship will load a cargo of finished stainless steel for shipment via Rotterdam. Everything works like clockwork thanks to the ice services provided by the Finnish and Swedish authorities.

In this report we detail the analysis of the economic value generated by the use of satellite imagery in supporting winter navigation in the Baltic Sea. It uses a methodology which traces the impact of such usage on the information and services through several steps in the value chain. At each step, the benefits are assessed and the value calculated.

The value-chain analysed in this case takes steps starting with the icebreakers that work to keep the Finnish sea lanes and ports open throughout the winter. Finland is 90% dependent on sea transport for its exports and imports and so keeping the factories open and local populations supplied with goods throughout the year has a significant value. Finland has a very close co-operation with Sweden so the study also covers the impact on the Swedish economy.

Finnish and Swedish icebreakers use satellite radar images (which replaced the use of helicopters) to help find the best routes through the ice. Thanks to the wide-area view provided by the satellites, they are able to find better routes through the ice saving time, saving fuel and reducing the uncertainty in the ship arrival times in the ports. This has a positive impact on the various activities downstream and the wider economy.

According to our analysis, between €24m and €116m per annum of economic value is being generated in Finland and Sweden thanks to the use of satellite radar images.

¹ To avoid any doubt, this is an imaginary account of what could be a typical winter's day in the Gulf of Bothnia.

1 Introduction and Scope

This report describes part of the outcomes obtained in the frame of the study “*Assessing the detailed economic benefits derived from Copernicus Earth Observation (EO) data within selected value chains*”, undertaken by the European Association of Remote Sensing Companies (EARSC) under an assignment from the European Space Agency (ESA). The goal of the project was to gather quantitative evidence that the usage of Copernicus Sentinel data provides an effective and convenient support to various market applications. As part of the project, we defined and applied a new methodology to assess the full benefits (direct and indirect) stemming from the use of EO-derived geo-spatial information, in a way which has not been tackled before. We examined how the benefits of using these data either do or can affect a full value chain by starting from the primary usage and then following the related impact down various identified tiers in the value chain. At least 4 to 5 tiers were identified, where we believe it was still possible to model some marginal impact from the usage of EO data. The new methodology was applied to three use cases, which have been selected considering the maturity of the application as well as the feasibility for the sake of the study.

The results are captured in separate, dedicated reports which are written to benefit policy makers, in Europe as well as in ESA/EU Member States, who are concerned with (EO) space programmes. However, each single report should also be of interest for the private industries, public authorities and policy makers involved at any level in any of the specific applications described therein.

The current report describes the results obtained for the first of these cases; the case of Winter Navigation in the Baltic where satellite radar imagery is used to support the ice-breaking services of the Finnish and Swedish Maritime Administration (SMA). The analysis differs from previous ones (for example that carried out in the GSE Icemon project²) because it looks at the extended value chain beyond the initial usage of the satellite data. In this case, the icebreakers and ships which are serving factories and communities in the Baltic Sea and in particular in Finland. We provide a detailed analysis of the Finnish situation and have been able to gather enough information to extend this to Sweden.

When we started, we expected to be able to draw on analyses which would show the impact or the benefit of the ice-breaking services to the Finnish (or Swedish) economies. Our task would then have been to assess the significance of the role played by satellite imagery in those services. We were surprised to not be able to find such analyses and hence have needed to go back to more fundamental information and parameters relating to the services. It seems that the variation in the severity of the winters is by far the largest variable and has the largest impact on the need for ice services and hence the Finnish economy. This also means that there is no real reference for the situations with and without the satellite services which we wish to analyse. Hence our analysis has had to go back to some fundamentals starting with the impact of the ice-services before assessing the added value of the satellite imagery. The analysis has been based around figures and information coming from Finland and in some cases also from Sweden.

² Holt Andersen, B. and Schumacher, N. (2004), Cost Benefit Analysis of ICEMON Service Analysis, Report for ESA-ESRIN

Case Study of Winter Navigation in the Baltic

The report is based on research and interviews with persons in Finland and Sweden who are directly involved in operating the services as well as considerable background research to provide back-up numbers. Since direct information is not available for many of the parameters we are looking to analyse, some of the analysis is based on assumptions which are clearly declared. We shall welcome further discussion on these assumptions and/or the opportunity to refine the analysis in the future. In the meantime, this analysis shows significant economic benefits to the economies of Finland and Sweden.

We should like to thank the following people for their assistance in preparing this report:

Patrick Eriksson, Eero Rinne, Marja-Liisa Tuomola: Finnish Meteorological Institute

Jarkko Toivola, Esa Pasanen, Antti Arkima: Finnish Traffic Agency

Ulf Gullne, Johny Lindvall: Swedish Maritime Administration

Markus Karjalainen: Arctia Shipping

Robin Berglund: VTT

Pentti Kujala: Aalto University

Jukka Kailio: Port of Helsinki

Mikaela Dahlman-Tamm: Sveriges Forskningsforbund

With a particular especial thanks to Patrick Eriksson for his role in helping to identify some of the initial contacts and to help with organising the field trip to Helsinki in May 2015.

2 Overview

Previous economic benefit analyses on the use of EO data have largely been top down³⁴. In each case, macro-economic values, for example concerning the impacts of climate change, are used to assess a value for EO missions by assigning a potential percentage contribution from satellite data. A more recent study⁵ takes a step further by identifying 6 major domains associated with the Copernicus services and looks at economic impacts in each one of those. This leads to conclusions regarding a future economic value and particularly estimates of the impact on jobs.

This Copernicus Economic Value Study builds upon previous work in this area but differs in several respects. Most significantly, it seeks to work bottom up by identifying a specific product out of the thousands that exist and, by looking at the way it is or can be used, estimate the economic value of the product right through the value chain.

Cost-benefit analyses of ice services have been conducted in the past. Most notably the IceMon cost benefit analysis studies the case of navigation in the Baltic and has provided us with some useful information which in part compensated for the lack of wider analyses of the ice services. However, the parameters used to assess benefits are quite broad and we are seeking a more detailed and precise analysis.

In this report we look at a radar product which comes from Sentinel 1 and its use to support winter navigation in the Baltic. However, our goal is not to assess the utilisation of this product but to look at the economic impact that its use has. We start by providing a detailed overview of the history and operation of the ice services in Finland and in Sweden. We chose these two countries because this is where the impact is greatest. For Finland, some 90% of the external trade passes by sea⁶ and as such Finland is sometimes considered as a quasi-island. Furthermore, Finland is the only country where all of its ports are frozen in a normal winter. Hence the importance of icebreaking services to the Finnish economy.

We go on to describe the whole value chain where this product plays an economic role. It starts with the icebreakers and passes through the ships and ports to the factories and consumers which rely on goods and services. At the start of this chain, the visibility of the product and its use is very high, whilst further down the chain, its use may be unknown even if it is helping to ensure the reliable flow of goods.

We develop a simple model which helps explain and understand how it affects the various players and we conclude with an economic assessment of the impact; noting that precise data is often lacking and that we must rely on many assumptions developed through our research. It is fair to note that we have been

³ PricewaterhouseCoopers (2006), Socio-Economic Benefits Analysis of GMES, ESA Contract 18868/05

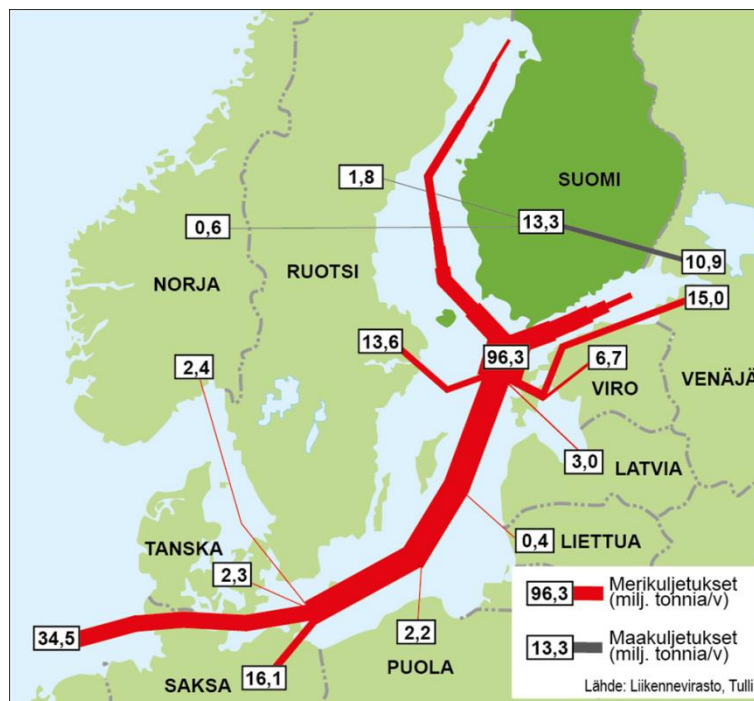
⁴ Booz & Company (2011), Cost-Benefit Analysis for GMES, Report for the European Commission

⁵ SpaceTec Partners (2012), Assessing the economic value of Copernicus, Reports

⁶ Winter Navigation and Traffic Management - No MoS in Finland without reliable ice-breaking services! Lassi HILSKA, Senior Adviser, Leading Expert Finnish Ministry of Transport and Communications.

Case Study of Winter Navigation in the Baltic

somewhat surprised not to find more information on which to construct our analysis. We had expected to find analyses of the value to the Finnish and Swedish economies coming from the provision (by the governments) of ice services. Despite many requests and extensive searching we have been unable to locate such studies. Indeed a current EC project WinMOS⁷ seeks to provide a model which will help in this analysis. Unfortunately it is not due until the end of 2015; but when it is available it will help to develop this case even further.



Suomen tuonnin, viennin ja transiton määrä ja kohdemaat vuonna 2013 (milj. tonnia). Transitoa oli 7,5 milj. tonnia.

Figure 2-1: Sea transportation of goods. Finnish Imports, exports and goods in transit and the destination countries in 2013. Transit goods 7.5m tonnes.

Our conclusion is that the benefits are substantial. Our estimates used throughout the work are conservative and we shall welcome them to be challenged. We have found the assessment to be illuminating and with much potential to be developed further.

⁷ Winter Navigation; Motorways of the Seas. <http://www.winmos.eu/>

3 Description of the Case

At the same time as the merchant ship entered the Gulf of Bothnia, Sentinel 1A passed overhead; its Synthetic Aperture Radar imaging the ice-covered sea below. Within a short time (around 1.5 hours) the picture taken will be on the screen of the icebreakers clearing the way for the merchant ships to pass through on their way to the Northern Finnish ports.

The ship (an ice class 1A⁸), carrying a cargo of stainless-steel waste for recycling by the works in Tornio, follows the instructions received from the lead icebreaker, the Voima, and sets sail for the first designated waypoint marking the Dirway (the directed way). The captain is satisfied because he has had to wait less than 1 hour for the instructions. Given a fair wind (because the wind is one of the main factors determining and changing the ice conditions) he should be able to arrive at the port on time. He steams ahead at a steady 10 knots and should be able to arrive in Tornio in time to berth in the morning.

He radios ahead to the port to confirm his arrival time. The iron ore will feed the furnaces of Outokumpu without delay. The factory will keep working and the ship will load a cargo of finished stainless steel for shipment via Rotterdam. Everything works like clockwork thanks to the ice services provided by the Finnish and Swedish authorities.¹

A few years ago this would not have been possible. Satellite images have only been available for regular use since around 1999 when the European Envisat was launched to operate alongside the Canadian Radarsat system. Both satellites carry powerful Synthetic Aperture Radars providing a wide-area view of the ice conditions in the Baltic. They can take pictures twice every 3 days and unlike the helicopters which were used before 2003, they can do so day and night and under all weather conditions as the radar signal is able to penetrate the thick snow-laden clouds.

As a result, the icebreakers can operate much more efficiently saving thousands of tons of fuel each winter season. They also have made large savings by removing the helicopters which used to operate from each of the main icebreakers. The 20,000 ships travelling through the Baltic to the Finnish ports in an average winter all save fuel as well and because they do not have to wait so long until an icebreaker arrives they are able to make the total journey in less time. At around €20k Euro per day operating cost this soon adds up.

⁸ The Finnish and Swedish maritime authorities have elaborated and issued Finnish-Swedish ice class regulations (or rules, FSICR) since 1971. The regulations have also been incorporated into the rules of the classification societies. The ice class regulations define the minimum engine output, hull strength, machinery and rudder strength of ships navigating in ice. The ice class affects the net tonnage of the ship, which in turn forms the basis for determining the size of the fairway due to be charged. When restrictions concerning icebreaker assistance are imposed, it depends on the ice class whether a ship is entitled to assistance or not. The aim of the regulations is to ensure that ships operating in the Baltic Sea are capable of navigating in ice and winter navigation runs safely and smoothly. See: http://www.trafi.fi/en/maritime/ice_classes_of_ships

Case Study of Winter Navigation in the Baltic

Better and more efficient operation also reduces the risk of collisions between the ships. Whereas in 2001 there were around 100 accidents which required repairs, this was reduced to 10 last year. This not only reduces the cost of repairs but also the time the ship is unavailable and the insurance premiums.

But the biggest gains lie with the ports and the factories being served. Just-in-time working practices means that every part of the supply chain has to operate smoothly. Any dislocation and costs can quickly add up as production lines stop or new delivery methods need to be found – as happened to the paper mill which had to air-freight its news print or risk losing a valuable customer. Hence the icebreakers play a pivotal role in the Finnish economy and all the other countries bordering the Baltic. Yet Finland, with all of its ports frozen in the winter and with over 80% of its goods transported by sea is the most vulnerable and the most dependent. As a result a whole industry has been built up around ice and ice-breaking.

As a quasi-island, the Finnish economy depends on sea transport. Many of the industries, especially those in the Gulf of Bothnia depend on shipping all year round and hence, during the winter, the ships transporting the goods depend on the ice-breaking services to be able to receive and deliver raw materials and products. Therefore, these businesses could not manage without efficient sea-transportation. The ships in turn depend on the icebreakers to navigate efficiently during the winter months and the icebreakers “depend⁹” on the satellite radar imagery to be able to conduct operations most efficiently. Satellite radar imagery plays an important role in the Finnish economy; how important?



Figure 3-1: Finnish Ice Service and FMI.

⁹ “Depend” seems too strong a word to use since clearly the icebreakers can operate without satellite imagery as they did before it became available. Nevertheless, the imagery plays such an important role in assuring efficient operations that it seems appropriate to use this word in any case. We were repeatedly told that the single most important element in keeping the icebreakers operating is the satellite imagery.

Case Study of Winter Navigation in the Baltic

An overview of the service is provided by the FMI which is the provider of imagery and information to those managing the ice-breaking service.

Our goal in this study is to try to answer this question and evaluate the economic value of the satellite services taking into account their use throughout the value chain. To do this we first need to understand the value of the icebreakers to the Finnish economy and then attribute a part of that to the satellite data. Everyone we asked said that the single most important element of the ice service is the satellite data. Putting a value on this will not be easy but it is the target we set ourselves.



Figure 3-2: Finnish icebreaker URHO in operation

4 Ice Breaking in Finland

4.1 “Finland is an Island”

Finland has a long experience in ice monitoring as a means to help the passage of ships; it has a good need to. As shown in Table 4-1 below, in 2014, some 77.5% of Finnish imports and 89.6% of exports passed by sea. Over the last 5 years, these figures have remained roughly constant and it is no surprise that Finland is sometimes described as a quasi-island!

	Imports by sea	Imports total	%	Exports by sea	Exports total	%
2014	44,570	57,694	77.5	40,579	45,328	89.6
2013	45,414	58,649	77.5	39,770	45,197	88
2012	44,033	55,934	78.7	37,610	42,951	87.6
2011	50,594	60,988	82.9	39,528	45,045	87.8
2010	47,335	60,483	78.3	36,445	41,624	87.5

Table 4-1: Finnish customs trade statistics: Imports and exports by sea (mtonnes).

Finland has around 60 ports in total of which 25 have a significant economic role. Given that the whole Finnish coastline freezes over in a normal winter it is no surprise that the ice breaking services which keep these ports open assumes a great importance to the Finnish economy.

Finland is the only country in the world where all ports freeze over in winter. In the absence of wind, the ice will remain quite flat and if lanes are cleared they can stay open for several days. However, in stormy conditions, the ice is blown around and open water can quickly close up. Furthermore, the ice is blown into ridges which trap ships and prevent sea transport. Icebreakers clear “fairways” into the ports throughout the winter as well as guiding merchant ships successfully through the Baltic. In this respect the lead icebreaker determines the rules and routes which ships must follow; as each ship entering the Baltic passes Aland Island it must agree to navigate under these rules or to forego assistance.

4.2 A Short History of the Ice Services

It was in 1971 that the decision was taken that the 25 ports should be kept open throughout the winter and all-year-round commercial shipping could be assured. Before this, ships could become stuck in the ice and taking days to break clear of the ice or worse. Sometimes the ship could even be lost. It could simply get crushed or trapped in ice and by drifting ice it can be forced into shallow water, where it eventually starts sinking.

Case Study of Winter Navigation in the Baltic

Finland's first icebreaker entered into service in 1889. The Murtaja "*demonstrated its value at once: without transport delays, the exports of butter for example doubled in just a few years*¹⁰". This moment also heralded the start of the systematic monitoring of the ice conditions around the Finnish coast which had first started around 1850. In 1915, a weekly ice report was published in a national newspaper.

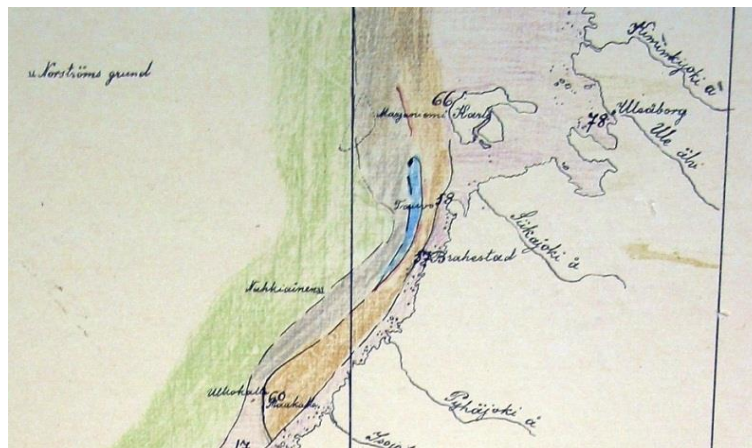


Figure 4-1: Early ice chart

Ice charts provide a useful snapshot but the ice moves with the winds; yet models of the effect of winds on the ice fields have produced limited results. The interaction is very complex, depending on the wind, the type of ice, where it is broken into open water. If there is no wind, the ice remains unmoved for many days since Baltic currents are quite weak, but when it starts to blow, the conditions change rapidly and a weekly view, whilst useful, is insufficient. Hence, following the decision in 1971, improvements in the monitoring of the ice conditions became a priority and the Finnish Institute of Marine Research started to work on the means to improve them.

At the time, aircraft were being flown along the coast with an ice expert on-board who would mark up a Decca chart by hand showing where the ice was situated. Later, helicopters were operated off the icebreakers to gather information around the ship. But both methods have severe limitations regarding the area which could be covered and the flying conditions. Some ships were equipped with on-board radars but these also had limited range (a few nm from the ship) and cannot provide the large-scale overview which allows effective route planning.

Hence there was a strong interest for the use of satellite imagery as it started to become available in the 1980's. However, imagery at this time came from optical sensors and the cloudy conditions often associated with the more Northern latitudes and poor weather conditions meant that their use was rather limited. This changed in 1991 with the launch of ERS-1 which carried a Synthetic Aperture Radar (SAR) instrument which has the capability to take images at night, under all weather conditions and can

¹⁰ From "Brute Force – The Story of Finnish Ice-Breaking" by Ari Turunen and Petja Partenen. We shall use many quotes from this book, first published in 2011, which tells the story of the ice-breaking services in Finland.

Case Study of Winter Navigation in the Baltic

“see” through cloud. After trials and further research, the decision was taken to stop using helicopters in 2003 when the service became dependent on the use of satellite radar coming from Envisat and Radarsat.

Today, Finland is operating 9 icebreakers where 7 of these are large ships owned by Finland, one is an ice-breaking tug and the 9th is leased from Sweden. Sweden has 8 icebreakers, including the one leased to Finland, so the two countries operate 16 icebreakers between them. In addition, some of the ports have ice-tugs which can clear lanes and assist ships in the harbour and approach fairways. A number of private companies in both Finland and Sweden also own ice-tugs which are chartered to ports and harbours for use in local waters.

4.3 The Different Actors

The key actors in the ice breaking services of Finland and Sweden have all been consulted in preparing this report. There are other actors which are crucial to keeping the service operating but those which we especially wish to refer to are.

Finnish Transport Agency (FTA)¹¹ (or Liikennevirasto in Finnish) is responsible for the services in Finland coming under the Ministry for Transport and Communications. The FTA is responsible for the Finnish roads, railways and waterways. Its main occupation is to promote an effective transport system, traffic safety and a sustainable development of the regions. One of the responsibilities of the FTA is ensuring winter navigation.

Swedish Maritime Administration (SMA)¹² (or Sjöfartsverket in Swedish) is responsible for the ice services in Sweden. The SMA is a governmental agency and enterprise within the transport sector and its primary mission is to promote favourable conditions for the maritime sector in Sweden and for Swedish shipping. Icebreaking and maritime traffic information are among the services SMA provides.

Arctia Shipping¹³ is wholly government owned company established in 2009 to take ownership of and to operate the Finnish fleet of icebreakers in order to ensure reliable sea connections for commercial use during the winter season. Furthermore, Arctia Shipping is also involved in offshore and oil recovery activities. The icebreaking activities of Arctia Shipping comprise assignments carried out in accordance with the contract concluded with the Finnish Transport Agency.

Finnish Meteorological Institute (FMI)¹⁴ (or Ilmatieteen Laitos in Finnish) is a public body under the Ministry of Transport and Communications, providing weather services in Finland. It assumed responsibility for the Ice Services in 2009 when the Finnish Marine Institute was dissolved and merged with other organisations. FMI organises the reception of the satellite data and its processing for onward transmission via IBnet. FMI generates the ice-charts used throughout Finland.

¹¹ FTA (2015b), Finnish Transport Agency. <http://portal.liikennevirasto.fi/sivu/www/e>

¹² SMA (2015a) Swedish Maritime Administration. <http://www.sjofartsverket.se/en/>

¹³ Arctia Shipping (2015), Arctia Shipping. http://www.arctia.fi/front_page

¹⁴ FMI (2015), Finnish Meteorological Institute. <http://en.ilmatieteenlaitos.fi/>

Case Study of Winter Navigation in the Baltic

4.4 Co-operation in the Baltic

Finland and Sweden have co-operated very closely for several years. Discussions are underway with Estonia to join the arrangement sharing common ice-breaking services. Beyond this, all the Baltic States co-operate to a certain degree through the organisation Baltic Ice Management best described by the following extract from their web-site:

Baltic Icebreaking Management, BIM, is an organisation with members from all the Baltic Sea states. BIM is a result of the annual meetings of the Baltic states icebreaking authorities which have assembled for more than 20 years.

After a difficult winter navigation season 2002/2003, a project was launched within the framework of [HELCOM¹⁵](#) aiming at improving the safety of winter navigation in the Baltic Sea. The HELCOM Recommendation on the Safety of Winter Navigation in the Baltic Sea Area was adopted in March 2004.

Within the EU concept Motorways of the Sea, which is one priority project in the trans-European network, the Baltic Sea countries established a working group with the aim of creating more efficient winter navigation through cooperation between the Baltic Sea countries. In 2004 the icebreaking authorities around the Baltic Sea decided that this work would continue within the framework of BIM, where also non-EU member states are taking part. BIM is now an organisation for the development of safe, reliable and efficient winter navigation between the Baltic Sea countries.

The overall objective of BIM is to ensure a well-functioning, year-round maritime transport system in the Baltic Sea through enhancing the strategic and operational cooperation between the Baltic Sea countries in the area of winter navigation assistance.

The member countries of BIM are Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, Russia and Sweden¹⁶.

The BIM publish annual reports summarising the operations over the ice-season. Figure 4-2 is taken from the 2013/14 report and shows the number of icebreakers which were operating in any given week. The peak was 12 large sea icebreakers in early February, visualised by the red columns. Note that the smaller icebreakers (other icebreakers are smaller, tug-like vessels often used to clear ice in harbours), marked in blue, are not taken into account in this report and that we fully focus on the Finnish and Swedish fleet (jointly amounting to 17 sea ice breakers).

¹⁵ HELCOM: Baltic Marine Environment Protection Commission also known as the Helsinki Commission.

¹⁶ Taken from the BIM website Baltice.org.

Case Study of Winter Navigation in the Baltic

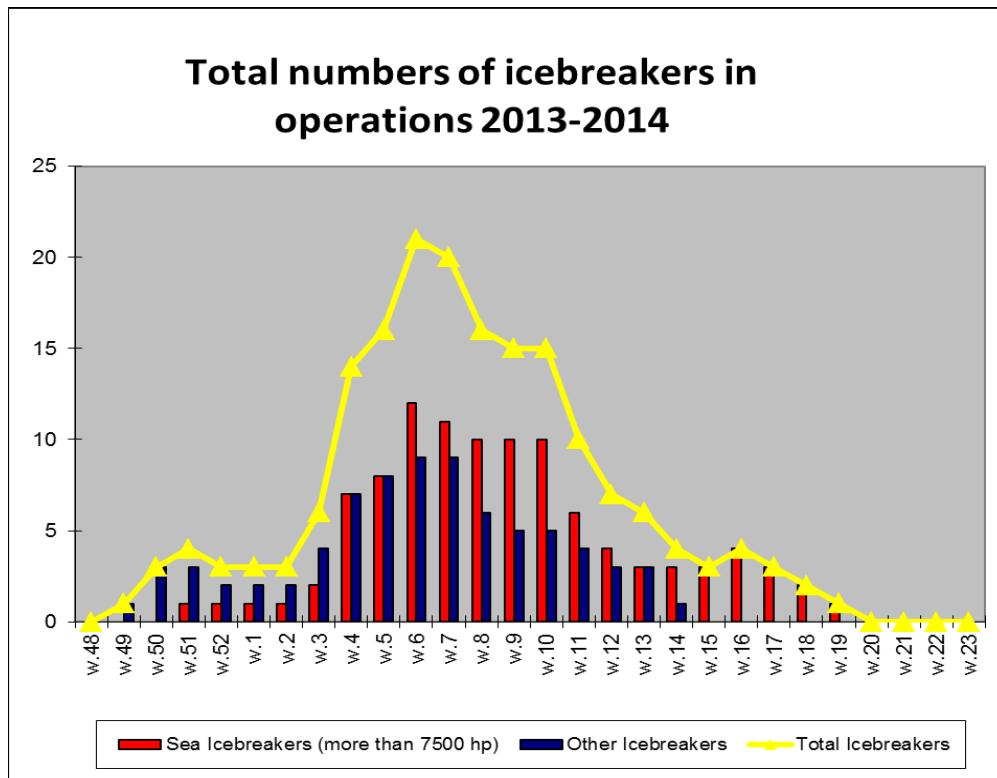


Figure 4-2: Number of icebreakers in operation each week during winter 2013-14

4.5 IBNet information system

A shared information system called IBNet is used to help control and manage the operations of the icebreakers. Screen shots of the information presented are shown below.

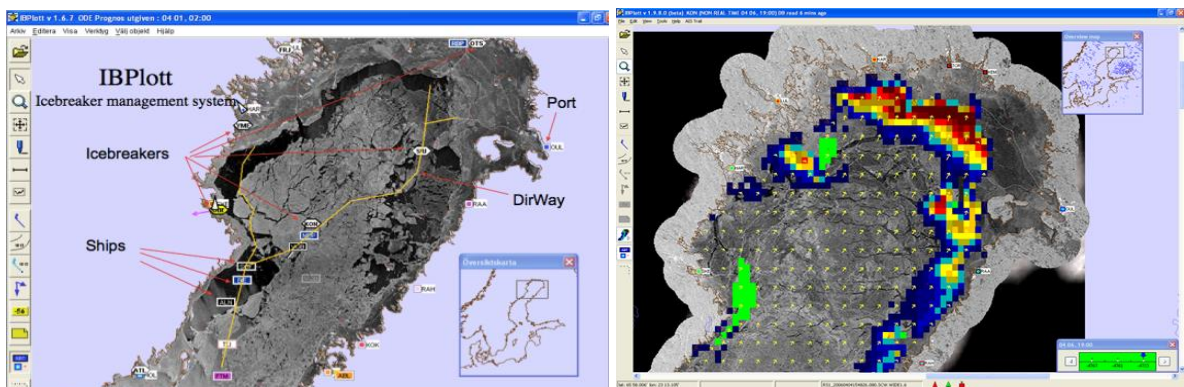


Figure 4-3: Ice images within IBNet.

The Finnish and Swedish transport authorities co-ordinate their efforts to a very close degree and have jointly developed the IBNet system. The combined fleet of 17 icebreakers is used in the most effective way possible. Estonia is now joining the collaborative effort whilst co-ordination amongst all the Baltic

Case Study of Winter Navigation in the Baltic

states helps the transfer of information between them. IBNet is already installed on the 2 Estonian icebreakers.

Information is transferred using a satellite VSAT system. This limits the information transfer capacity and is one reason why the SAR image is resampled (see chapter 6).

The icebreakers work together as a team. One icebreaker acts as the lead co-ordinator for Finland and a second one acts for Sweden. The lead co-ordinator instructs the other icebreakers and directs them where to operate. In particularly severe conditions where the ice stretches right through the Gulf of Bothnia, each country will nominate two lead co-ordinators with one covering the Southern waters and one the Northern waters.

4.6 The WinMOS project

The ice services today face many challenges; not least of these is to renew their fleets of icebreakers. The fundamental operations have not changed since the 1970's when many of the icebreakers first entered into service, but as we found these have not been fully evaluated. Today with climate change forecast to reduce the number of severe winters questions are being asked about the required investment of more than €1b.

This has led to efforts to understand better the future use of the icebreakers and for their design which is one goal of the project WinMOS, funded by the EC under the Trans-European Networks programme. WinMOS or Winter Motorways of the Seas is a two year project involving both Finnish and Swedish authorities as well as other Baltic states.

Task 1 of WinMOS includes an economic assessment of the use of the icebreakers where a model will be developed to help assess the impact of various parameters on the future needs. For instance the trends in shipping are such that new vessels are being designed to the EEDI (Energy Efficiency Design Index) which reduces weight and drag but also reduces the power available to the ship. This makes them less suitable to navigate in ice conditions and increases the need for icebreakers. Similarly, global trends are bringing more ships into icy waters where the captain has no experience of sailing under ice conditions. At the same time better icebreaker design and certainly the use of the satellite driven information system has made operations more efficient. A further trend is climate change where winters in the Baltic are becoming less severe.

These trends all affect the need and design for future icebreakers. Both Finland and Sweden must renew their fleets in the next 15 years and the WinMOS project and model will help improve the knowledge of the impact of the services and how they can be optimised / improved. One of the key parameters used by the authorities is their policy for charging for the services. We shall show the significant benefits that we estimate accrue from the provision of these services which are no doubt considered essential and strategic by all the communities which benefit. But politicians need to justify large, state investment decisions for which WinMOS should provide the arguments.

4.7 Operating charging Policy

The ships must accept the conditions of sailing in the icy waters once they pass Oland Island off the coast of Sweden. No ship is charged directly for any assistance given in ice, provided it has accepted the conditions to enter the Gulf of Finland or Gulf of Bothnia. Instead the cost of the ice services are fully covered by Fairway fees which apply when a ship enters a Finnish port.

Ships entering Finnish ports pay a “fairway Fee”; the fairway being the channel maintained at the entrance to the port and extending sometimes many kilometres into the open sea due to the shallow waters in some areas of the Baltic. The policy over the setting of fairways fees is interesting and has a strong influence over the ships serving the ports. There is strong discussion going on at the time of writing as to whether the fairway fee system is fair to all ships and to all ports since the southern ones need the ice-breaking services far less than those in the North. Industries served are requesting a reduction.

Nevertheless, the principle of equal sharing still applies and the fees are used not just for winter services but also for dredging the fairways and to maintain the marker buoys that delineate the channels.

The fee is paid for every transit whether in winter or summer. However, after 12 visits to a specific port, no further fees are due so the cost is essentially capped. The fee is calculated based on the ice-class of the ship such that ships with greater protection against the ice pay a lower fee than those with a lower ice class and hence lower resistance. These tend to be the ships which are lighter and more fuel efficient.

European and international regulations aimed at reducing emissions and pollution from ships have the effect of reducing the power available and making the ships lighter; exactly contrary to the needs of ships sailing through ice. The recent “Sulphur Directive” from the EU came into force in 2015 and has the effect of driving up fuel costs. Ship owners seek to use more efficient ships to then reduce the cost. The Finnish government has temporarily reduced the fairway fees so as to offset some of these additional costs. This in turn drives revenues down and puts further pressure on the cost-recovery model of the ice-breaking services.

So ship design and legislation is driving towards the need for more ice-breaking services. On the other hand, global warming is reducing the ice cover for an average winter and in the long term some predictions say that the Baltic will become ice-free in 2050. What should be the policy regarding the replacement of the icebreakers which are already long beyond their initial design lifetimes?

WinMOS hopes to answer this question by developing a model where the different parameters can be tested in scenarios. Unfortunately it will not be ready until the end of 2015 so will be too late to help with our study. If it existed, we could use it to construct the model distributions for ship transits which we shall discuss later in chapter 7. Nevertheless, it is certainly needed to understand how many icebreakers should be deployed under what ice conditions and with differing ship types, goods to be transports and transportation patterns.

Case Study of Winter Navigation in the Baltic

5 The Value Chain

5.1 Description of the Value Chain

The first key step in the process of getting to grips with the value brought about by the imagery, we have analysed a value chain deriving from the use of the EO products. For this case – Winter navigation in the Baltic - the value chain deriving from the use of EO services is shown in Figure 5-1 below. The steps in the value chain are characterised by the need for a different form of information which is shown along the bottom of the picture.

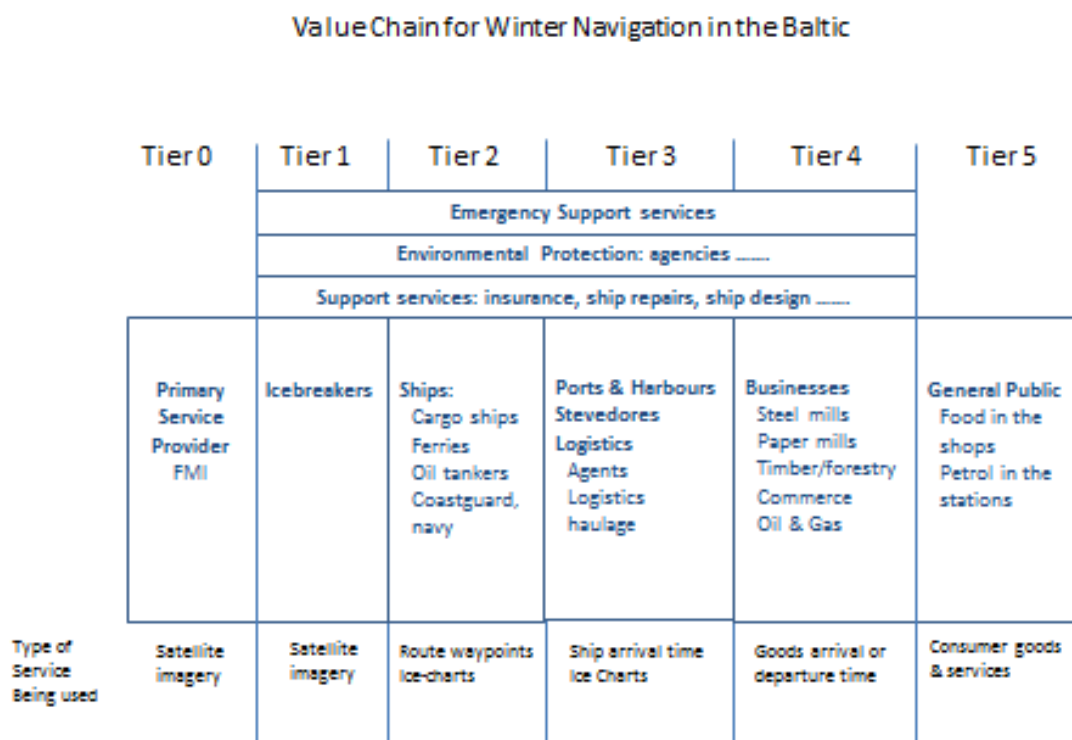


Figure 5-1: Value chain for “Winter Navigation in the Baltic”¹⁷

The value-chain has been divided into 6 tiers starting with the service provider and ending with the Finnish consumers relying on goods that have been transported through the ice. Let’s look in more detail:

- Tier 0: Primary Service Provider

¹⁷ Note that not all the elements of the value chain have been studied as time to do so was too limited. We have concentrated on those parts where most value is being created. A subsequent study could look at other elements of the value chain to develop a more complete picture.

Case Study of Winter Navigation in the Baltic

The core value chain flows through the centre of the picture starting with the Primary Service Provider, which is the Finnish Meteorological Institute (FMI). It is responsible for gathering the satellite images and for disseminating them to the users; and especially to the icebreakers through the IBNet system. The images received are resampled to 200m resolution to reduce the bandwidth of transmission. The FMI also produces ice charts throughout the winter months which are disseminated via the Internet and which are understood to be used by ships and ports. Ice charts provide a more complete picture of the ice situation including thickness and ice-feature information and are also more easily understood by the non-professional user e.g ship-owners, agents charterers and administrations.

- Tier 1: Icebreakers

Tier 1 is characterised by the imagery using by the icebreakers. The icebreakers take the images directly through IBNet and determine the best routing for the ships. They analyse the images on-board and assemble ships in convoys to lead them through the ice. Once a route is open, they will define a set of waypoints which the ships must follow if they are to receive assistance.

- Tier 2: Ship operators

Tier 2 is characterised by the routing information (waypoints) provided by the icebreakers and used by the vessels. Primarily merchant vessels are guided or directed by the icebreakers. The key factor for the ship is the time taken to travel to its destination and the amount of fuel used. The former depends on two factors; the first is the time a ship has to wait for assistance and the second is the time taken to sail through the ice. The latter depends on the sailing time which is considerably reduced by the use of the satellite imagery by the icebreakers.

Passenger ferries also benefit from the ice services but since they have more power than merchant vessels they can break through the ice under most conditions. Only exceptionally will assistance be required when conditions become really bad. If this occurs then ferries become a priority for assistance due to the larger number of people on board.

- Tier 3: Ports & harbours, stevedores and logistics

Tier 3 is characterised by the information on the time of arrival of the ships in the port. For the ports, the arrival time of the ship is the key piece of information for availability of dock-side and preparation of the stevedores and equipment for unloading and/or loading the ship. Uncertainty in the time of arrival increases costs through the need to have crew on stand-by together with disruptive costs to the logistics supply chain. Onward logistics i.e. haulage are also included at this point.

- Tier 4: Businesses

Tier 4 is characterised by the security of supply of goods in the factories and shops where the critical time is not the ship arrival/departure but that of the goods. The ports can act to a certain extent as a buffer where goods can be stored for some short periods so a delay of the ship arrival or departure may not translate directly into a cost to the factory. A variety of goods transit

Case Study of Winter Navigation in the Baltic

through the ports but the most critical are those for key industries such as timber/paper and cardboard, steel and oil products which are also needed to keep the local economy functioning.

- Tier 5: General public
At the end of the chain are consumers who are served by the shops and the petrol stations where excess delays can cause hardship.

In addition to the core chain, certain beneficiaries appear in various tiers of the chain as shown along the top of figure 5-1:

- Ship repair yards where damage is repaired after a collision
- Ship designers which use ice data to help establish design limits. Finland is the leading constructor of icebreakers and the same technology is used in cruise liners and other shipping.
- Insurance companies where premiums are affected by the reduced number of accidents.
- Emergency support services where ice conditions can affect their operations
- Environmental agencies and researchers where even local offices around the Finnish coast benefit from the ice charts and comparison with the actual conditions.

The 6 tiers in the value chain from the satellite image provider through to consumers are characterised by different information types. As we move down the value chain, the visibility of the impact of the satellite data becomes smaller even as the value of the economic activity for which it is relevant increases. Below, we present a simple model to explain this which shows the relative value of the satellite imagery with respect to the assessed economic benefit brought by the ice-breaking services on the various tiers.

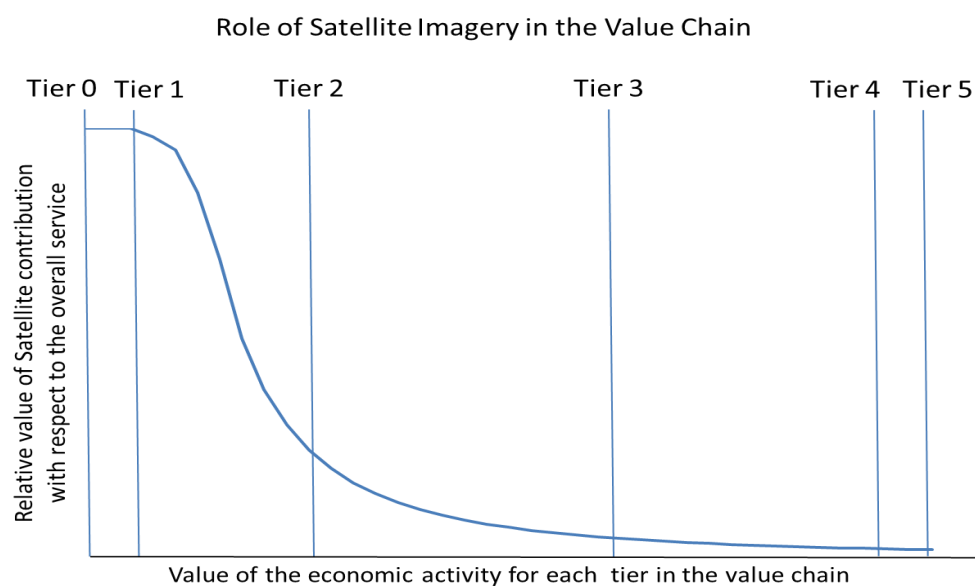


Figure 5-2: Model of the use and impact of satellite imagery

Case Study of Winter Navigation in the Baltic

We shall use this model to help assess the value of the satellite imagery as compared to the value of the ice services in chapter 8.

5.2 Tier 1: The Icebreakers

The icebreakers are of course the key to the service. Finland has developed a world-leading capability in their design and manufacture. In Finland the icebreakers are owned and operated by Arctia Shipping a company established in 2009 specifically for this purpose; in Sweden they are owned and operated by the Swedish Maritime Administration.

Icebreakers are generally characterised by the power available where smaller vessels are referred to as ice-tugs. The design of icebreakers has evolved significantly to improve efficiency although some of those operating today were built 50 years ago. Generally the life-time of an icebreaker is considered as being around 30 years and a major programme is underway in both Finland and Sweden to renew the fleet.

IB Reserves today and usage 1996-2012

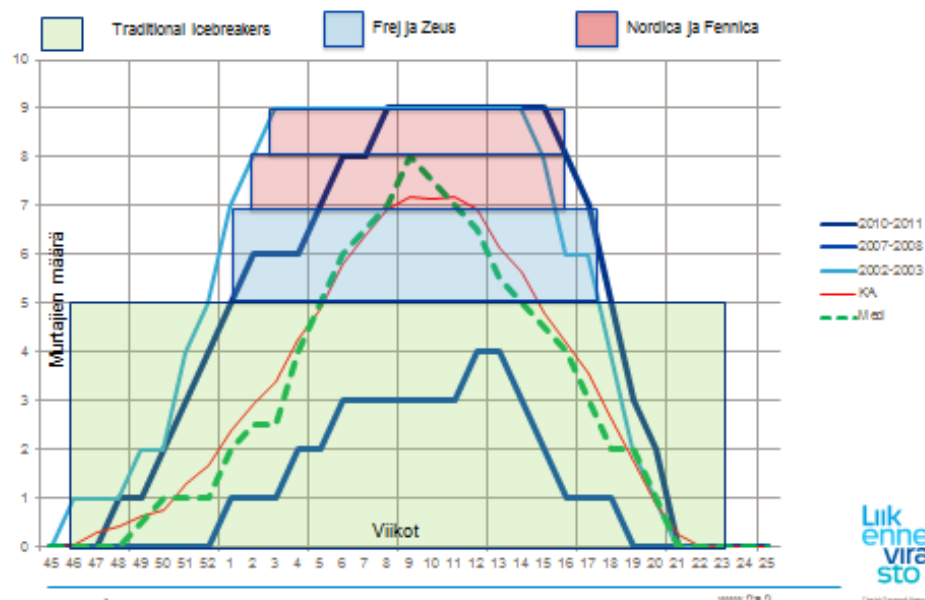


Figure 5-3: Number of Icebreakers used through certain winters¹⁸.

Figure 5-3 shows how the use of icebreakers varies through the winter season. 2002-2003 and 2010-2011 were hard winters where all possible resources were deployed whilst 2007-2008 was a mild winter where at the peak only 4 breakers were used.

¹⁸ Frej and Zeus are 2 ice tugs, Nordica and Fennica are 2 multi-purpose icebreakers.

Case Study of Winter Navigation in the Baltic

5.3 Tier 2: The Ships

On any one day, there are around 2000 ships sailing in Baltic waters. Not all are destined for Finnish or Swedish ports or have left them. Indeed many are bound for or leaving Russia where there is a strong flow of oil & gas tankers. We need to know how many are bound for or leaving Finland and how many of those are assisted by the icebreakers.

The annual BIM reports provide a lot of information on the ships assisted over the last 10 years¹⁹ but the figures are mixed between the various countries. An alternative source was provided to us by the Finnish Ministry of Transport and Communications, see **Erreur ! Source du renvoi introuvable.** Below, which shows the number of assistances to ships arriving at or departing from Finland each year in the different parts of the Baltic. Clearly the number is much higher when the winter is harder and the ice extent is greater and the season longer.

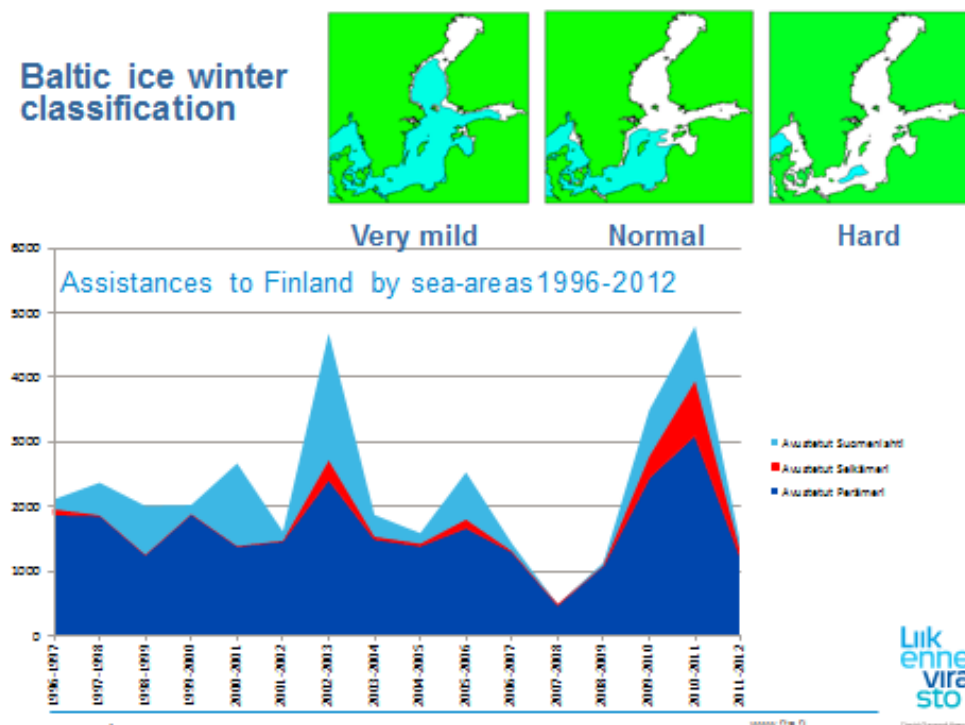


Figure 5-4: Numbers of ships assisted in Finnish waters.

We focus our analysis on freight transport as passenger ferries are far less affected. Generally they have adequate power to break through most ice conditions. Only, in extremes may need assistance but in this case the economic consequence is quite high as passenger ferries delayed under severe ice conditions

¹⁹ Baltic Sea Icebreaking Report: <http://portal.fma.fi/portal/page/portal/baltice>

Case Study of Winter Navigation in the Baltic

may need to cancel a round trip with the subsequent revenue loss. Nevertheless, given the infrequent occasions when this arises we have not included this effect in our analysis.

5.4 Tier 3: The Ports

Most of the ports are privately owned or they are owned by the local municipality (i.e. Tornio) or by the factories which they serve. As a result, most do not publish detailed figures concerning their revenues or expenses. Mostly the ports own the berths and the land facilities and are then leased out to other companies. The ports derive their revenues from berthing fees, from terminal fees for passengers and for the use of facilities in the port for goods.

The Table 5-1 below shows the major ports of Finland and the goods traffic going through them for 2014. The total traffic is 100mtonnes.

Port	Imports (tons)	Exports (tons)	Total (tons)
HaminaKotka	4401891	9036899	13438790
Hanko	1800846	1939284	3740130
Helsinki	5569842	5260284	10830126
Inkoo Shipping	910568	516597	1427165
Kaskinen	498953	467872	966825
Kemi	867102	1083886	1950988
Kokkola	1876579	6692386	8568965
Loviisa	195252	747413	942665
Naantali	4139799	2523817	6663616
Oulu	2005118	1440346	3445464
Pietarsaari	442954	528847	971801
Pori	2765435	1243991	4009426
Raahe	4376974	1032157	5409131
Rauma	1745247	3919902	5665149
Sköldvik	12515048	9916975	22432023
Tornio	1614230	1174182	2788412
Turku	1253242	1303043	2556285
Uusikaupunki	739763	1052693	1792456
Vaasa	1338496	241412	1579908
Listed total	49057339	50121986	99179325

Table 5-1: Traffic through the main ports in Finland

5.5 Tier 4: The Factories

The main industries in the North of Finland and in Sweden are timber, paper, ore and steel. In addition Neste Oil transports refined products into the area from refineries in the south of Finland. Outokumpu (in

Case Study of Winter Navigation in the Baltic

Tornio) and SSAP (in Raahе) are two of the major steel industry players in the region whilst Metsa Group is a large timber products company.

Factories which are working to just-in-time processes require their raw materials to arrive within a small time window and their finished goods need to be shipped in time to meet customer requirements. A significant delay in either will cause additional costs. We heard of some examples in our research:

- In the hard winter of 2010/11, a paper mill was forced to air freight rolls for news-print or lose the customer.
- A container ship delayed in one port may not be able to make a scheduled call at another port forcing containers to be transported by road.

There is a delay beyond which production is affected. These are the extreme points on the statistical distributions which have a significantly reduced probability of occurring when the icebreakers are operating. The risk may be quite low but the economic consequence is rather high.

5.6 Tier 5: The Citizens and Local Economy

The fact that the ports are kept open means that the local economy can develop much more than if the towns and regions were isolated for periods through the winter months. The transportation of goods, fuel and petrol, food and other essential supplies, and especially perishable supplies - would all be more difficult and costly without the icebreaker services – supported by the satellite imagery.

Hence each citizen is affected by the ice service provision through improved job prospects and the overall quality of life. The impact on jobs is primarily taken care of through our assessment of the factories and their links to the local economies. Hence the question here is more what value each individual would place on the knowledge that the basis infrastructure of transport, heating, healthcare and food are taken care of.

In reality, individual citizens will expect the government to supply this re-assurance and the “price” of this is reflected in total taxation (whether collected at national or local levels). But the mechanism by which the “price” is recovered does not matter the societal benefit is the same. Hence we can consider the price that each citizen could be prepared to place upon the improvement to the quality of life for them self and their family.

6 The use of Satellite Imagery

Satellite images play a key part in this process. Before they became available, the icebreakers used to have a helicopter on board. The helicopter would fly with the captain or a crew member who would photograph and mark up an ice chart by hand as they flew over the sea. This allowed them to detect ice features which are now identified through the satellite imagery.

The range of the helicopters was limited and the time taken to fly an area meant that it could change more quickly than the icebreakers could react. Of course in the worst weather conditions when the need for accurate up-to-date information is at its most critical, the helicopters could not fly at all, nor at night – and during the winter the nights are long over the Baltic!

Hence when SAR imagery became available from around 1991, after the launch of ERS-1, offering wide-area coverage, day and night and under all weather conditions it has changed the operations enormously. When talking to experts, in every case the imagery is cited as the single most valuable input to the ice services; more important than changing ship design, better communications etc.

The main advantage of SAR imagery is that it provides wide area, synoptic pictures to be taken of the ice conditions. Hence, instead of a limited number of local pictures of the ice conditions around the icebreakers and along certain coastal stretches, a single picture²⁰ could show the conditions over the whole of the Baltic. Through the IBNet system, each icebreaker has access to the image which has been pre-processed by FMI to meet the requirements of IBNet. Ice charts are also produced by FMI. These are not used by the icebreakers but are used by others (see later in this chapter).

But the single most important element in the service to keep the sea lanes, the “motorways of the sea” open are the icebreakers and these use the imagery directly rather than relying on an image interpreter located in a central control room. The reason is simple; by virtue of being in the middle of the ice, each icebreaker captain has important in-situ information on the conditions simply by looking over the bows. By combining this knowledge with the imagery, the captain is able to build up a better picture of conditions over the whole of the Baltic. This allows a more accurate picture to be built up than is possible from remote interpretation of the imagery.

With a synoptic view, the icebreakers can see which routes are the best to follow. For example, an image may show three different channels through the ice; but only the icebreaker captains’ know that two of these are old ones and which is the most recent. In general, the images are not needed when conditions are stable. The ice does not change too much and passing through does not pose too much of a problem; a single sea-lane may stay open for days. Unfortunately, this is an unusual state, and more usually winds

²⁰ In reality, this may not be a single picture but one built of several images. Imagery can be obtained as the satellite passes overhead which it does on average around 2 times every 3 days. There is a limit as to how far the satellite can “see” and hence the imagery seen by the icebreaker captain may be composed of several images stitched together. As new radars have been launched the size of the possible image has become greater along more frequent observations of a particular area of the Baltic.

Case Study of Winter Navigation in the Baltic

blow the ice into ridges and lanes which have been opened are closed within hours of a ship passing. Alternatively, the wind may blow the ice away from the shore opening a clear lane along the coasts of either Sweden or Finland.

Initially, ERS-1 was used to gather the images. ERS-1 was the first civilian satellite to carry a synthetic aperture radar (SAR). Launched by the European Space Agency in 1991, it quickly showed the utility of radar observations through a plethora of scientific research showing practical applications. ERS-1 was followed by ERS-2 launched in 1995 and then by Envisat in 2002. Envisat carried an advanced Synthetic Aperture Radar which offered wider coverage and a finer resolution.

Meanwhile, the Canadian Space Agency also launched a radar satellite, Radarsat-1 in 1995 followed by Radarsat-2 at the end of 2007. Both these satellites offered complementary imagery to that from the European satellites (they all operated in C-band) and gave re-assurance to the Finnish and Swedish maritime transport authorities that there was a good likelihood that imagery would be available throughout each winter period. An example of the imagery and ice chart is given in Figure 6-1

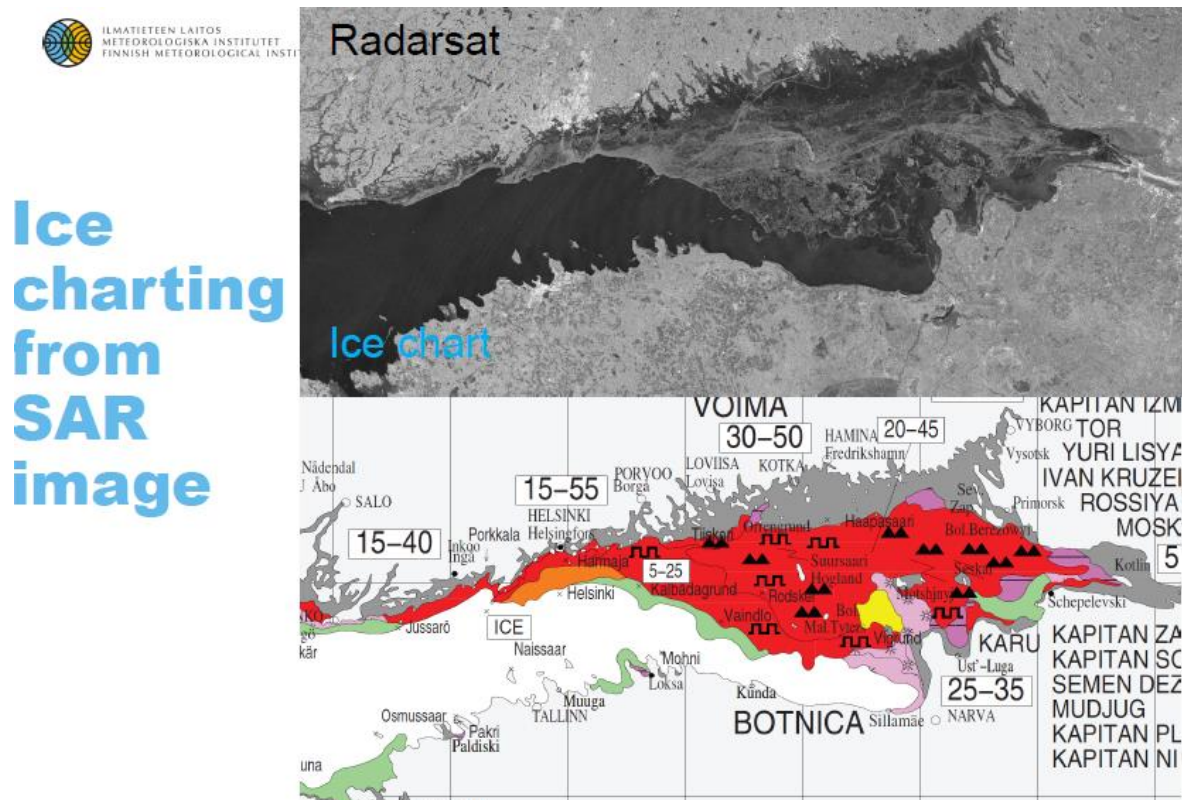


Figure 6-1 : SAR Image (Radarsat) and associated ice chart (FMI).

Case Study of Winter Navigation in the Baltic

In 2014, Sentinel 1A was launched being the first of the Sentinel satellites forming part of the European programme Copernicus. Sentinel 1B and C will follow and Copernicus offers sustainable and assured observation capacity for the foreseeable future (currently planned up to 2025 but anticipated to be renewed up to 2040 and beyond. Sentinel 1 also operates in C-band and hence provides comparable imagery to the previous satellites but with a much wider coverage and potential for more frequent observations.

Around 700 images are used throughout a winter season²¹ which are taken on average every two to three days from one satellite which becomes around twice every 3 days depending on the latitude. With multiple satellites in operation more frequent observations become possible. Ideally, an image would be available once per day and taken at the same time each day. An early morning image is most useful as it fits best into the planning cycle for the icebreakers. Visual / optical band images are also taken which, when the imaged area is clear of cloud, give complementary information on the ice. The images from Sentinel 2 which will shortly be available, promise very wide coverage at around 10 to 20m. It is anticipated that they will be analysed and if possible integrated into the system.

FMI also produce ice charts using the imagery coupled to the meteorological models and in-situ data. These are made available to users through their web-site. Table 6-1 below demonstrates the numbers of downloads since 2007. It should be noted of course that the actual (indirect) users will be much higher as the 'second use' – users downloading from the first users – are not covered in the numbers.²²

Year	Number of ice-chart downloads from FMI web-site
2007	261831
2008	130760
2009	316446
2010	1266098
2011	1196432
2012	1126125
2013	832218
2014	1529035
2015	453662

Table 6-1: Number of downloads of the ice charts per year

Unfortunately, we have not been able to obtain information on which are the organisations downloading these charts. Some will be the ports and harbours, some will be ships in the Baltic (or even outside), some will be local sailors or fishermen looking for the latest conditions.

²¹ Presentation of FMI ice services; Patrick Eriksson.

²² Stats provided by FMI ice services (Patrick Eriksson).

7 Linking Economics to Reality

In seeking to understand the various parameters which interact and which could characterise the winter navigation in the Baltic, we realised that a model could help develop the links between the various tiers. Our key challenge is to understand how the use of satellite imagery affects the supply chain during the winter conditions. To do this, we firstly need to understand the impact of the ice services i.e. the icebreakers used to keep ports open throughout the winter. To explain this we have developed a simple model based on the probability of the ship arriving at its destination at a specific time ie it compares the Estimated Time of Arrival (ETA) of the ship with the actual time of arrival.

Figure 7-1 shows the variation of the ship actual time of arrival under different sailing conditions. In Chart a is shown the probability of arrival at a certain time in ideal conditions. In ideal summer conditions, a ship leaving Rotterdam will take on average 5 (TBC) days to reach the port of Helsinki. The estimated time of arrival is known in advance and logistics operations can be planned based on this. If the ship is early or late this creates some additional cost as the logistics need to be updated.

In normal summer conditions, the arrival time (t_x) will be respected quite closely since any variation caused by favourable or adverse sailing conditions will be compensated for by the ship's captain sailing slower or faster accordingly (but of course this does have an impact on fuel used). This leads us to conclude that there is a fairly narrow distribution of arrival times – with variance v_x - around the nominal expected time of arrival. This is illustrated in Chart a.

Now in winter conditions (without the use of icebreakers), the sailing times change; sometimes quite dramatically. The delay in the time of arrival is directly related to the extra time taken to pass through the ice compared to normal, ice-free conditions. We model this in chart b showing both a much longer transit time and delayed “most-likely” arrival time (t_b) but also a much greater variation (v_b) in the arrival time. The transit time is longer as the vessels cannot maintain the same speed as in ideal conditions and indeed, could be delayed for long periods if the worst happens and they become stuck in the ice plus the risk of an extreme delay is also strongly increased (p_{ex}). The variation is caused by the varying ice-conditions affecting the sailing speed.

Chart c shows the situation with the use of icebreakers under normal winter conditions. With the use of icebreakers the transit time is reduced as is the variation in uncertainty and the probability of an extreme delay. The improvement depends on many factors including the disposition and use of the icebreakers and the severity of the ice conditions being the main ones. If an icebreaker is not available then the vessel may have to wait and waiting time is a critical measure of the overall ice system effectiveness.

Nevertheless, whilst all the parameters i.e. transit time, uncertainty of the ship arrival time, probability of an extreme delay, increase compared to summer conditions they are all reduced by the use of the icebreaker services. This leads to a distribution somewhat characterised in chart c of Figure 7-1.

Case Study of Winter Navigation in the Baltic

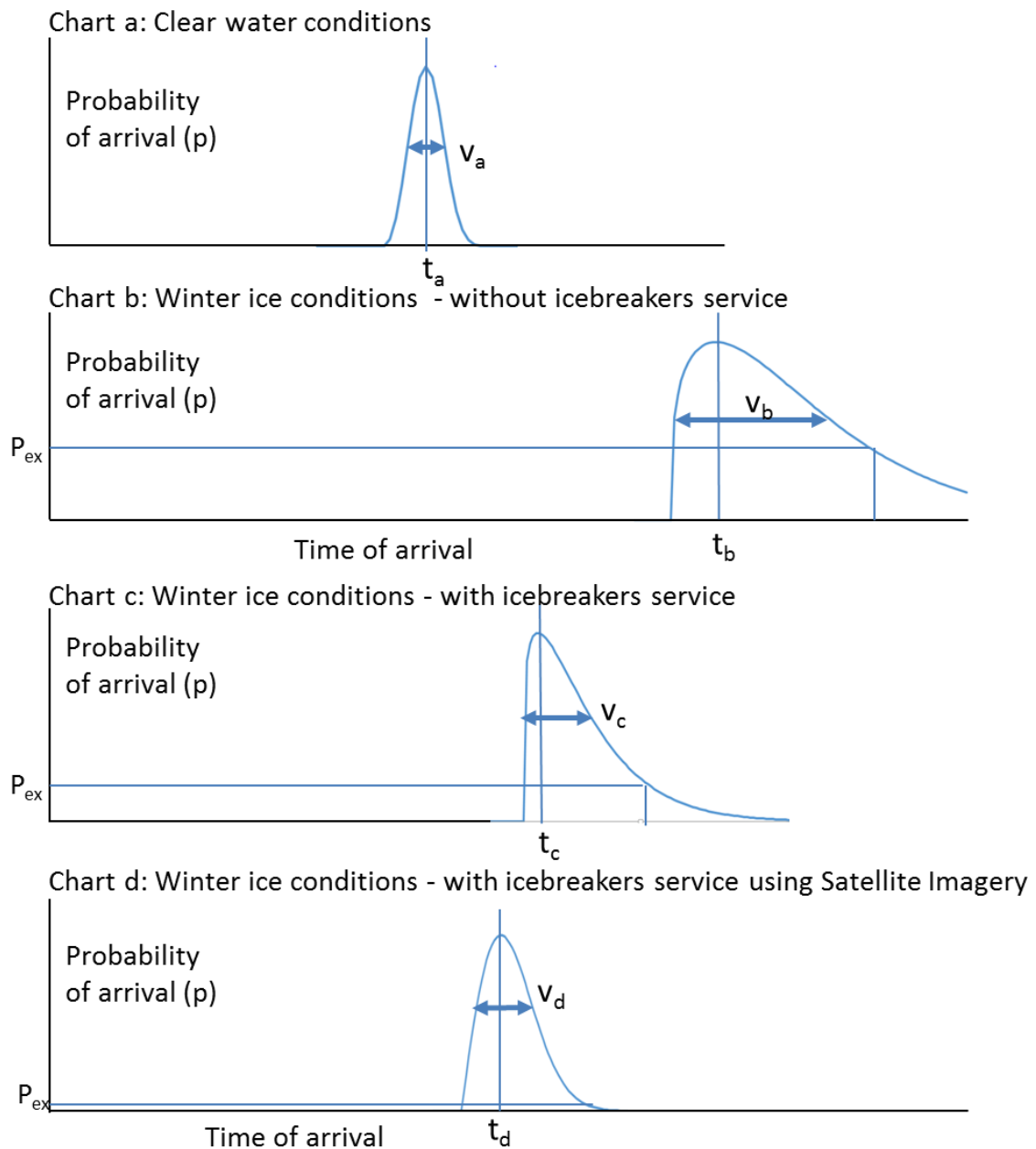


Figure 7-1: Distribution of ship arrival times.

It is necessary to note at this point that all these curves are theoretical without any numbers attached to them. We shall use some values in chapter 8 to calculate the economic benefit but these are assumptions. The WinMOS project mentioned in chapter 4 has the goal to develop a model of the services which, once completed, could be used to put numerical values to these charts and lead to a more precise calculation.

In chart d, we model the impact of using satellite imagery to inform the ice services. This has the effect of improving the ice service hence reducing the delays to ships, reducing the uncertainty in their time of

Case Study of Winter Navigation in the Baltic

arrival and reducing the probability of extreme events which cause disruption in factory production processes.

Hence from our distribution of the ship arrival times we can extract three parameters being the difference between navigating in winter ice conditions with or without the aid of icebreakers, which have different influences on the supply chain economics:

1. The reduction in likely time to transit the Baltic and reach the port of destination ($t_c - t_d$). This leads to operational savings for the icebreakers and the ships they are serving (tier 1 and tier 2).
2. The reduction in uncertainty of the vessel arrival time ($V_c - V_d$) so improving logistics operations around the ports (stevedoring, haulage etc) (tier 3).
3. The reduced likelihood of extreme delays ($P_{ex} \rightarrow P_0 \int [\text{chart } c - \text{chart } d]$), being the integral of the long tail effects, which would lead to production loss or customer penalties for the industries being served: (tier 4 and tier 5).

Whilst these models work, they do not tell the whole story. These theoretical curves are driven by yet another factor; the ice conditions. Throughout our discussion there was extreme reluctance to place any values on these parameters. We were surprised not to be able to get hold of existing statistical analysis and especially that experts were unable to say what the mean saving in transit time could be. One reason could be that the impact of the variation of ice conditions on sailing times and performance is so heavily affected that the variation is greater than the variations shown on the theoretical curves. Furthermore, the number of ice-breakers assisting many vessels is relatively few and hence small changes in sea conditions has huge domino-effects on the operational situation making it very difficult, even for the experts, to put values on the parameters which we should like to use.

Nevertheless we shall try to do so in the next chapter where we shall attempt to model the economic benefits and calculate some hard figures.

8 The Economic Assessment

8.1 The economic Impacts

The introduction of ice-breaking services has had a significant impact on the Finnish economy. Some measure of that can be gained from this report since we look at the overall benefit before trying to assess the portion which can be ascribed to the use of the satellite imagery. In this chapter we shall calculate the differing levels of benefits for both the overall ice services and the satellite imagery.

The use of the satellite imagery has resulted in a number of concrete benefits. The correlation between the use and the emergence of some benefits (cut in helicopter costs and decrease in ice-related damages) is quite strong and robustly backed up by statistics. For some other benefits (savings in fuel consumption and other operating costs) the correlation is also manifest, however, putting exact monetary values to it appears to be more challenging. For those, to some extent at least, we had to rely on proxies and assessments as well some assumptions (which are described in the text of course).

In the value chain (chapter 5) we identified 6 tiers from the service provider through to consumers. They are characterized by different types of activities and use different types of information, and we shall assess the benefits separately for each tier in turn, distinguishing the impact of ice services and then isolating the relative contribution of satellite imagery therein. Each of the tiers then leads to different forms of cost savings as described in the following sections. In each category, the impact of the satellite imagery is discussed and as we get further down the value chain and away from those elements which benefit directly from the imagery, so the benefits become more disbursed.

8.2 Tier 1: Icebreakers

The icebreakers are at the core of the provision of the ice services and are the most important element in the service provision. The use of satellite imagery reduces the cost of these services through:

- a. Reduced fuel consumption
- b. Abolishment of usage of helicopters stationed on-board

We assess these in turn.

- a. Costs savings due to reduced fuel consumption

As mentioned in Chapter 7, the usage of satellite imagery helps in reducing the likely time to transit the Baltic and reach the port of destination. This translates into reduced fuel consumption; which has been confirmed by all interviewees. From the Swedish side an overall average saving of 10%²³ has been suggested, which has been the basis of our calculations. For the period 2008 – 2011 the exact numbers on

²³ Source: Ulf Gullne, Swedish Maritime Administration

Case Study of Winter Navigation in the Baltic

the Finnish icebreakers' fuel consumption are available.²⁴ For the other years we have based our calculation on proxies indicating the severity of the winters (based on the yearly total number of weeks that the icebreakers were active and the maximum size of the ice coverage in km²)^{25 26}. Furthermore, as during the first years of the availability of the satellite imagery the frequency and quality still had to mature, we have phased in the benefits over a period of 4 years as of 2004, each year adding 25%, so that as of 2007 the (10%) savings are regarded to be fully phased in.

As Table 8-1 below demonstrates the estimated total fuel costs savings of the Finnish icebreakers resulting from the use of the satellite imagery (as of 2004 up to and including the 2014) amounts an overall sum of 6 million euro. The Swedes have reported less detailed figures on the amount of icebreakers' fuel costs per year, indicating a range rather than exact figures per year. However, based on the numbers of icebreakers active over the years, we would expect the Swedish icebreakers fuel consumption savings to be in a range 65 – 80% of the Finnish savings and we have taken a value of 75% in our calculations.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
Maximum ice coverage in 1000 KM2	153	178	211	139	49	55	244	309	179	177	100	
total # weeks icebreakers active in Baltic region					59	137	260	367	171	263	103	
Fuel costs Finnish icebreakers per year	5,9	6,9	8,2	5,4	1,6	3	10	12,5	5,1	8	3,1	69,7
Savings in Meuro	0,15	0,35	0,62	0,55	0,16	0,3	1	1,25	0,52	0,8	0,31	6,01

²⁴ BIM reports 2008, 2009, 2010, 2011

²⁵ BIM reports 2004 - 2014

²⁶ We have (1) related the authentic figures on the fuel costs (2007-2011) to the authentic figures on the number of weeks that the ice breakers active in winter time (2007-2014) (2) related the average amount of (1) to the authentic figures on the ice coverage in km² (2004 – 2007) (3) this resulted in a full range of authentic (2007- 2011) and assessed (2004 – 2007 and 2011 – 2014) figures of fuel consumption, allowing for calculating the savings, based on the assessment of 10% from the Finns and the Swedes).

Case Study of Winter Navigation in the Baltic

Table 8-1: overview fuel costs savings Finnish icebreakers in the period 2004 - 2014

Accordingly, we assess the total icebreakers fuel costs savings of Finland and Sweden to be in the range of €10.5m (Finland €6m and Sweden €4.5m) corresponding with an average of just under €1m p.a.²⁷

b. cost savings due to abolishment of usage of helicopters stationed on-board

In the 'old' days, icebreakers used to have a helicopter on deck which would occasionally fly out to observe the ice conditions and the locations of the ships that would (possibly) need assistance. Typically, the captain or a specialist crew member would be flown out, allowing him to do these inspections, after which he would return to the icebreaker and take his decisions based on his observations, other intelligence and, of course, his expertise in combining all these sources of information.

The availability of the satellite imagery and ice charts brought a radical change. No longer had people to be flown out: the radar data would allow for a much better synoptic view, allowing for overlooking the ice conditions of the entire Baltic region. Not only did this result in better informed decision making, it also allowed for a significant cost cut, as the helicopters were no longer needed.

The costs of the helicopters – and accordingly the savings made – are linked to the national set up. The Swedish Maritime Administration never owned any helicopters. It had entered into a multi-year contract with a helicopter company that in the summertime used the helicopters for forest spraying. During winter time it had three helicopters at its disposal on board the icebreakers and the possibility to bring in a 4th one in case of severe winters. Under this deal it paid a fixed sum for having the helicopters and pilots onboard. In addition to that it paid for the variable costs like fuel, flight hours and landing fees, as well as the flight hour cost, which was based on the basis of the historical maintenance costs. In the year 2003 – a severe winter where the full helicopter capacity was used – the total costs amounted to 4,6 Million Swedish Kronas which today (2015) would equal about 550.000 euro. Roughly these costs could be divided into 75% fixed cost and 25% variable costs.²⁸ Relying on the figures of the number of icebreakers in operation during the years 2008-2014²⁹, the average cost savings per year amount to around 546.000 euro (price level 2015), accumulating to a total saving over the period 2004-2015 of €6m.

Likewise, The Finns never owned any helicopters. However, they have less detailed figures on the cost structures, and assess the average yearly all-inclusive rental costs at €750k per year (price level 2015) for servicing their fleet of icebreakers.³⁰ This leads up to a total saving of €8.25m.

²⁷ When assessing the future benefits, obviously the phasing in period (2004 – 2007) should be left out of the equation. In fact, the benefit is likely to increase as the quality and in particular the frequency of provision will increase significantly due to the launch of the Sentinels. Starting in 2008, obviously, the amount will be higher.

²⁸ Source: Johny Lindvall, Swedish Maritime Administration, 2 and 4 June 2015

²⁹ BIM Reports of those years

³⁰ Source: Markus Karjalainen Arctic Shipping, 5 June 2015

Case Study of Winter Navigation in the Baltic

Accordingly, the costs savings from no longer using the helicopters by both the Swedish and Finnish icebreakers over the last 11 years amount to approximately €14.26m³¹ or an average of €1.3m p.a.

8.3 Tier 2: Ships

Obviously, not only the icebreakers benefit from the availability of the satellite imagery: the ships serviced – the next part of the value chain – accumulate significant gains from the more effective services of the icebreakers. Tier 2 covers the ships of all types being assisted by the icebreakers to reach their port of destination. As mentioned in chapter 7, this results in cost savings from the ships and icebreakers spending less time to complete their journey. These gains can be divided into less fuel consumption, a decrease in damages, lower insurance costs and other savings in operational costs.

- a. Savings due to less fuel consumption by ships serviced by the icebreakers
- b. Savings in operational costs due to reduced transit and waiting time
- c. Savings due to a decrease in ice related damages (repair costs and insurance costs)

- a. Savings due to less fuel consumption by ships serviced by the icebreakers

An important benefit resulting from the use of the imagery is the savings in fuel costs of the ships serviced. As the icebreakers can operate more effectively, the overall sailing time is reduced significantly, as both the waiting time for the services of the icebreakers as well as the transit time through the ice diminish. Obviously, one could argue that also the ships navigating through the ice not serviced should be taken into the equation, as the effectiveness of the icebreakers will also have an impact thereon, for instance as a result of advises from the ice breakers on the ideal speed to be developed by the vessels, given the conditions in the channels created. To remain on the safe side, we have decided to leave those out.

Although the BIM reports hold some statistics on the average waiting time, correlating them to the ice conditions and the specific region in the Baltics is practically impossible. With the support of Trafi and VTT we have tried to dig out numbers from the IBNet data for 2014, but the observations are insufficient, in particular as the Expected Time of Arrival (ETA) which is logged in manually by the captain of the ship serviced is not updated and there is no link between the ETA in the IBNet system and the Actual Time of Arrival (ATA) in the port registration system. Furthermore, if updated, the IBNet ETA is deleted, making comparisons and aggregations impossible.

Nevertheless, all interviewees acknowledge the time savings and two of them were willing to put a number to it: Ulf Gullne (Swedish Maritime Administration) assesses the fall in transit time to be around an average of 3 hours and the average waiting time to have dropped by (at least) around 2 hours, whereas Markus Karjalainen (Arctia Shipping) estimated the average time to have dropped by around 8

³¹ Costs savings in other countries operating icebreakers in the Baltics (like Estonia, Latvia, jointly having 3 icebreakers) have been left out of the equation, as reliable figures are missing.

Case Study of Winter Navigation in the Baltic

hours. Based on these numbers an assessment can be made of the fuel costs saved (for the two scenario's (5 respectively 8 hours).

We can put a fairly exact value to the savings, based on the reports on shipping costs maintained by Moore Stephens Accountants, which is *the* authority in this field³². The average daily fuel costs of the ships that will typically sail the Baltics in the winter over the period 2004 – 2014, enables us to calculate the savings. Again, as we did with the fuel savings of the icebreakers, we have phased in the gains as of 2004 over a 4 year period, so that as of 2007 the gains are attributed to 100% to the availability of the satellite imagery. Table 8-2 below captures the relevant figures.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
# ships assisted in winter by Finnish icebreakers	1900	1600	2500	1400	500	1100	3500	4800	1300	2600	650	
fuel costs per day average (all ships)	7493	7785	8576	9617	11011	10616	10824	11053	10741	10699	11011	
transit time minus 3 hours												
Normal fuel consumption in euro (half speed of average speed in open sea)	3746	3892	4288	4808	5505	5308	5412	5526	5370	5349	5505	
fuel savings per transit per ship on the basis of 3 hours gained in euro	468	486	536	601	688	663	676	690	671	668	688	
<i>total fuel costs savings due to lower transit time * 1000 euro</i>	222	389	1005	841	344	730	2368	3316	873	174	447	12275
waiting time minus 2 hours												
normal fuel consumption in euro (5% of average speed in open sea)	374	389	428	480	550	530	541	552	537	534	550	
fuel savings per ship on the basis of 2 hours waiting time gained in euro	31	32	35	40	45	44	45	46	44	44	45	
<i>total fuel costs savings due to lower transit time * 1000 euro</i>	15	26	67	56	23	49	158	221	58	116	30	15
Total fuel costs savings * 1000 euro	237	415	1072	898	367	779	2526	3537	931	1855	477	13093

Table 8-2: Assisted Ships fuel savings.

³² OpCosts 2000 - 2014, Moore Stephens, <https://opcost.moorestephens.org/>

Case Study of Winter Navigation in the Baltic

For the waiting time, we have worked on the assumption that the captain will either throw out the anchor or just hover around, both at very low fuel consumption. To be on the safe side we have taken 5% of the average fuel costs when navigating in open sea (without ice). For the transit time, we taken 50% of the average fuel costs when navigating in open sea (without ice), as this is the ship's 'safe speed' when navigating in ice.

Accordingly, we assess the fuel costs savings (resulting from the use of satellite imagery in the period 2004 up to and including 2014) of the ships serviced by the Finnish icebreakers to amount to:

- **Scenario that per ship journey 5 hours are gained: €13.09m and €1.19m p.a. Applying the rule of thumb that the savings of Sweden will be around 75% of those of Finland, these can be set at €9.8m and €0.89m p.a., adding up to a total of €22.89m or €2.08m p.a.³³**
- **Scenario that per ship journey 8 hours are gained: €20.95m and €1.58m p.a. Applying the rule of thumb that the savings of Sweden will be around 75% of those of Finland, these can be set at €15.71m and €1.43m p.a., adding up to a total of €36.66m or €3.33m p.a.**

b. Savings in operational costs due to reduced transit and waiting time

Next to a reduction in fuel costs, obviously the reduced journey time also has a positive impact on the total operational costs³⁴ of the ships as paid for by the customer (charter time). Also, ships which have asked to be assisted will often be asked to wait for the icebreaker to be able to help them through the ice. This has a cost since the ship is not available for use elsewhere under other charters. It is our understanding that the owner of the goods charters the ship and hence the risk of delays falls upon the charterer but, irrespective of where the actual cost falls, any loss of time by the ship in arriving at its' destination has a real value that falls somewhere – just most likely not on the ship owner. Conversely, any saving in that time has a real value.

We have seen in subparagraph a above that the average journey time has fallen by around 5 to 8 hours – the two assessments – since 2003 when the satellite imagery was introduced. Whilst there are no doubt other effects than the satellite imagery (for example better communications) it would seem that it has made a very significant contribution to the overall efficiency of operating the icebreakers. To be conservative we take 80% of the economic benefit as being due to the use of satellite imagery.

The average cost of charter for a large vessel lies between €20k and €30k for large tankers. Hidden in these averages are the super-tankers and super-container ships which are mostly not being used in the icy waters (as they are optimised for operation in milder climates). Hence we shall use a conservative

³³ When assessing the future benefits, obviously the phasing in period (2004 – 2007) should be left out of the equation. In fact, the benefit is likely to increase as the quality and in particular the frequency of provision will increase significantly due to the launch of the Sentinels.

³⁴ In maritime economics a distinction is made between (a) fuel costs (b) other operational costs and (c) depreciation costs, see: M. Pocuca: *Methodology of Day-To-Day Ship Costs Assessment*, Promet-Traffic&Transportation, Vol. 18, 2006, No. 5, 337-345

Case Study of Winter Navigation in the Baltic

charter cost for a ship of €20k per day. However, this includes the fuel costs which are 50% of the daily cost for a vessel³⁵ (other operational costs are 28% and depreciation 22%) the gains for which have already been calculated. Hence the daily cost is taken at €10k.

From the numbers underpinning Table 8-2, the average number of ships being assisted in Finnish waters is around 2000 each year. Using this figure for ships assisted, the time saved as between 5 hours and 8 hours, the daily operating cost of €10k and 80% attributable to the satellite imagery, yields:

- **Scenario that per ship journey 5 hours are gained and that 2000 ships benefit from assistance: annual saving to customers in Finland of €3.34m. For Sweden we shall assume 75% of the figure for Finland i.e. €2.5m giving a total of €5.84m as the total economic benefit.**
- **Scenario that per ship journey 8 hours are gained and that 2000 ships benefit: annual saving to customers in Finland of €5.38m. For Sweden we shall assume 75% of the figure for Finland i.e. €4.04m giving a total of €9.42m as the total economic benefit.**

c. Savings due to a decrease in ice related damages (repair costs and insurance costs)

(i) Decrease in ice related damages and subsequent repair costs

There appears to be a strong correlation between the increased use of the satellite imagery as of 2004 and the decrease in ice related damages incurred by the ships serviced. Unfortunately, there is a gap in the longitudinal data on this matter, however, the interviewees also strongly suggested the existence of this relationship, which is confirmed by scientific research done by one of the key authorities in this field, Professor Pentti Kujala, who submits: *“One key aspect on knowing the sea ice conditions, is the opportunity to better plan the navigational pattern of a ship. This plan also serves to anticipate the possible effect of ice on ship design and performance, and also to establish in advance the necessary propulsion and the needed characteristics for manoeuvring the ship. Thus, having monitored and reported the daily sea ice conditions, potentially to enable linking those conditions with the coordinates reported in accidents during winter ice navigation³⁶.”*

Measurements before the usage of the imagery started (before 2004)

³⁵ OpCosts 2000 - 2014, Moore Stephens, <https://opcost.moorestephens.org/>

³⁶ Source: Valdez Banda, O.A., F. Goerlandt, J. Montewka & P. Kujala (2013), Winter navigation in the Baltic Sea: an analysis of accidents occurred during winters 2002-2003 & 2009-2013. In: Safety and Reliability: Methodology and Applications, pp. 83-92. (p.85)
<https://books.google.nl/books?id=KOqsBAAAQBAJ&pg=PA83&lpg=PA83&dq=Accidents+and+incidents+in+sea+ice+baltic+sea&source=bl&ots=GzNOGobsEW&sig=yBbUO0CRz1mJOXUKlydLfWly0H8&hl=en&sa=X&ei=0dZuVdiFBMassAHmCw&ved=0CDMQ6AEwAw#v=onepage&q&f=false>

Case Study of Winter Navigation in the Baltic

The first statistics on this matter come from the report *Damage statistics of ice-strengthened ships in the Baltic Sea 1984-1987*³⁷ describing and analysing the ice damage to a sample of Finnish ships navigating in the Baltic Sea during the winters 1984-1987. Table 8-3 below captures the main figures.

# of ships in sample per construction type	Longitudinal			Transverse			Total		
	10			51			61		
Ice class of the ship ³⁸	1AS	1A	1C	1AS	1A	1C	1AS	1A	1C
	8	2	0	23	26	2	31	28	2
# of damaged ships	9			6	14	0	29		
% of ships damaged	90.0%			26.0%	54.0%	0.0%	47.5%		

Table 8-3: Ice related damages incurred by a sample of Finnish ships for the years 1984-1987.

As table 8-3 above demonstrates, almost half of the ships included in the sample were damaged. Unfortunately, the statistics do not link to the total number of Finnish ships that were navigating through the ice in that period, making it hard to relate the sample to the population.³⁹ Furthermore, account should be taken of the severity of the winters of 1985, 1986 and 1987 - only the winter of 1984 was an average winter – which may have caused a rise in damages.

The significant numbers of damages in the pre-satellite era is confirmed by Swedish research on this matter from 2003, stating that “the total number of different types of incidents included in the statistics of ice damages was about 100, and the total number of ships that visited Finnish ports was about 1000. This means that approximately 10 % of the ships had some sort of ice-related damage or incident during the winter of 2003. The total number of ship visits in Finnish ports was about 10 000. This means that during 1

³⁷ Source: Kujala, P. (1991), Damage statistics of ice-strengthened ships in the Baltic Sea 1984-1987. Helsinki University of Technology, research report no. 50.

http://www.trafi.fi/filebank/a/1352716465/2c77653e6c15301e82555185992ed8a0/10728-No_50_Damage_statistics_of_ice-strengthened_ships_in_the.pdf

³⁸ in order to set limits and designate adequate assistance, the Finish-Swedish winter navigating system has specific 'ice class rules' for the requirements of structural strength and engine output for vessels to be included within a Finnish/Swedish ice class. The system also determines the minimum ice class and that weight permitted in a certain area for icebreaker assistance. See:

http://www.trafi.fi/filebank/a/1328276514/fd8f09505d63024b9eec2167f8af0ea1/9136-Guidelines_-_20_December_2011_-_Final.pdf

³⁹ This being said, the report acknowledges the fair representation of the sample: “the sample taken is regarded to be representative for the ice-strengthened tonnage navigating in the Baltic Sea”. Kujala, P. (1991), Damage statistics of ice-strengthened ships in the Baltic Sea 1984-1987. Helsinki University of Technology, research report no. 50., page 3. http://www.trafi.fi/filebank/a/1352716465/2c77653e6c15301e82555185992ed8a0/10728-No_50_Damage_statistics_of_ice-strengthened_ships_in_the.pdf

Case Study of Winter Navigation in the Baltic

% of the voyages some kind of ice damage occurred". Keeping in mind that the percentage of the 1984-1987 report – 47.5% of the ships were damaged – cover a period of 4 years, the 10% does not seem to be wide off the mark⁴⁰.

Measurements after the usage of the imagery (as of 2004)

Over this period we have more longitudinal data, both from the statistics kept by the Finnish Transport Safety Agency (Trafi) as well as the BIM Reports⁴¹ and statistics are gathered in the report *Winter navigation in the Baltic Sea: an analysis of accidents occurred during winters 2002-2003 & 2009-2013*⁴². As demonstrated we see a strong fall in the number of damages as of 2003. The variance of the numbers nicely correlate with the severity of the winters (measured in terms of maximum ice extent in km²).

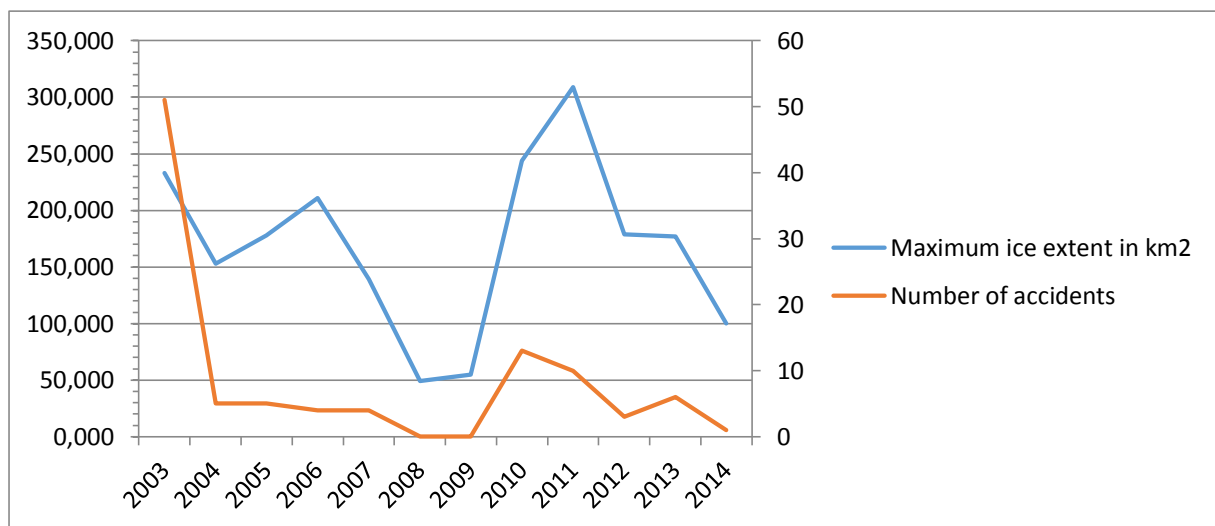


Figure 8-1: Maximum ice extent and number of accidents in the Baltic Sea for 2003-2014⁴³.

Clearly, there appears to be a significant reversal looking at the absolute numbers of accidents when comparing the period before the use of satellite imagery kicked in and the period thereafter. This also applies when taking a height of the number of square kilometre of maximum ice coverage over the years. Put differently: the reversal cannot be explained by the decreasing amount of ice. Accordingly, this

⁴⁰ Obviously, this is assessment 'ceteris paribus': likely the development in technology has also contributed to a decrease in damages. However, the steep drop we can see here can most certainly only partially be ascribed to a technological changes.

⁴¹ See reports listed here: <http://portal.liikennevirasto.fi/sivu/www/baltice>

⁴² Source: Valdez Banda, O.A., F. Goerlandt, J. Montewka & P. Kujala (2013), Winter navigation in the Baltic Sea: an analysis of accidents occurred during winters 2002-2003 & 2009-2013. In: Safety and Reliability: Methodology and Applications, pp. 83–92.
<https://books.google.nl/books?id=KOqsBAAAQBAJ&pg=PA83&lpg=PA83&dq=Accidents+and+incidents+in+sea+ice+baltic+sea&source=bl&ots=GzNOGobsEW&sig=yBbUO0CRz1mJOXUKlydLfWly0H8&hl=en&sa=X&ei=0dZuVdiFBMassAHmCw&ved=0CDMQ6AEwAw#v=onepage&q&f=false>

⁴³ Finnish Transport Safety Agency statistics, provided by Esa Pasanen (TRAFI), 8 June 2015

Case Study of Winter Navigation in the Baltic

decrease is likely to be explained, to a large extent, by improved icebreaker services due to the use of satellite imagery after 2003.

(ii) Decrease in insurance costs

To assess the monetary value of the decrease of the damages we wish to look at insurance premiums as a measure. Obviously, the knife cuts at both ends: as the number of accidents has fallen dramatically, leading to concrete savings in terms of lower repair costs, also the insurance costs have gone down.

Insurance costs are normally divided into P&I insurance costs and other insurance costs. P&I insurance provides cover to ship owners, operators, and charterers for third-party liabilities encountered in the commercial operation of entered vessels. It is distinguished from ordinary marine insurance covering the vessel's hull and machinery insurance and alike.

Longitudinal statistics on ships' operating costs acknowledge that the insurance remain at a stable level of around 11% of the daily operating costs of a vessel⁴⁴. However, the whilst we are told that rates for the shipping in the Baltic region have been decreasing, we have been unable to get any figures from the insurance companies which we have contacted..

8.4 Tier 3: Ports and logistics

As we move further down the value chain, the impact of the use of the satellite imagery becomes more indirect and diffuse even if the total economic impact may be greater (see Figure 9-3above). Hence we shall attempt to look at parameters which relate to the savings to costs of operations around the ports and harbours.

In this category, the critical information is the arrival time of the ship in the port and more importantly the uncertainty in this time. The ETA changes as the vessel follows its route and we are interested only in the part where it is sailing through ice.

Hence, the focus is on savings which result from a reduction in the uncertainty of time of arrival for the ship. The main beneficiaries are the ports and associated logistics operations which can plan better use of resources and avoid waste. We consider that the benefits arrive in 3 areas:

- a. Port savings
- b. Stevedores savings
- c. Logistics savings

⁴⁴ Average of the yearly numbers provided in OpCosts 2000 - 2014, Moore Stephens, <https://opcost.moorestephens.org/>

Case Study of Winter Navigation in the Baltic

Supposing that the images were not available, what would be the consequences? Ships would take longer to arrive and berth so reducing the numbers which could be serviced each year. Consequently there are less ships arriving over the winter season and less goods which can be carried. Each reduces the revenue to the port and the goods which can be transported. What is the impact?

a. Port savings

We understand that 25 ports are able to operate throughout the winter as a result of icebreaking operations most of which were listed in section 5.3. We have been able to gather the financial figures for two of the ports; Kemi (1.9m tons of goods and annual turnover €6.6m)⁴⁵ and Helsinki (10.8m tons of goods and annual turnover €90m)⁴⁶. Helsinki also has a large passenger traffic of around 10m per annum. The Helsinki price-list for goods gives a fee of around €3 per tonne with some variation for the type of good (bulk/container/timber etc). Similar charges can be found for other ports. Often a separate berthing fee will be charged for the vessel which is also tonnage dependent.

Taking an average figure of €3 per ton of goods would give a total port revenue spread over all Finnish ports of around €300m per annum; based on the total goods being shipped of 100m tonnes per annum⁴⁷. How much of this depends on the ice breaking services? The length of ice season for each port varies and also varies from year to year but if there were no ice-breaking services then the ports would be closed for several weeks / months depending on their location; in which case the traffic and revenues would fall to zero.

In Table 8-4, we show the calculation of revenues which would be lost if the operating ports were closed in the absence of ice services. The loss is calculated by taking the number of days when the ice services applied to the region in which the port is located. We have only included them when ice assistance was requested by a port (from the BIM reports) even though in all likelihood ships arriving at the ports were themselves assisted earlier in their voyage.

The financial loss is calculated from €3 per tonne for the freight handled by the port during the season when ice regulations applied (ie percentage of days' x total freight passing through x €3). The total is then €50.8m for 2014.

⁴⁵ Port of Kemi Annual Report 2012: <http://www.keminsatama.fi/en/port-of-kemi/annual-report.html>

⁴⁶ Port of Helsinki Annual Report 2014: http://www.portofhelsinki.fi/port_of_helsinki/publications

⁴⁷ Finnish Transport Agency port statistics: <http://www.finnports.com/eng/statistics/?stats=yearly&T=8&year=2014>

Case Study of Winter Navigation in the Baltic

Port	Imports (tons) in 2014	Exports (tons) in 2014	Total (tons) in 2014	Area	Region	Number of days when icebreaker assistance needed	Total loss if no icebreakers in 2014 (€k)
Turku	1253242	1303043	2556285	Archipelago Sea	<i>Varsinais-Suomi</i>		
Kemi	867102	1083886	1950988	Bothnian Bay	Lapland	145	2325
Kokkola	1876579	6692386	8568965	Bothnian Bay	Central Ostrobothnia	145	10212
Oulu	2005118	1440346	3445464	Bothnian Bay	Ostrobothnia	145	4106
Pietarsaari	442954	528847	971801	Bothnian Bay	Northern Ostrobothnia	145	1158
Raahe	4376974	1032157	5409131	Bothnian Bay	Northern Ostrobothnia	145	6446
Tornio	1614230	1174182	2788412	Bothnian Bay	Lapland	145	3323
Kaskinen	498953	467872	966825	Gulf of Bothnia	Ostrobothnia	36	286
Pori	2765435	1243991	4009426	Gulf of Bothnia	Satakunta		
Rauma	1745247	3919902	5665149	Gulf of Bothnia	Satakunta		
Uusikaupunki	739763	1052693	1792456	Gulf of Bothnia	<i>Varsinais-Suomi</i>	36	530
Vaasa	1338496	241412	1579908	Gulf of Bothnia	Ostrobothnia	36	467
HaminaKotka	4401891	9036899	13438790	Gulf of Finland	Kymenlaakso	127	14027
Hanko	1800846	1939284	3740130	Gulf of Finland	Uusimaa		
Helsinki	5569842	5260284	10830126	Gulf of Finland	Uusimaa		
Inkoo Shipping	910568	516597	1427165	Gulf of Finland	Uusimaa		
Loviisa	195252	747413	942665	Gulf of Finland	Uusimaa	127	983
Naantali	4139799	2523817	6663616	Gulf of Finland	<i>Varsinais-Suomi</i>	127	6955
Sköldvik (Kilpilahti)	12515048	9916975	22432023	Gulf of Finland	<i>Varsinais-Suomi</i>		
Total loss							50823

Table 8-4: Potential loss of revenue by the ports in 2014 in the absence of icebreaking services.

Since the number of days when the ice regulations apply and assistance may be required differs for each year, the methodology described in Table 8-4 is used to calculate the potential loss for each of the previous years. The result is shown in Table 8-5 where the loss in 2014 is seen to be less than in many of the previous years.

Case Study of Winter Navigation in the Baltic

	2014	2013	2012	2011	2010	2009	2008	2007
Total loss for the Bothnian Bay (€m)	28,1	28,4	19,7	33,4	29,6	20,6	24,8	23,1
Total loss for the Gulf of Bothnia (€m)	0,20	5,9	7,5	19	16,6	9,3	12,2	13,3
Total loss for the Gulf of Finland (€m)	22,5	53,9	4,8	82	59,2	14,8	40,7	28,9
Total loss (€m)	50,8	88,2	32	134,4	105,4	44,7	77,7	65,3

Table 8-5: Total potential port revenue loss over last 8 years.

If we take an average over these years, we see a potential loss of port revenue of €80.4m which we shall now take as being the value of the icebreaking services. In reality, this is probably conservative since,

1. Not all the ports are included in the calculation even though they almost certainly were all dependent on the service
2. as we explained earlier, many of the businesses shipping goods would probably not exist if there were no ice services.

The calculation of these benefits is based on the ice services keeping the ports open. This can be done without the use of satellite imagery which plays a role in improving the services being offered. Most particularly, as we identified in our model in chapter 7, the improvement is manifest in a reduced uncertainty of the arrival time of the ships.

In the time we have had, we have not been able to ascribe any firm numbers to this improvement. Since the introduction of the use of satellite imagery, we understand that the average ship waiting time has been reduced by between 4 and 8 hours and the sailing time by around 3 hours. Hence the uncertainty is most certainly also reduced by a few hours which translates into savings in the use of port facilities. There will be a direct but not 1:1 relationship and not necessarily a linear relationship.

How much of the overall economic benefit can we ascribe to the use of satellite data? We are told that it is the single most important input into the ice services hence it cannot be negligible and it clearly plays an important role in reducing the uncertainty in arrival times. Hence we consider that it should be at least 1% and could be as high as 5% of the benefits due to ice services. On this basis, this leads to an **annual benefit due to use of satellite imagery of between €0.8m and €4m for the ports in Finland.**

b. Stevedoring services

But the port operation is not the whole story. Stevedoring and logistics are handled separately from the port operations in Finland. Dedicated companies provide stevedoring services and the

Case Study of Winter Navigation in the Baltic

logistics/transportation companies are separate again. We were told that it needs around 5 Stevedores to unload or load a ship on average. Better certainty in arrival or departure times leads to less time with men and equipment on standby awaiting the vessel. There is also an availability cost since the berth is either vacant for longer than expected or is occupied for longer than planned reducing the throughput of goods.

In general, in the absence of particular factors, the benefits of an action distribute themselves evenly between interested parties. Let us take this as the basis and assume that the same scale of benefit accrues to these services as it does to the ports ie €0.8m to €4m of benefits annually arising from the use of satellite imagery.

c. Logistics services

If we make the same assumption for the logistics ie savings of haulage and lorry costs, then based on these albeit limited but reasonably conservative assumptions, we can estimate an annual economic benefit of the ice-breaking services to the logistics part of the value chain also of €0.8m to €4m.

For simplicity, we shall assume the same ratio of economic benefits are felt in Sweden as was taken earlier for the ship fuel savings ie .75%. **This leads to a total economic benefit of €4.2m to €21m (€2.4m / €12m in Finland and €1.8m / €9m in Sweden).**

Comparison Metric

As a comparison, in a separate interview, we learned that the port of Rotterdam consider that if they were to know the precise arrival time of a vessel, they could cut operating costs by around €80k. Rotterdam is a much busier port and some of the parameters which make up this potential saving are not relevant in the ice case in the Baltic. Nevertheless it gives us a scale to work with.

If we assume roughly a quarter of this figure ie €20k for a typical port in Finland and we assume that any delay over 12 hours becomes less relevant as alternative plans will be made, plus we assume a linear relationship between delay and cost. Recall the earlier statements that waiting time has been reduced by between 8 and 12 hours and that transit time has been reduced by around 3 hours, then, improvements in the knowledge of the arrival time in a range of 2-4 hours will yield savings of around €4k-€8k per ship which benefits from the service.

There are around 20,000 ships visiting Finnish ports throughout the year and we saw earlier that some 1000 of these are assisted by the icebreakers but that more benefit as a result of Dirways being opened. However, taking the round number of 1000 ships benefiting by an improvement in arrival time uncertainty of 2-4 hours, **we arrive at total savings of €4m to €8m which are within the range of values we have calculated based on the tonnage of goods going through the port.**

We conclude that these estimates are reasonably sound.

Case Study of Winter Navigation in the Baltic

8.5 Tier 4: Factories and the local economy

The local economy is certainly benefiting to a very large extent by the ice breaking services. In the limit, many of the factories and businesses just would not exist if the ports were not open all the year round. Hence, whilst we could reasonably take the total value of the local economies in the regions bordering the Baltic Sea, we shall continue to work with the period of the year when the ice services are needed.

The main industries operating in the Northern parts of the Gulf of Bothnia are steel and timber/paper products. Hence we shall concentrate on these for our assessment. In addition, Neste Oil supplies petrol and other refined oil products. No oil refineries exist in the North of Finland or Sweden and only refined products are transported. Nevertheless, these are essential for the local industry as well as local population.

In order to produce a rough estimate of the overall benefit we choose to look at the value of the local economy. Since it would require significant research to look at this from the perspective of the industry we shall take a proxy by using the local population numbers and GDP per head figures for Finland.

Arguably, we could use the whole of the Finnish population for this estimate but we shall use the number of citizens living and working in the districts which border the Baltic Sea. Multiplying by the GDP per head will give us an estimate for the value of the local economy. This is shown in Table 8-6 where the value is factored by the number of days when ice-assistance was requested by the ports (in 2014).

Area	Region	Population	Number of days port iced in.	Total loss for the local economy in 2014 (€m)
Bothnian bay	Lapland	181 748	145	2,711
	Central Ostrobothnia	68 832	145	1,027
	Northern Ostrobothnia	403 287	145	6,017
Gulf of Bothnia	Ostrobothnia	181 156	36	671
	Satakunta	223 983	36	829
	Varsinais-Suomi	472 725	36	1,751
Gulf of Finland	Kymenlaakso	179858	127	2,350
	Uusimaa	1 603 388	127	20,953
Total Finnish Coasts				36,312

Table 8-6: Value of the local economies

Overall, we consider that this is a very conservative estimate, where we calculate that we are dealing with a local economy of around €36b which is directly dependent on the continued ice services. Of course, even without the ice-breakers there would still be an economy and people living in the districts. How much exists because of the icebreakers? 10% is probably conservative whilst 20% is reasonable and

Case Study of Winter Navigation in the Baltic

probably still conservative (given that we have only calculated the overall value for the winter months). Using these two figures gives us a value to the Finnish economy of between €3.6b and €7.2b.

What part of this can we ascribe to the use of the satellite imagery? The benefit which it brings according to our model, are the benefits in the knowledge of arrival but also the reduction in the number of extreme events whereby the ship turns up more than 12 hours or even several days late.

That there are benefits is very clear. The anecdotes we were told about a paper mill needing to transport rolls of newsprint by air to avoid losing a key customer demonstrate this very clearly. If ships are delayed by several days then factories risk grinding to a halt and significant losses can result. This is avoided by keeping stocks of raw materials and storing finished goods before shipping but this costs money and capital tied up in stock or finished goods is non-productive.

Hence we can identify three ways (there are probably more) in which the more reliable arrival and departure of ships could affect the local businesses.

- **Reduced stocking costs:** reducing the level of uncertainty of arrival and increasing the confidence that stocks will arrive within a certain period, allows stock levels for both input materials and for output goods to be reduced. A reduction of (say) 1 day can be used to reduce capital tied up and hence improve the financial efficiency of the firms.
- **Greater customer confidence:** similarly, a reduction in one day of uncertainty translates into greater surety on the customer side and into reduced costs for them. In economic terms this will translate into a more robust pricing regime for the suppliers in Finland (ie those factories which we consider are being served by the ships in question) and hence in better financial conditions (stronger price, better profitability) for the factories.
- **Production efficiency:** better management of just-in-time processes leads to overall improved production efficiency.

But how to evaluate this? With more time we should have liked to analyse further this part of the value chain and understand better how costs are being affected by shipping delays. We should also need to know the change in the distribution of delays to arrival times which for the moment we have been unable to discover. Whilst we feel that there are some big impacts being felt here and that the role of satellite data is significant, the time available for this study does not permit us to go further than identifying some of the possible impacts.

Hence we follow the curve which we introduced in chapter 5 and also at the beginning of this chapter where we estimate a contribution due to the satellite imagery which is a factor of 10 lower than the previous tier in the value chain. **This gives us a factor of 0.1% to 0.5% and an economic benefit for the imagery of €3.6m (0.1% times €3.6b) to €36m (0.5% times €7.2b).**

8.6 Tier 5: Consumer Benefits

Benefits extend to the consumers in the local population living in regions served by the ice-bound ports; they can be more assured to have fuel to run vehicles and heat homes and they can be more assured to have food in the shops and supermarkets as well as medicines in the pharmacy. So the icebreaking services certainly add to the quality of life for the residents. They will also to some extent reduce prices for the same reason as for the factories since stocks can be reduced when there is greater certainty of supplies arriving on time (or within a certain reduced window of time).

How much is this worth in economic terms? A full and detailed survey would be needed to answer this question which is well beyond the scope of our work here. As a citizen, how much would you be prepared to pay to be assured that you would have access to petrol and food all the year round? €1 per year? Certainly. €10 per year? I think so. €100 per year? Most likely. €1000 per year (€3 per day)? Possibly. €10,000? Too much.

Let's assume that each citizen would be willing to pay €1 per day for this re-assurance. The population of Finland is 5,471,753 which gives a total figure of €1.99b per annum. Note, for simplicity, we assume that this is a fee collected all year round rather than just through the winter months. We could start to also factor in the number of days when ice assistance is required but then we would assume that an individual would pay more when the service is really needed. Hence €1 per person per day or €2b total per year seems a useable value.

If we limit this rough analysis to the Gulf of Bothnia, at the end of 2010, 1.3 million people lived in the municipalities that have a coastline on the Bothnia Sea. Of these, around 681,000 lived in continental Finland, 631,000 in Sweden and 10,000 in Åland⁴⁸. Based on the same assumptions, this leads to a still substantial benefit of €474m.

Note we also make no assumption about the collection or payment of this "tax". We presume that people would see it as a government provided service and hence is somehow buried within the overall taxation; the precise mechanism is unimportant.

But if €2b is the value of the ice services, what is the value of the satellite imagery in this? Since the overall benefits are to the local economy the value of the satellite imagery for Tier 5 should probably be the same as for Tier 4 i.e. 0.1% to 0.5%. This gives us an economic value of €2m to €10m. We are aware that this calculation is very rough and ready!

Scaling to include Sweden, we could use the ratio of populations (Sweden has 9.775m citizens in 2015) but they are far less dependent on the ice services since there are ports open all year round free of ice and alternative transport routes. However, we shall use the same 75% of the benefits felt by Finland as a more realistic figure. These are included in the Table 8-7 in section 9.7.

⁴⁸ Hermanni Backer & Manuel Frias (eds.) 2013. Planning the Bothnian Sea –key findings of the Plan Bothnia project.

Case Study of Winter Navigation in the Baltic

8.7 Total Economic Return

Based on our research we come to the following assessments of the benefits resulting from the usage of the imagery by the Finnish and Swedish icebreakers as a per annum figure:

	Benefit of:	Finland €m	Sweden €m	Total €m
Tier 1	Icebreakers			
	<i>a. Fuel saving by the icebreakers</i>	0.54	0.46	1.0
	<i>b. Removing the helicopters from the icebreakers</i>	0.75	0.54	1.29
Tier 2	Ship operators			
	<i>a. Fuel saving by the ships</i>	1.19-1.58	0.89-1.43	2.08 – 3.33
	<i>b. Reduced operational costs due to lower journey time</i>	3.34-5.38	2.5-4.04	5.84-9.42
	<i>c. savings due to less repairs and insurance costs</i>	TBD	TBD	TBD
Tier 3	Ports and harbours, stevedores and logistics	2.4 - 12	1.8 - 9	4.2 - 21
Tier 4	Businesses	3.6 - 36	2.7 - 27	6.3 - 63
Tier 5	General public	2 - 10	1.5 – 7.5	3.5 – 17.5
	Total	13.1 – 65.5	9.8 – 49.4	24.2 – 116.5

Table 8-7: Assessments of the benefits resulting from the usage of the imagery by the icebreakers

Based on the assumptions defined, we assess the economic benefit coming from using satellite imagery to inform the ice services in Finland and Sweden to be at least €24.2m per annum. We consider the assumptions to be quite conservative yet they yield this significant figure. Based on less conservative but still (we consider) reasonable assumptions, the total economic benefit rises to €116.5m. p.a. The range of benefits seems large reflecting the cumulative effect of the assumptions which are made.

If we aggregate the average benefits over the years that the imagery has been used (as of 2004) we get a total amount for Finland and Sweden that lies in the range between €223m and €1.2b – figures which would justify a dedicated satellite observation system!

In making these calculations, we also looked at the benefit to the Finnish economy of the ice services which we consider is in the range of €4b to €10b per annum and quite possibly higher.

9 Summary of Findings

9.1 General Approach & Methodology

The study introduces a new way to examine the economic impact which satellite imagery can provide in an operational situation. For the first time, a full value chain is studied and the way in which information derived from satellite imagery flows along it. Rather than merely taking a market approach where the potential sales of products is assessed by the immediate value to the user, we have gone further to look at the impact it has on subsequent users of the services. Hence, starting from the satellite imagery we look at how this is transformed by various steps in the chain of use. This has been done with the help of experts in the field with whom we have met and talked and discussed / reviewed the findings.

To support the value-chain assessment we have developed a model which links each part of the chain and allows an economic analysis of the benefits coming from the services provided. We have defined a second model which allows us to assess what proportion of the total benefits can be considered as coming from the use of satellite imagery.

In future cases we shall seek to apply this methodology to other products in different economic sectors and to test its applicability to them.

9.2 Economic Benefit to Winter Navigation in the Baltic

In this first case to be looked at, we have identified the extended value chain for users of satellite imagery providing ice-breaking services to shipping in the Baltic. We have looked at the impact on the economy of Finland and extended this to Sweden. We have postulated a model to explain the impact and used this to help us understand the full picture and to assess the added value coming from the satellite imagery.

In doing so, we have been surprised not to have found prior analysis of the added value of the ice breaking services; an analysis which is in process as part of a European project WinMOS from which results will be available next year (2016). Consequently we have made our own estimates of this added value based on assumptions which we consider are quite conservative.

We have also rationalised that the value increases as we move away from the primary users of the service. This arises because whilst the impact of the use becomes less, the economic activity being affected becomes greater. In this case, this leads to maximum economic benefit at Tier 4 of the value chain (the local industry and economy) but this will not be the same for all cases where satellite data is being used.

At the same time the uncertainty increases also due to the range of assumptions being taken. This is seen quite clearly in the two charts where for tiers 1 and 2, the numbers are quite precise whereas for tiers 3 & 4, a minimum and maximum value has been calculated.

Case Study of Winter Navigation in the Baltic

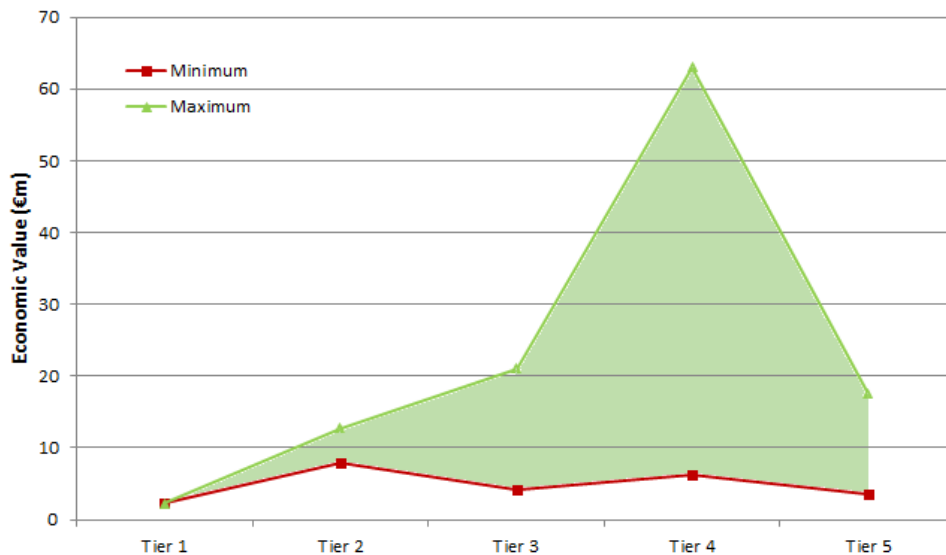


Figure 9-1: Economic value of the satellite imagery for each tier of the value chain

The result has shown a cumulative added value due to the use of the satellite imagery which lies between €24m and €116m p.a. The two charts Figure 9-1 and Figure 9-2 show these results. The former shows the range of economic value for each tier in the value chain and the latter shows this in cumulative form.

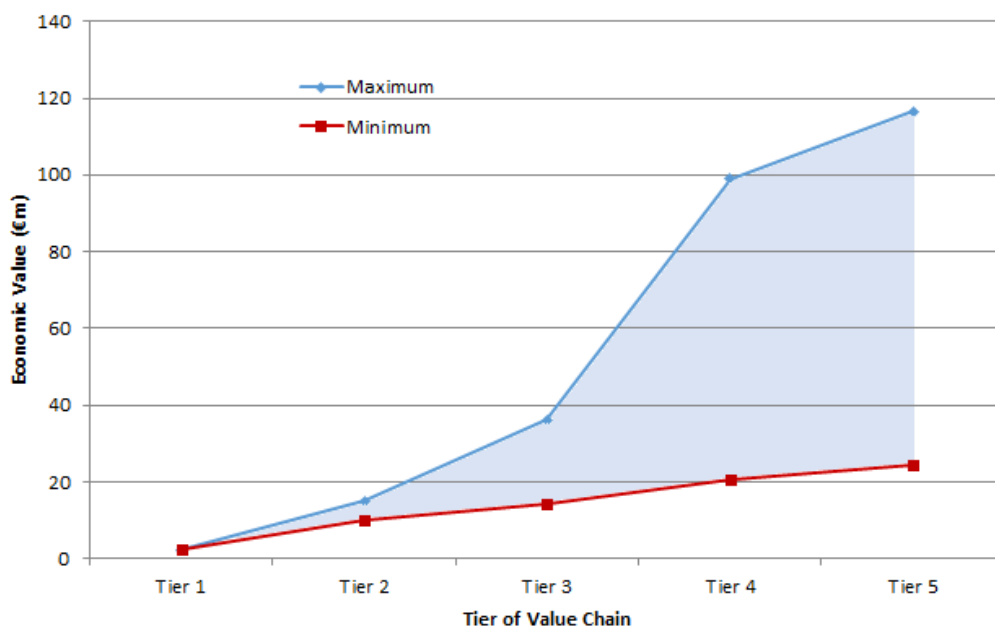


Figure 9-2: Cumulative economic value at each tier of the value chain per annum

Case Study of Winter Navigation in the Baltic

The study covers Finland and Sweden but does not extend to other Baltic states. It will be interesting to extend the analysis by extrapolation to the other countries with ports on the Baltic. The Baltic Icebreaking Management (BIM) organisation seeks to extend co-ordination and eventually co-operation amongst these countries which in addition to Finland and Sweden are: Russia, Estonia, Latvia, Lithuania, Poland, Germany, Denmark and Norway. Estonia is entering into agreement with Finland and Sweden and already benefits from the satellite imagery but this is not yet the case for others. Hence a fairly straightforward next step could be to extrapolate the potential benefits to these other countries by devising some metrics of comparison.

The use of the WINMOS model to place more precise numbers on the model distributions would also be an interesting development. It would enable many of the assumptions made to be tested and would reduce some of the ranges which we have taken. It would also allow the impact of the severity of the winter to be introduced into the analysis for which today there are too few data points to be able to safely calculate the effect.

9.3 The Impact of the Imagery

In chapter 5, we introduced a simple model which illustrated the reducing impact of satellite imagery on the economic activity as the value of that activity increases. As we have assessed the benefits, we have assessed the contribution for each tier, coming from the use of the imagery by the icebreakers as a proportion of the total value coming from the ice services for that tier. In other words it is the added value to the operations covered by the tier resulting from the use of imagery in tier 1.

In figure 9-3 we place the tiers and the percentages used in the assessment of value onto the chart. Each percentage value represents the proportion of the value to the ice services of using satellite imagery. Hence in Tier 1, the icebreakers, the proportion is 100% because the cost savings made by eliminating helicopters and reducing fuel costs are 100% attributable to the use of the imagery.

For tier 2, the ships, of the savings made by the ships from using the ice services, 80% of the saving is attributed to the use of the imagery. This may seem high and of course does depend on the parameters which are being used. In chapter 8.3 we used the savings in time estimated by the experts which had been made as a result of using the imagery to guide the ice breakers. Since it is the marginal savings over and above the “normal” use of the ice breakers, then we feel justifies to use a high percentage; 80%.

For tiers 3, 4 and 5, the benefit from the ice services is very large but the marginal impact of the use of imagery is much smaller. The values used are shown on the figure.

Hence this approach allows us to visualise and estimate the marginal benefits provided by the use of the imagery compared to not using it. We consider the approach will be transferable to other situations and is part of the overall methodology developed.

Case Study of Winter Navigation in the Baltic

Role of Satellite Imagery in the Value Chain

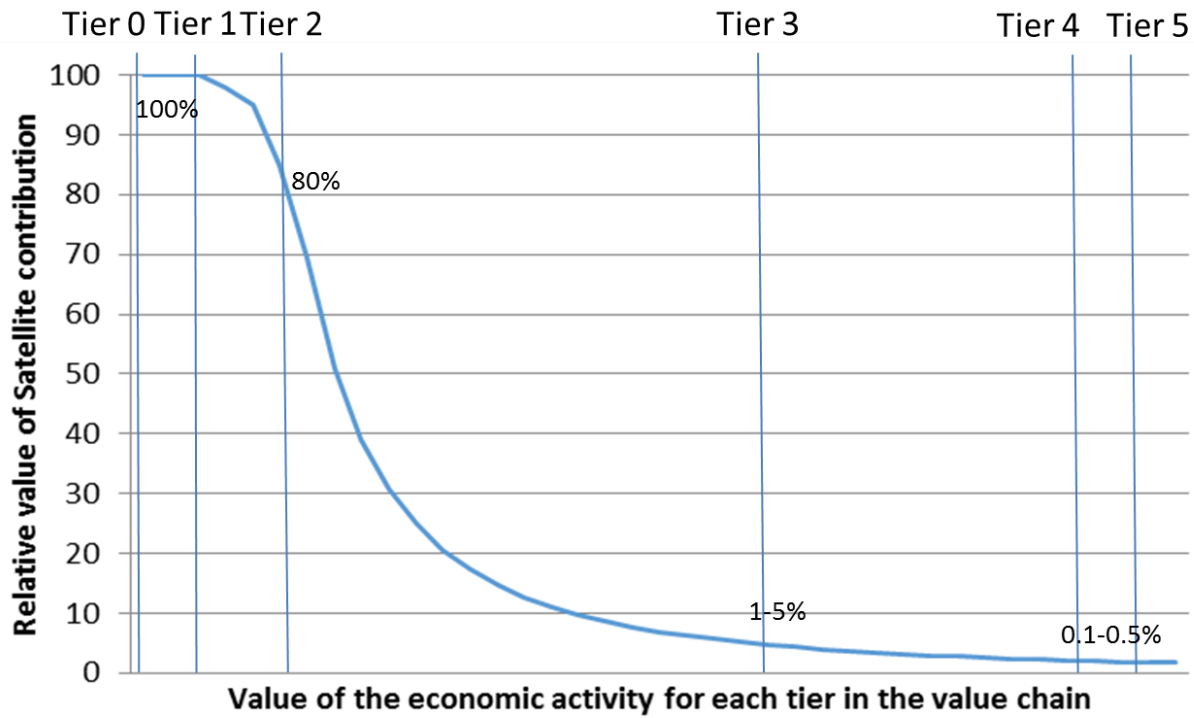


Figure 9-3: Reducing impact (relative value) of satellite imagery down the value chain.

9.4 Conclusions

In conclusion, the economic benefits to the Finnish and Swedish economies of the ice-breaking services and the added benefit which they derive from the use of satellite imagery are significant. At the outset of this study we expected to find a number of sources of value; we did not expect to find such a strong link between the use of the imagery and the local economy in Finland and Sweden. The numbers have surprised us. Those linked to the icebreakers and the ships are relatively solidly based on actual figures and sound assumptions. For the ports, the factories and the local economy, the assumptions which we have had to make seem reasonable and even conservative. We shall welcome discussion on those assumptions and to be challenged upon them if this can lead to more accurate estimates of the economic value of the imagery.

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Annex 3: List of abbreviations

ATA – Actual Time of Arrival

BIM – Baltic Icebreaking Management. The overall objective of BIM is to assure a well-functioning maritime transport system in the Baltic Sea all year round by enhancing the strategic and operational cooperation between the Baltic Sea countries within the area of assistance to winter navigation.

C(S)EVS - Copernicus (Sentinels’) Economic Value Study

EARSC – European Association of Remote Sensing Companies

EEDI - Energy Efficiency Design Index

ESA – European Space Agency

ETA – Expected Time of Arrival

FMI – Finnish Meteorological Institute. The FMI is a public body under the Ministry of Transport and Communications, providing weather services in Finland. It assumed responsibility for the Ice Services in 2009 when the Finnish Marine Institute was dissolved and merged with other organisations. FMI organises the reception of the satellite data and its processing for onward transmission via IBnet. FMI generates the ice-charts used throughout Finland.

FTA - Finnish Transport Agency. The FTA is responsible for the services in Finland coming under the Ministry for Transport and Communications, in the fields of roads, railways and waterways. Its main occupation is to promote an effective transport system, traffic safety and a sustainable development of the regions. One of the responsibilities of the FTA is ensuring winter navigation.

GDP – Gross Domestic Product

HELCOM – Helsinki Commission. The Baltic Marine Environment Protection Commission, also known as Helsinki Commission, is an intergovernmental organization governing the Convention on the Protection of the Marine Environment of the Baltic Sea Area.

IBNet – Shared information system on the location of vessels.

SAR - Synthetic Aperture Radar

SMA - Swedish Maritime Administration. The SMA is responsible for the ice services in Sweden. It is a governmental agency and enterprise within the transport sector and its primary mission is to promote favourable conditions for the maritime sector in Sweden and for Swedish shipping. Icebreaking and maritime traffic information are among the services SMA provides.

Case Study of Winter Navigation in the Baltic

Trafi – Finnish Transport Safety Agency. Trafi develops the safety of the transport system, promotes environmentally friendly transport solutions and is responsible for transport system regulatory duties.

WinMOS – Winter Motorways of the Seas. WINMOS is a Swedish, Finnish, Estonian project which is co-financed by the European Commission. The main objectives of the WINMOS project are to develop the maritime winter navigation system and safeguard required icebreaking recourses to the future requirements in EU's northernmost waters during winter time.