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Cover: Icebreaker ploughing an ice-field in the Gulf of Bothnia. Photograph from Pixabay.

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Abstract

The International Energy Efficiency Design Index (EEDI) regulations have gradually enforced higher demands on the energy efficiency of all newly built vessels (from 2013 and onwards) which furthermore has affected the overall performance of merchant vessels. The Finnish–Swedish Winter Navigation System (FSWNS) is a co-operation between Finland and Sweden aiming to establish an effective and safe navigation system, from and to the ports of both countries. The objective of this master thesis is to carry out an assessment of how the energy efficiency regulations of EEDI have affected the operating capability of the FSWNS until this point in time.

The operating capability of the FSWNS is measured by assessing how efficiently the competent authorities of Finland and Sweden offered their IB services. Moreover, the impact of the EEDI ships on the FSWNS is measured by assessing their ice-going capability in comparison with ships constructed prior to the enforcement of the regulations. The methodology for gathering data to assess the impact of the EEDI on the FSWNS was carried out through a mixed methods approach of semi-structured interviews and a maritime data collection.

Overall, it was found that up until this point in time the impact of EEDI on the operating performance of the FSWNS was not significant and not majorly noticeable. A few justifications for these results are that the regulations do not apply for the vast majority of the fleet operating in the Bay of Bothnia and even though a reduced ice-going capability of the assisted vessels was apparent, it was believed to be mainly due to external factors. One of the most important factors appears to be vessels aiming to increase their open water efficiency (e.g., design modifications) in order to decrease fuel consumption and thus reduce overall operating costs.

As aforementioned, this study puts a greater focus on the winter season of 2017-2018 in the Bay of Bothnia, primarily due to the existing ice conditions which were considered somewhat normal in perspective with the records of the last decades. Furthermore, the interview's target groups were employees of the Finnish and Swedish maritime administrations, shipping companies' representatives, researchers as well as individuals operating in the research topic.

Keywords: EEDI, FSWNS, Vessels, Baltic Sea, Bay of Bothnia

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List of acronyms

CO_2 - Carbon dioxide

EEDI - Energy Efficiency Design Index

FMI - Finnish Meteorological Institute

FS - Finnish Swedish

FSICR - Finnish Swedish Ice Class Rules

FSWNS - Finnish Swedish Winter Navigation System

FTIA - Finnish Transport Infrastructure Agency

IB - Icebreaker

IMO - International Maritime Organization

KPI - Key Performance Indicator

SMA - Swedish Maritime Administration

SMHI - Sveriges Meteorologiska och Hydrologiska Institut (Meteorological and Hydrological Institute of Sweden)

WMO - World Meteorological Organ

1. Introduction

The research presented in this thesis intends to present how, and to what extent, the EEDI regulations have impacted the FSWNS. The influence of EEDI consists of enforcing stricter demands on the energy efficiency of all vessels which furthermore affects the performance of merchant vessels navigating in the Baltic Sea and the availability of icebreaker assistance in the area.

1.1 Background

Essential information about the thesis topic is presented under this chapter. More specifically, it involves key information about the Baltic Sea that points out its diversity and characteristics. Additionally, a description of the ice conditions in the area is presented along with the main components of the FSWNS and fundamental information regarding the EEDI regulations.

1.1.1 The Baltic Sea

The Baltic Sea is located in Northern Europe (Kuliński, K., & Pempkowiak, 2012). It is connected with the North Sea and they are separated by a parallel drawn between Skagen in Denmark and Gothenburg in Sweden (HELCOM, 2016). The Baltic Sea has a size of 370.000 km^2 and it is considered one of the largest concentrations of brackish water (HELCOM, 2016). One of the major causes of permanent stratification in regions of the Baltic, with water depths greater than 80 m, is saline and thick seawater inflows mainly directed from the North Sea (Kuliński, K., & Pempkowiak, 2012). An important characteristic of the Baltic Sea according to Holm (2019) is the somewhat shallow waters which have the impact of an increased fuel consumption due to the fact that an increased resistance is generated when the water depth below the keel is relatively low.

Moreover, one of the most significant features for the chemical and biological deep-water environment of the Baltic Sea is the distinctive permanent salinity stratification (Voipio, 1981). According to Kuliński & Pempkowiak (2012), the largest source of freshwater in the Baltic is the substantial river runoff measured at 428 km^3/year, which contributes to its brackish character. A brackish superficial layer is produced due to the incoming fresh-water in the area and additionally, the supply of subsurface flow produces layers of more saline concentrations (Voipio, 1981). Even though the distribution of saline in the area is not considered strong, it is described as cyclonic due to the low levels of saline water are being concentrated in the coast of Sweden and at the same time the high-level saline deep waters are mainly directed inwards to the coasts in the east Baltic Sea (Voipio, 1981).

Additionally, due to the low salinity levels in the area of the Gulf of Bothnia and the Gulf of Finland, the formatted ice is much tougher than a usual first-year sea ice. As a result, navigation during the winter is difficult due to ice conditions with pressure ridges and fair-way channels of cumulative brash ice from frequent icebreaking (SSPA, 2017).

1.1.2. Ice Conditions

The ice conditions in the northern part of the Baltic Sea and especially the Bothnian Bay, impact shipping to a great extent, as the area is covered with ice during the winter months (Voipio, 1981). Similarly, and to a different extent, other areas of the Baltic Sea are covered with ice, such as the Gulf of Finland, Gulf of Riga, the coastal zone of Åland Sea while the likelihood of an ice coverage in the Baltic Proper is low. According to Lindborg & Andersson (2020), during the winter months, parts of the sea turn into ice and in order for the vessels to reach their destinations, icebreakers need to assist them. The formatted ice is affecting, to a large extent, not only the time period of the voyages but also the ability to operate in such areas (Bergström & Kujala, 2020).

According to the Ritari (2015), the ice conditions are vital in order to ensure a prosperous ship design. The defining factors are the following; the extreme dimensions of an iceberg, the extreme width of multi-year formatted ice, the extreme width of rafted first year ice, the extreme size of a consolidated ice ridge, the highest wind power to provide speed and course for the ice movement and lastly the extreme current to provide speed and course for the ice movement.

The area of the Baltic Sea is described as of average intensity in terms of the severity of the ice conditions. However, the winter conditions differ to a great extent from season to season and therefore they are categorized as follows. Mild, normal and severe winters (Dyrcz, 2017). The official records used to compare the severity of the winters go back to the 1960s and therefore the degree of severity is strongly correlated with the availability and history of the recorded ice conditions.

In the Swedish Meteorological and Hydrological Institute's (SMHI) (2017) ice chart *(see Appendix 1)*, the average ice extent is illustrated according to the severity of a winter in the Baltic Sea. On average, the northern part of the Gulf of Bothnia is covered by ice even during a mild winter. During a normal winter the ice extent reaches the whole Gulf of Bothnia, the Gulf of Finland and the Gulf of Riga. Lastly, during severe winters the ice extent reaches the majority of the Baltic Sea, except for some parts in the south east Baltic Sea, near Lithuania and Poland where the ice conditions do not prevail.

The types of ice in the Baltic Sea vary and similarly their descriptions vary as well. In order to avoid any misconceptions, the SMHI has adopted the terms and definitions issued by the World Meteorological Organization (WMO) in the international Sea-Ice Nomenclature (SMHI, 2017). According to the WMO (2014) the ice type is initially described by the location it settles in. It is either sea ice, ice of land origin, lake and river ice respectively. Except for that, the WMO describes the types of ice in 12 more categories, according to its development, forms of fast ice, the occurrence of floating ice, the floating-ice motion processes, the deformation processes, the openings in the ice, the ice-surface features, the stages of melting, the ice of land origin, the sky and air indications, the terms relating to shipping and to submarine navigation. The type of sea ice that illustrates the stage of its development is separated as follows. New ice, nilas, pancake ice, young ice, thin first-year ice/white ice, old ice and snow ice. Each category offers subcategories which further elaborate and specify even more the ice type.

1.1.3. The Finnish–Swedish Winter Navigation System

The objective of the Finnish–Swedish Winter Navigation System (FSWNS) is to establish an effective and safe navigation system, from and to the ports of both countries. The FSWNS handles navigational challenges by utilizing three main components, the Finnish-Swedish Ice Class Rules (FSICR), the traffic regulations and the available icebreaker (IB) assistance (Bergström & Kujala, 2020).

According to the SMA's annual report (2019), Sweden's state-owned IBs are five in total, ALE, ATLE, FREJ, ODEN and YMER. Except for them, the anchor handling tug supply vessel THETIS is added to the fleet when needed. Additionally, the two-buoy tender-vessels

BALTICA and SCANDICA, along with other third-party owned vessels are being chartered in cases where additional assistance is necessary. Responsible for manning all of the IBs is the privately owned company Viking Supply Ships.

On the other side, Finland's IB assistance is being operated by the state-owned company Arctia. They own and operate eight IBs in the area. URHO, SISU, OTSO, KONTIO, VOIMA, FENNICA, NORDICA and the latest vessel to join the Finnish Baltic Sea IB fleet, POLARIS (FTIA, n.d.).

According to the Finnish Transport Infrastructure Agency (FTIA) 2020-2021 annual report (n.d.) and the SMA annual report (2019), in order for the authorities to ensure safe navigation despite the increased traffic in the area, an efficient coordination and exploitation of the existing IBs is needed. Sweden and Finland have therefore enforced traffic restrictions. IB assistance is provided as long as the vessels operating in the area are in accordance with restrictions the authorities have put into place. More specifically, by taking into consideration the weather and ice conditions, the authorities issue the vessel's minimum Finnish- Swedish (FS) ice class and deadweight (DWT) required for safe navigation to each port of both countries.

According to the thickness of the ice, a certain FS ice class is required for a ship to reach the ports of Finland and Sweden and it is regulated by the FSICR (HELCOM, 2016). For the different FS ice classes there are specific requirements regarding the ship's structural design and engine power. The requirements in terms of ship design for the different FS ice classes refers to the ability of maintaining a minimum speed of 5 knots in the subsequent brash ice channels' ice thickness: 100 cm (and 10 cm consolidated layer of ice) for IA Super, 100 cm for IA, 80 cm for IB and 60 cm for IC (Sjöfartsverket, 2019).

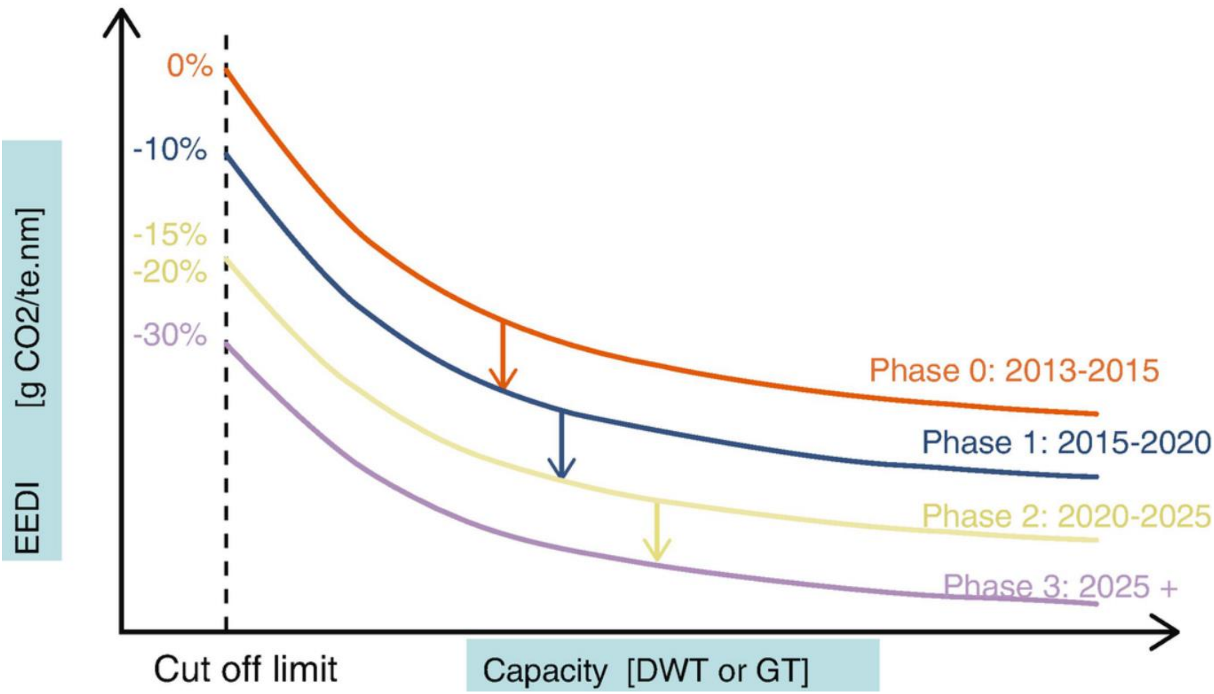
For ships that, according to the regulations of TSFS 2009:111 (Transportstyrelsen's regulations and general advice on FS ice class), are existing ships and have ice class IA Super or IA, the older engine power provisions apply until January 1, 2005 or January 1 the same year as when 20 years have passed since the ship was delivered, whichever comes first (Sjöfartsverket, 2019). The total propulsion machinery power for which the ship is designed for is considered the ship's (installed) propulsion power. However, if the ships' machinery power is limited by any kind of technical implementations which are used to prevent the machinery from operating at full power, or if these measures are prohibited by the regulations in place on board, then the machinery power limited in this manner is considered to be the ship's propulsion power. The engine output power should in no case be less than 1000 kW for the FS ice classes IA, IB and IC, and not less than 2800 kW for FS ice class of IA Super (Sjöfartsverket, 2019).

1.1.4. The Energy Efficiency Design Index (EEDI)

It is believed that one of the impacts of global warming is that in certain areas the need for IBs could be decreased and at the same time the volume of trading will increase (SSPA, 2017). The EEDI has, according to Westerberg & Karlsson (2014), been developed by the Marine Environment Protection Committee (MEPC), under the International Maritime Organization's (IMO) remit, in order to improve the energy efficiency of the world's merchant fleet and to reduce greenhouse gas (GHG) emissions by promoting the use of more energy efficient equipment and engines. The EEDI regulations came into force January 1st 2013 and have a direct effect on the allowed engine power on all ship designs since that date (Westerberg & Karlsson, 2014). In more detail, Riska (2014), states that the EEDI is a measure for CO_2 emissions from ships which is the result of calculating the ratio between the CO_2 emissions and the work performed by a ship, or as Ren et al. (2019) expresses it as the ratio between the impact to the environment and the benefit for the society.

IMO (n.d) states that EEDI is specific for each individual ship design, expressed as grams of CO_2 per a ship's capacity-mile, and the permitted level is to be tightened incrementally through phases (phase 0 to 3) (see *figure 1*), in order for the shipping industry to demand a continued innovation and technical development on all components that has any kind of influence on the fuel consumption of a ship. Phase 0 is, according to Forsman (2018) applicable for ships built between 2013 and 2015 and requires that those ships have a design efficiency which is at least equal to the "reference line". The reference line (also known as baseline) is the average efficiency of different ship types constructed from 1999 to 2009 and sets the maximum allowable amount of CO_2 emissions per ship type and size in order to carry a unit of transport work. Phase 1 is applicable for ships built between 2015 and 2020 and requires that the design efficiency of those ships is at least 10%, with a few exceptions, below the reference line. Phase 2 is applicable for ships built between 2020 and 2025 and requires that the design efficiency of those ships is at least 20%, with a few exceptions, below the reference line. Lastly, phase 3 is applicable for ships built after 2025 and requires that the design efficiency of those ships is at least 30% below the reference line (Forsman, 2018).

Figure 1. Phases for reduction factors of EEDI. IMO (n.d).



Furthermore Bergman (2018) states that, in order to ensure a good ice-going capability for ice classed ships, the EEDI regulations allow these ships to have a higher propulsion power (compared to ships without an ice class) by including an ice class correction factor in the EEDI calculation. Despite the higher allowed propulsion power for ice classed ships, Bergström & Kujala (2020) argues that it is expected that the stricter EEDI regulations in the upcoming years will reduce the average propulsion power and, accordingly, the average ice-going capability of ice classed ships. A ship's decreased ice-going capability means both a lower threshold in terms of the toughest ice conditions at which the ship can work independently and a lower ice-going speed (Bergström & Kujala, 2020). A decreased ice-going capability would result in an increased number of occasions of ships in need of icebreaker assistance and the length of each instance of assistance, resulting in an increased demand for such assistance (Bergström &

Kujala, 2020). The EEDI, together with other factors, will have an impact on the performance of the FSWNS in terms of its performance indicators such as the transport capacity (number of ship arrivals per port), number of instances of icebreaker assistance and the icebreaker waiting times. The other factors that will affect the performance of the FSWNS is e.g., the prevailing ice conditions due to climate change, the availability of icebreaking assistance, the volume of maritime traffic and ice-classed ships being optimized to operate in open water (Bergström & Kujala, 2020).

1.2 Objective and research question

The objective of this master thesis is to carry out an assessment of how the energy efficiency regulations of EEDI have affected the operating capability of the FSWNS.

Research Question: *What has been the impact of EEDI on the operating performance of the FSWNS since the enforcement of the regulations?*

1.2.1 Delimitations

The geographical area that is investigated in this research is delimited to the area of the Baltic Sea and particular emphasis has been given to the Bay of Bothnia, during the winter season of 2017-2018. The motivation behind the selection of such a time period was due to the severity of the ice conditions. The ice conditions of 2017-2018 are considered normal when compared with the ice conditions records since the 1960s. However, when compared with the records of the past decade, that particular season is considered one of the most severe ones. Furthermore, the selection of the Bay of Bothnia for particular emphasis is due to the fact that this region has the most severe ice conditions in the Baltic Sea, which calls for a demand of IB assistance as well as it constitutes the commonly IB operated region between Finland and Sweden.

Moreover, even though the impact of the whole fleet operating in the area has been investigated through interviews and data collection, the assessment will primarily focus on the impact of the newbuilds, constructed after 2013, where the EEDI is enforced.

2. Theory

This section aims to provide necessary knowledge of what is known of the topic as of today, in detail it provides information of what previous research has discovered concerning the following areas: The *Impact of EEDI on Winter Navigation*, the *Operating Capability of the FSWNS* and the *Alternating Ice Conditions*.

2.1 Impact of EEDI on Winter Navigation

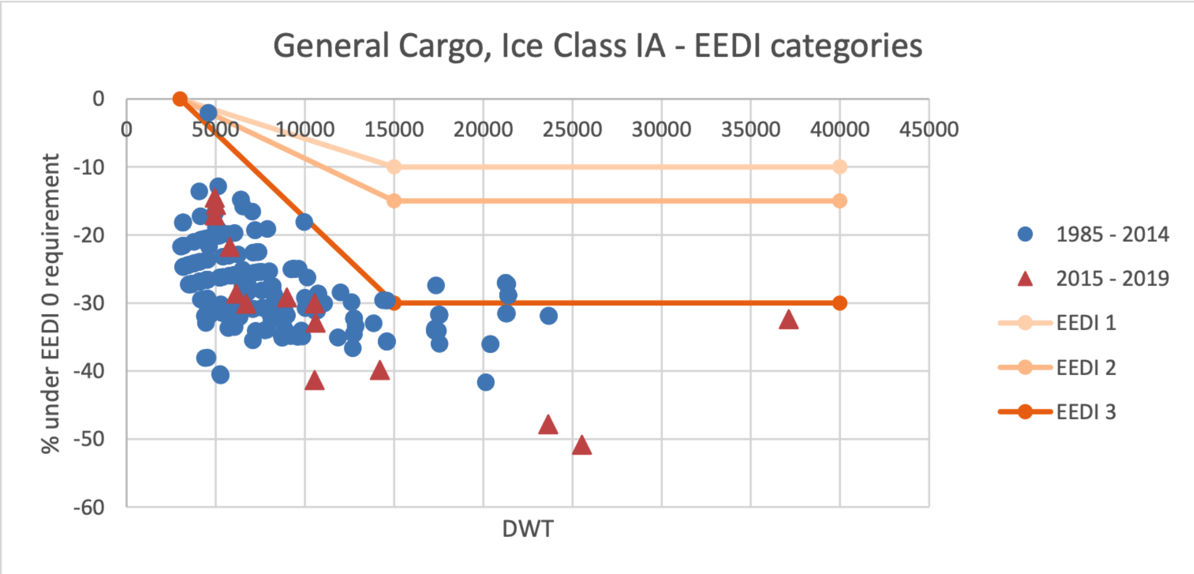
Hasan (2011) argues that even though the EEDI phases are already enforced since 2013, accurate observations might take more time considering the change of the energy efficiency requirements during the different EEDI phases and the average lifespan of the vessels. In detail, the author puts emphasis on the impact of the operation of vessels constructed during Phase 0 (2013-2015) which would be unchanged as their emissions would be as well. Taking into consideration that such vessels could operate for approximately 25 years then it is understood that the impact of EEDI will take place as long as the merchant fleet is gradually being replaced by new more energy efficient vessels.

Perälä & Tikanmäki (2020) states that the increasing restrictions on emissions in the shipping industry, which are imposed by IMO, is partly achieved with the EEDI. EEDI is a measure to demand the design of more efficient vessels and its implementation furthermore has an effect on the overall power output (decreasing power) of the new merchant vessels as well as their structural designs in order to decrease CO_2 emissions. The decreasing engine power of merchant vessels is also, as Rehmatulla, Calleya & Smith (2017) explains, a result of the shipping industry's continuous attempt to reduce fuel consumption, which is commonly achieved by installing smaller engines with a lower design speed. Furthermore Perälä & Tikanmäki (2020) argues that new regulations with increasingly tightened restrictions for reduced carbon dioxide emissions also call for a replacement of the fuels which are causing high emissions. Restrictions to reduce emissions are positive measures from an environmental perspective, but they can possibly make the ice-going performance of the vessels worse.

As aforementioned about the fact the EEDI regulations have had an impact on the power output of newbuilds, Berglund & Huttunen (2014), further argues that there is a clear correlation between ships with weak engine power and longer (compared to ships with higher engine power) assisting times for icebreakers. This also means that ships with stronger engines have a considerably higher average speed in ice, e.g., an increase of 100 kW per meter (machine power divided by the ship beam width) increases a ship's speed in ice by 0,89 knots (Berglund & Huttunen, 2014). The statement that ships with more engine power performed better in ice conditions compared with ships with less engine power was once again concluded in a research project conducted during winter 2011 in the Baltic by Riska & Lesisti (2014). From their data analysis it was found that the ratio of installed power to required power (in accordance with the FSICR) explains quite well the quality of a ships' ice-going capability, thus providing a rather fairly given index for a ships' ice performance.

An eligneting study conducted by Perälä & Tikanmäki (2020), investigates the General cargo ships with an IA FS ice class that have visited the Bothnian Bay during the winter season of 2019. The authors claim that the vast majority of the ships fulfill the EEDI requirements even during phase 3. As it can be seen in *figure 2,* the fleet's lion share has a DWT below 15.000. Moreover, as shown by the lines representing phase 1, 2 and 3 of EEDI, all ships fulfill the EEDI requirements for phases 1 and 2. Only in a few cases, the ships do not fulfill the EEDI requirements during phase 3. The ships take advantage of their relatively small size, and the linear reduction of the EEDI requirements, which occurs for vessels below 15.000 DWT. The EEDI vessels having been constructed after the enforcement of the regulations appear to easily fulfil the requirements. There are 2 cases displayed on *figure 2* where the reduction, when compared to phase 0 reference value, reaches approximately 50%.

Figure 2. General cargo vessels that have been navigating in the Bothnia Bay during the winter season of 2019. Perälä & Tikanmäki (2020).



Note: The Y- axis represents the variance of calculated EEDI and phase 0 EEDI in percentage. The lines illustrate the rest of the EEDI phases' requirements. The vessels constructed after 2014 are highlighted.

2.2 The Impact of the EEDI Compliance Measures on Winter Navigation

Since the enforcement of the EEDI regulations, different measures of compliance have been identified. Forsman (2018) suggests that the measures heavily selected up to this point tend to emphasize the optimization of the vessel's hull and its propulsion system. Even in cases where the optimization concerns vessels navigating in the ice which have an ice class attained, additional optimization is possible to be carried out. Nonetheless, as a result these hull optimizations often take a toll on the ice going capability of the vessels and therefore their ice going capability is reduced.

The hull optimizations refer to alterations to the ship's specifications such as its capacity or to its hull resistance. Alterations to the ship's capacity in terms of DWT, would benefit the ship's energy efficiency only when increasing it, rather than decreasing, since the ship would be able to carry out more transport work in relation to the CO_2 emitted (Forsman, 2018). A study conducted by ABS (2013) states that attaining a high FS ice class notation while simultaneously complying with the EEDI regulations is feasible for larger ships. More specifically, when comparing the transport efficiency of containerships of different carrying capacity (TEUs), and while keeping a similar speed it is possible for economies of scale to be applied. Thus, the study claims that the fuel consumption per tonne-mile of a containership in the size of approximately 4.500 TEUs is significantly increased in comparison with a larger sized containership of 8.000 - 14.900 TEUs.

Additionally, an example of a hull resistance optimization is the bulbous bow. The extent of the ship's hull in contact with water affects a great volume of the ship’s frictional resistance (Forsman, 2018). Therefore, even though this bow optimization has a great prospect in increasing the ship’s energy efficiency, it also impacts its performance when navigating in ice. When aiming to achieve a high FS ice class notation for a ship with bulbous bow, such as the example vessel used in the study by Forsman (2018), a remarkably increased required engine power is designated when set side by side with a vessel of a commonly used ice bow.

According to the same study, measures focusing on increasing the engine's energy efficiency are believed to have great prospects. The designing of a high-performance engine while simultaneously having a decreased fuel consumption which affects to a great extent the EEDI calculation would be of great significance. Moreover, it is essential that upcoming technologies and measures continue to be developed in order to further increase the energy efficiency for each operation and type of vessel (Forsman, 2018).

2.2.1 Ship Design

After the enforcement of EEDI, another interesting discussion surrounded the ability to achieve a higher FS ice class notation while at the same time complying with the EEDI regulations. According to the case study conducted by Mattsson, (2016) the operating capability of three bow types have been assessed during EEDI’s Phase 1 and Phase 3 for an example vessel. The example vessel is an LNG carrier with a displacement of 18.500 tons. In depth, the following bow types have been assessed, the traditional IB bow, the bow with vertical stem which is also known as “EEDI type of bow form” and lastly the hybrid bow type “Semi bow” which has been designed for both open water navigation as well as navigating in ice conditions.

The study’s results designate that during Phase 1 of the EEDI, the selected bow type will determine whether the vessel is able to comply with the EEDI regulations while at the same time achieving a high ice class notation. The EEDI bow type is the least compliant of the three bow types compared and it can only achieve an IB ice class. In addition, the increased EEDI requirements during Phase 3 will prevent the vessels from acquiring the highest ice class notations, IA and IA Super. Furthermore, the results indicate that during Phase 3 by selecting either the ice bow or the semi bow, an IB ice class can be achieved, while it would not be feasible with the EEDI bow (Mattsson, 2016).

Similarly, a study conducted by Eto et al. (2019) assesses the capabilities of an EEDI compliant vessel for ice navigation. Through the study, an EEDI optimized hull form has been designed for the vessel and ice model tests have been conducted along with an observation voyage onboard a current ice classed vessel. A comparison has been carried out between two vessels of the similar particulars. However, the first vessel has an EEDI optimized hull form while the second one has a hull form optimized for ice navigation. The ice conditions that the model tests were conducted in were the ones that are somewhat anticipated during winter in the Bay of Bothnia. The observation voyage took place onboard a standard IA Super classified vessel during the harshest period of the winter of 2017.

In detail, one of the conclusions that has arisen from the observation voyage, was that when navigating in open water and in mild ice conditions the power levels used were approximately half of their full installed capacity. However, high-capacity levels were only used when the prevailing ice conditions got harsher. The recorded vessel's speed remained almost unchanged both when the vessel was assisted by an IB but also when it navigated independently and it was approximately above 10 knots. Even though the authors attempted to recreate comparable ice conditions as the ones on the observation voyage, it was not fully feasible.

The results from this study illustrate that the EEDI designed bow had similar and perhaps an even better performing capability than the ice bow, standard for ice navigation, in almost all of the experienced ice conditions. Conversely, when the EEDI bow vessel navigated outside the open channel, a clear drop in the performance of the vessel has been noticed which according to the authors might call for safety related concerns in case it encounters a vessel in a channel. Lastly, Eto et al. (2019), suggest that the ice going capability of the EEDI hull form is very much reliant on the mode of the IB assistance as well as on how the bow is performing in brash ice channels. However, it is stated that the conclusions should not be treated as decisive since the objective of the EEDI designed hull form was not only to optimize it for open water navigation but for navigation in ice as well (Elo et al., 2019).

2.2.2 Alternative fuels to comply with EEDI

Apart from making alterations to the ship design, constructing an EEDI compliant ship can be achieved by switching to fuels with a lower carbon content in order to reduce the CO_2 emissions instantly from the moment of combustion in the engines, according to Lindstad & Bø (2018).

Liquefied Natural Gas

Lindstad & Bø (2018) suggest that one alternative fuel for achieving EEDI compliance is liquefied natural gas (LNG). LNG is known to have increased ratios of hydrogen to carbon in comparison with conventional bunker oils and diesel. The engine selection for LNG is separated between low-pressure and high-pressure engines. Additionally, Lindstad et al., (2020) agrees that LNG can replace conventional fossil fuels in order to achieve EEDI compliance. However, LNG's well-to-tank emissions along with any possible methane spills or any other CO_2 equivalents have not been taken into consideration, since it falls out of the scope of EEDI. With that being mentioned, an LNG compliant engine would without significant effort be able to comply with the EEDI threshold during Phase 3. The authors nonetheless put emphasis on the necessity to include all GHGs emissions from shipping under these policies and not only the CO_2. A suggested resolution is to incorporate the un-combusted methane in the EEDI calculations, by adding CO_2 equivalents' emissions in the formula and not only specifying CO_2 emissions (Lindstad et al., 2020).

The usage of LNG-propelled vessels will become particularly attractive in emission control areas (ECAs), such as the Baltic Sea, according to Kołwzan & Narewski (2012). The reason for this is that these ships can comply with the regulation for the Tier III NO_x emissions, as well as the permitted SO_x levels, without needing any after-treatment system for the exhaust gases. However, one of the challenges of using LNG-propelled vessels is the lack of LNG fuels in bunkering ports, which needs to be solved before these kinds of vessels will be practical on a bigger scale (Kołwzan & Narewski, 2012). Solving this problem could then further on in the future decrease the proportion of the world's merchant fleet of vessels running on traditional marine fuels in general, and for the fleet operating in the Baltic Sea in particular. Another drawback of LNG is, when compared to diesel fuel, that it only contains about ⅔ as much energy on a volume basis and around 90% as much energy on a weight basis (Kołwzan & Narewski, 2012). This disadvantage puts more demand on the engine specifications for a LNG vessel to get to the same level of power output, and thereby a similar ice-going capacity when comparing technical data, as the engines running on diesel fuel.

Biofuels

Another fuel alternative to diesel fuel which would result in less carbon related emissions is biofuel. Biofuels are defined by Kołwzan & Narewski (2012) as fuel derived from biomass and some variants of this fuel are: biogas, bioethanol, biomethanol, biodiesel, bio-dimethyl ether and bio-oil. The main benefit of using biofuels, as with LNG, is the lower fuel cycle emissions (concerning e.g., CO_2 and SO_x) per unit of work done, compared with diesel fuel. However, the main challenges with biofuels are the high prices which unfortunately makes these fuels quite unlikely to be implemented in the nearest future on a larger scale, as well as the strongly delimited availability on the market. Additionally, the offer of marine engines which are suitable for using biofuels are quite limited as of today (Kołwzan & Narewski, 2012).

Hybrid solution with supplemented batteries

Another realistic way to comply with the EEDI regulations by targeting the CO_2 emissions from an energy usage perspective is, according to Lindstad & Bø (2018), to use a hybrid power system. With the hybrid power option, the main engine can provide the needed energy for propulsion and auxiliary systems when the vessel is running under normal operating conditions and batteries could then be used in critical situations. Critical situations occur when the load suddenly increases considerably and then the batteries can be used to compensate for these variations as well to boost propulsion if needed. The batteries can also be used as a primary energy source during times when the vessel is at idle at night, and the load is at minimum, to further decrease CO_2 emissions (Lindstad & Bø, 2018). Lindstad & Bø (2018) further argues that, since the main engines that are built nowadays tend to reflect what is needed of them to be able to provide in case a critical situation occurs, a hybrid setup with batteries could allow the main engine size to be reduced. This solution would enable shipowners to comply with the EEDI regulations without jeopardizing the safety at sea. One of the main obstacles with hybrid solutions using supplemented batteries are, according to Chin et al. (2019), the availability in terms of infrastructure, charging stations at the ports. Charging batteries at port is a process called cold ironing and then onshore power supply is used to charge the batteries (Chin et al., 2019).

2.3 The Impact of EEDI on the Operating Capability of the FSWNS

According to the case study conducted by Bergström and Kujala (2020), a series of simulations have been carried out in order to assess the operating performance of the FSWNS under different operating scenarios. It is based on the understanding that in due time the percentage of newly constructed EEDI compliant vessels will increase and in which alternative scenarios have been simulated where 1/3 and 2/3 of the fleet respectively have been replaced by EEDI compliant vessels in the area of the Bay of Bothnia. Under the scenario where approximately 1/3 of the fleet has been replaced by EEDI compliant vessels, the results illustrate an increase of 48% in the number of cases of IB assistance, while at the same time illustrate an increase of 78% in the cumulated waiting times for IB assistance. Similarly, under the second simulated scenario where 2/3 of the fleet has been replaced by EEDI compliant vessels, the results illustrate an increase of 116% in the number of cases of IB assistance as well as an increase of 565% in the cumulated waiting times for IB assistance.

As acclaimed in the same study and for both scenarios, a significant decrease in the aforementioned increased IB waiting times is expected by increasing the IBs operating in the area. Nonetheless, it is believed that this study's result is not incontrovertible since the absence of comprehended data on the actual impact on the capability of the new vessels to navigate in the ice, which is yet to be assessed.

Considering the impact of EEDI during Phase 1, Heinonen (2019) states that the number of newly constructed EEDI vessels that visited the researched area during the winter seasons of 2015-2016, 2016-2017 and 2017-2018 was only 23. Furthermore, the author argues that part of the aforementioned number is constituted by some sister vessels and therefore the designed EEDI compliance measures do not vary a lot among the vessels. The results illustrate that most of the older vessels navigating in the northern part of the Baltic Sea even though they have no obligation to comply with the regulations are able to fulfil the requirements of Phase 1. On the other hand, comparing the newly constructed EEDI compliant vessels with the older vessels, they appear to have a reduced installed power to DWT ratio. Moreover, the author states that it is likely that the upcoming EEDI vessels will have a reduced open-water speed as well as decreased installed power even below the EEDI requirements.

Heinonen (2019) also argues that there is a strong connection between a vessel's installed power to DWT ratio and its demand for IB assistance or towing since the latter one increases as the first one decreases. According to the data collected in the research, 30% of the EEDI compliant vessels required IB assistance, while on the other hand the percentage of the non-EEDI vessels was 10% during the winter seasons of 2017-2018 and 2016-2017. Likewise, the percentage of EEDI compliant vessels that required IB assistance during the season of 2015-2016 was 20%. However, the non-EEDI vessels that required IB assistance during the same period were only 5%. Even though all of these approximations are somewhat broad since they are based on the total winter period, they still provide interesting results on the trend of the EEDI complaint vessels having an increased demand for IB assistance. Similarly, the duration, speed and distances that the IB assistance and the towing was provided appear to have increased. Lastly, Heinonen (2019) addresses the need to increase the capacity of IBs in order to cope with the aforementioned increased demand. Nonetheless, at the moment the number of new EEDI vessels navigating in the area is relatively low and therefore there is room for more precise estimations in the future.

Furthermore, one global trend that is becoming increasingly popular and might in the near future have an impact on the operating performance of the FSWNS was acknowledged in the research study by Perälä & Tikanmäki (2020). The trend is about designing larger and wider merchant vessels in order to increase the cargo capacity. Vessels of large width could potentially pose a problem to the IBs in Baltic Sea since the channel made by one of the IBs might not be wide enough for those vessels, which furthermore as a consequence could lead to needing two IBs to make the channel sufficiently wide (Perälä & Tikanmäki, 2020). This would then possibly require an allocation of IB resources, alternatively an increase of resources to secure an efficient operation of the FSWNS.

2.4 The Impact of the Ice Correction Factors on Ice Class Notations

An ongoing concern of the Baltic Sea community is whether the ice correction factors need to be altered in the future so as to achieve high ice class notations by the EEDI compliant vessels. During the study carried out by Forsman (2018), vessels compliant with EEDI's Phase 1, built 2016 and 2017, as well as older, non-EEDI compliant vessels have been investigated. The selection of the vessels was among the ones classified with either IA or IA Super FS ice class notations and of different dimensions, varying from 85 meters to up to 265 meters in length.

The results indicate that the majority of the vessels are anticipated to comply with the upcoming phases of EEDI. More specifically, five of those vessels are even anticipated to comply during phase 3, which illustrates that ability of a vessel to comply with the future stricter phases of EEDI while achieving high ice class notations. The study's results also point out the significance of the ice correction factors for the vessels with ice class notations, which allow them to comply with the EEDI phases (Forsman, 2018).

Westerberg (2014) also reaches the conclusions that the upcoming and yet to be sticker EEDI regulations will heavily impact the ice-going capability of the vessels operating in the Bay of Bothnia. The author states the great necessity of the ice correction factors and acknowledges their impact on the calculation of a vessel's EEDI value, allowing them to comply with the regulations. Furthermore, the author suggests that perhaps one of the best alternatives in terms of energy efficiency would be to focus on increasing the ice correction factors rather than the IBs size or number. The existing vessels investigated in this study are able to achieve high FS ice class notations due to their high installed power. Therefore, due to the stricter EEDI regulations and the trend to reduce the ice going capability of the vessels, it is likely that vessels with increased installed power will not be constructed in the upcoming years (Westerberg, 2014).

2.5 Ice Conditions in the Baltic Sea

Haapala et al. (2015) argues that the ice conditions in the Baltic Sea vary greatly from year to year, but there has been a trend toward milder winters over the last 100 years. The ice season has been shortened and the peak ice extent has shrunk by about 2%. Furthermore Luomaranta et al. (2014) estimates that the ice thickness will continue to decrease in the upcoming decades and it is likely that the ice thickness around the port of Kemi, at the northern Bay of Bothnia, will decrease on average 20-25% in the period of 2041 to 2050, in comparison with observations made from 1971 to 2000. Exactly how much the ice thickness will decrease is dependent on e.g., the emission scenario. For estimations even further into the future, Luomaranta et al. (2014) estimates that the ice thickness, in the same region, will decrease in the range of 37-63%, however it is concluded that it is highly unlikely that the Baltic Sea will become totally free of ice during this century.

Despite the fact that the peak ice extent, as well as the length of the ice season and the ice thickness are all declining, ice-going merchant ships sailing the Bay of Bothnia will continue to have a need for IB assistance. Their need for IB assistance is becoming particularly evident when encountered with ice ridges, despite otherwise having a sufficient ice-going capability in ice channels. When the ice thickness is between 15 and 20 cm, ice is drafted and ice ridges are formed. As a result, the reduction in ice thickness can potentially lead to conditions that are more difficult for winter navigation than one would imagine (Perälä & Tikanmäki, 2020).

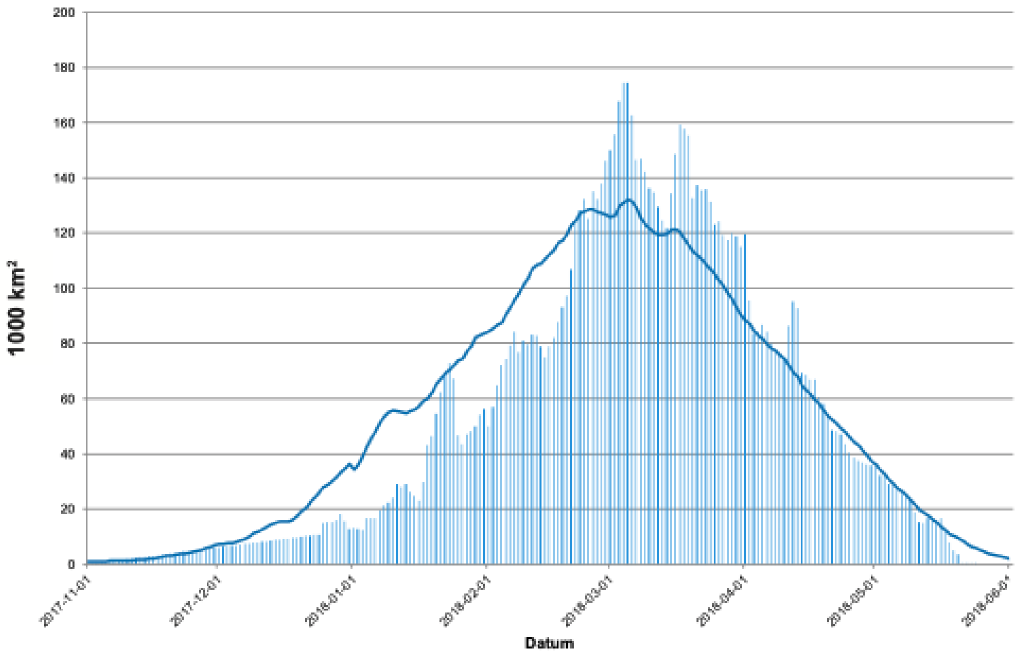
2.5.1 Ice Conditions during Winter Season 2017-2018

Even though the beginning of the winter season of 2017-2018 was believed to be mild, the conditions took a turn around February, where it became severe (Sjöfartsverket, 2019). According to the FMI (n.d.), the ice conditions of that season were described as normal, since the maximum ice extent reached 175.000 km^2 on 5^{th} of March (see *Appendix 1* & *Appendix 2*).

The first freezing took place in the inner bays of the Bay of Bothnia at the end of October. Within a month, the glacial area was around 4.000 km^2. By the end of 2017 the ice extent reached 13.000 km^2. During the end of January, a change in the conditions was noticeable, as the ice extent reached up to 73.000 km^2. Generally speaking, the ice thickness in the area is wide-ranged from 20 to 40 cm. In February, the belief regarding the severity of the winter changed from mild to normal as the glacial area exceeded 115.000 km^2. The weather conditions followed a similar pattern as the Arctic's cold air flowed from the east and extended the glacial area to 146.000 km^2. The peak of the ice extent was on the 5th of March where it reached about 170.000 km^2. Thereafter, the ice conditions slowly started to decrease with the only exception being around the middle of March. The glacial area started expanding again for a brief period of time, resulting from a combination of the low pressures subsiding and a flow of cold air which expanded the glacial area. Finally in April the ice extent shrank to a large degree, which by the end of the month was approximately 36.000 km^2 (FMI, n.d).

In *figure 3*, the progress of the ice extent is illustrated. The ice extent begins expanding during November and December and there is a noticeable increase during January and especially February. It reaches its peak during March with a glacial area of approximately 170.000 km^2. In general, it slowly started to decrease during April and May (Sjöfartsverket, 2019).

Figure 3.The progress of the ice extent during the winter season of 2017-2018 in the Baltic Sea. Sjöfartsverket (2019).



Emphasizing in the area of Bay of Bothnia, the traffic restrictions were enforced for the season's first time on 6th of December, while the toughest ones were enforced on 7th of February. The restrictions required a minimum of IA ice class notation as well as a minimum of 4000 DWT for all vessels sailing in the area. The traffic restrictions were enforced for all Finnish and Swedish ports in the Bay of Bothnia. The traffic restrictions were gradually lessened towards the end of April until they were finally completely lifted on 23rd of May, where the ice conditions slowly ceased to exist (Sjöfartsverket, 2019).

Sjöfartsverket (2019) also states that throughout the largest part of the winter season, the demand for IB assistance was extensive. The Swedish IBs along with the Finnish IBs operated collectively in the Bay of Bothnia where they assisted in convoys. The first IB assistance in the area was conducted on the 4th of January, while the final IB assistance of the season was provided on the 27th of April.

2.6 Statistics of the Winter Season of 2017-2018

Sjöfartsverket (2019) compares the average waiting time in Swedish ports, going back to 2003, only excluding data from the winter season of 2009-2010. Out of the 17 seasons included, the IB waiting time has exceeded the objective of keeping it below 4 hours, only 4 times, including the season 2017-2018. The average waiting time for IB assistance was 4 hours and 13 minutes for all Swedish ports.

Sjöfartsverket (2019) also states that for the winter season of 2017-2018, 1355 instances of IB assistance were conducted in total. Out of these instances, 53 (3,9%) have been provided to Swedish vessels while the rest 1302 (96,1%) to foreign vessels. Furthermore, operating expenses for the IBs were calculated to be around 292 million SEK while other expenses, such as the renting additional IBs, administration costs etc. were around 27 million SEK. However, Sjöfartsverket received an income of about 12 million SEK resulting from funding from the EU and other sources. Therefore, the net cost for IB assistance was approximately 307 million SEK.

3 Methodology

In this chapter, the research methods used in the study are described together with how the data analysis was conducted. Additionally, considerations concerning reliability, validity, generalizability and ethics have been expressed.

3.1 Research Methods

This research has been carried out by utilizing not only technological but human-factor methodologies as well. A mixed method approach has been selected as it allows the researcher to verify the validity as well as it increases the accuracy of one method's results against the findings of another method (Denscombe, 2010). Therefore, this research's data collection consisted of two primary sources. Interviews with valuable and experienced individuals followed by a collection of vessels' waiting time for IB assistance data in the Bothnian Bay for the period of January to April of 2018. It is believed that by utilizing the above-mentioned research methods, the amount of information would be significant to produce prosperous results that would enable the researchers to sufficiently and in depth investigate and comprehend the researched topic.

A deductive approach has been selected for the analysis of the data. This approach allows the researcher to evaluate a hypothesis by testing it against different data (Gilgun, 2019). In the case of this conducted research, a hypothesis has been formulated according to the studied literature on the topic. The hypothesis examined the reduced ice-going capability of the vessels having been constructed after the enforcement of the EEDI regulations, which is a commonly suggested viewpoint among the studied literature. The formulated hypothesis has later been tested against the interview findings along with the results from the analysis of the vessel's waiting time.

3.2 Data Collection

As aforementioned, two primary sources of data collection have been selected, as part of the mixed methods approach for this research. Through the conducted interviews, data was collected aiming to captivate the level of understanding and overall experience of the professionals operating upon the researched topic. Furthermore, real world data was collected in order to improve the understanding of the operating capability of the FSWNS, by emphasizing on the conducted IB instances and on its waiting time in the Bay of Bothnia between January and April of 2018.

3.2.1 Interviews

The conducted interviews were chosen to be semi-structured. According to Denscombe (2010), semi structured interviews allow a specific set of topics to be addressed while the participant is encouraged to develop ideas and express themselves more freely on these topics as well as to provide greater emphasis on areas that are of interest to the participant. It is believed that such types of questions are more appropriate and fitting, taking into account the variety of background, experience and roles of the participants. Moreover, semi-structured open-ended questions have the attribute of being able to provide data that the conductors did not expect nor had any knowledge about. Open-ended questions were drafted prior to the interviews, but the objective was to allow the interviewees to narrate themselves through the interview and emphasize on the topics they wish to. Follow up questions have been asked in order to ensure that the requested information needed for a concrete assessment had been acquired. Furthermore, due to the variety of the participants' location and the current COVID-19 situation, the interviews have been conducted through the following online meeting applications; Zoom and Microsoft Teams. The remaining follow up questions (concerning e.g., verification of correct interpretation of information and any uncertainties arising from the data analysis) were conducted through email.

The target groups for the interviews were employees of the Finnish and Swedish maritime administrations, shipping companies' representatives, researchers as well as individuals operating in the research topic. The participants were able to provide practical information gained from years of experience and they were separated among two different target groups, authorities and non-authorities. The respondents had fundamental experience with the ongoing EEDI regulations (Phase 0 - Phase 2) as well as had the prospect of maintaining their positions and involvement until and beyond Phase 3 of the EEDI regulations (2025 and onwards). Additionally, the selected participants had experience with and knowledge of the FSWNS and they were familiar with its components.

Interview participants were contacted via either their personal or professional email. As previously mentioned, the experience and contacts within the research field that the researchers had prior to the conduction of this research was limited. That fact, along with difficulties including in the interviews process representatives of certain companies and individuals, resulted in the identification of interview participants through other participants and their own contacts. Both upon the first encounter with possible participants and in the beginning of each interview, the researchers provided clear information regarding the research itself and the objective of these interviews. Additionally, all participants were informed to answer as many questions and to whichever extend, they felt comfortable. All interviews were recorded, only after participants gave their consent, in order to allow the researchers to easily and accurately transcribe them and later on analyse the results without jeopardizing their validity. All interview recordings were soon deleted after accurate transcription was completed. Lastly, taking into account the ethical considerations, no information that could negatively affect or cause disturbance to any individual, company or organization was published in this research.

3.2.2 Maritime Data

SMA has provided data concerning the merchant fleet's waiting times, in the bay of Bothnia during the period of January 2018 to April 2018. In detail, the data concerns the durations, positions and description of all waiting time instances for the merchant fleet operating in the area. The majority of those instances refer to merchant vessels waiting for IB assistance. However, there are records of waiting time unrelated to IB assistance which have also been analysed.

When assessing the ice-going capability of the assisted vessels, the collected quantitative data, together with a sample of 24 vessels was used. In order to compare the ice-going capability of the vessels constructed prior to and after the EEDI regulation, the vessels' required power as per FSICR was necessary. Traficom has provided the required power for a sample of 24 vessels. This information has been later on been used to calculate and compare the ice-going capability of vessels of various DWT and construction years. The sample of 24 vessels consisted of ships meeting the following criteria. A FS ice class of IA, general cargo vessel, a construction year between 2018 to 1996 and DWT range between 5.000 and 9.000. The criteria were primarily set by the characteristics of the assisted vessels. The majority of both the assisted ships as well as the EEDI ships in the collected data shared several similarities which contributed to these criteria selection. The vast majority were general cargo ships, with a FS IA ice class attained and of similar DWT range. The representation of these criteria was strong throughout the set of data. It is believed that the sample vessels, having carefully been selected, can provide strong indications about the ice-going capabilities of the EEDI vessels as well as in comparison with the rest of the assisted vessels.

3.3 Data Analysis

Selecting the appropriate analysis method for the interview data collected was of great importance. According to Braunand and Clarke (2006), thematic analysis is a qualitative data analysis method that is used for identifying, analysing and eventually reporting the results through several selected themes within the data. Hawkins (2018), suggests that this analysis method provides an extensive understanding of the total experience gained through a series of interactions, in this case interviews, and it is best suited in cases where the researcher's prior knowledge on the investigated topic is limited, which is among the reasons it was selected.

Hawkins (2018) also states the importance of the researcher to get familiar with the set of data and locating the themes according to their occurrence. In detail, themes can be selected through either information that has been stated specifically or that has been implied. Bearing in mind that the questions used in this research were semi-structured, which allowed the participants to emphasize on areas they thought of great importance, thematic analysis is therefore believed to be the appropriate method of analysing such interview results.

Due to the specific selection of participants required to meet high standards in terms of experience, several patterns in their responses were identified. However, as a result of the aforementioned semi-structured interviews and open-ended questions, repetitions among the answers as well as instances where participants were shifting outside the research's scope have been experienced. Thematic analysis provided the means to determine the prevalence, relevance and significance of ideas communicated (Hawkins, 2018). In detail, after the transcription of all interviews took place, a familiarization with the data has been performed. Due to the type of questions being open-ended, a selection of the answers, including the most relevant ones to the topic, was necessary in order to conduct a sufficient analysis. Therefore, by excluding repetitions in the answers as well as redundant information to the topic subject, the identification of patterns in the answers became easier.

The themes that met the criteria have been highlighted among the total set of data with different sets of colours, with each colour representing one theme. Using this method, the themes were visible among the whole set of data which enhanced the process's efficiency. Later on, the themes were transformed into significant to the topic categories, as for instance the "Increasement of the IBs capacity", which laid the foundation of the interview results.

However, the aforementioned interview data was not the only source of data collected and analysed in this research. Shortly after obtaining the maritime data, effort was put into validating them in order to ensure there are no major errors in them. Such actions consist of a comparison between waiting times for different time periods as well as for the total area of the Baltic Sea during the same period. Additionally, each instance of waiting time comment has been read ensuring the waiting time is correctly classified either as for IB assistance or as an unrelated waiting time. As Denscombe (2010) suggests, our initial analysis step was grouping the data in order to increase the levels of comprehensiveness. Therefore, the data has been separated into two categories, the IB waiting time instances and the unrelated waiting times. Furthermore, several statistical calculations have been conducted in order to get results for the analysis. Furthermore, the online tool Plotty has been used in order to plot the geographical locations where the waiting time took place using SMA's provided longitude and latitude. Additional information regarding the particulars of the vessels has been extracted from the maritime database *Sea-Web*.

In order to compare the ice-going capability of vessels constructed prior and after the enforcement of the EEDI regulations, a sample of 24 vessels has been selected out of the total number of assisted vessels. The hypothesis that the newly constructed, EEDI compliant vessels have a reduced ice-going capability in comparison with the older vessels has been tested. The emphasis on a sample of 24 vessels has been given due to difficulties arising from acquiring and handling all necessary information from the total population. The selection of the sample vessels has been conducted after ensuring that they are meeting a number of set criteria. The reasoning behind the set criteria was due to the EEDI vessels' specifications which determined among others the DWT range. A range of 5000 – 9000 DWT has been selected since the majority of the vessels as well as the EEDI vessels' DWT was among this range. It was found that the type of the vast majority of the total assisted vessels and the majority of the EEDI assisted vessels, is general cargo. Therefore, this ship type has been selected as one of the criteria, as it is believed that the indications would be stronger if emphasis was given on the dominant and the same ship type in the area. Lastly, ships with IA ice class have been selected to consist of the 24 sample vessels. The reasoning behind such a decision was the following. Firstly, the vast majority of the assisted vessels were classified with IA FS ice class, along with all assisted EEDI vessels. Secondly, the vessel's required power as per FSICR, has been used to compare the ice-going capability of the assisted vessels, which is determined by the obtained FS ice class. Therefore, any comparison would be beneficial as long as the parameters of the required power were similar.

The researchers' aim was that DWT of the selected vessels would vary while simultaneously their construction years would vary as well. In detail, various vessels have been selected provided that their construction year followed a linear pattern similar to the EEDI's vessels. Taking into consideration that two-thirds of the newly constructed EEDI assisted vessels met the set criteria, along with the fact that their construction year varied from 2018 – 2013, the selection of the rest sample vessels has been conducted accordingly, from 2012 and earlier. A linear pattern was noticeable until the year of 1996, thereafter the construction years of the vessels were scattered and varied to a great extent.

3.4 Reliability, Validity and Generalizability

When conducting interviews, Desecombe (2010) argues that it is difficult to achieve objectivity and consistency since the results are, to some extent, impacted by the interviewer and the context of the interviews. The qualitative data collected from this research method is considered unique due to the specific individuals involved, both interviewers and interviewees, and the specific circumstances for the interview occasions. This furthermore has an adverse effect on the reliability of the conducted research, which was to be taken into consideration when analysing the corresponding findings.

Furthermore, Desecombe (2010) states that it is important to include efforts to ensure that the data from the chosen research methods has been collected accurately and precisely in relation to the researched topic, which stipulates the validity of the study. These efforts consist of making sure that the gathered data has been appropriately collected and analysed for the purposes of the conducted research (Desecombe, 2010). Additionally, Frey (2018) suggests that the importance of validity is high since it determines the extent of how justified the outcomes of the research are. As a result, it mitigates the presence of inaccuracies and the impact of external factors in the results of the research.

In the first step towards validating the data, the authors assured themselves that the data received or used did not contain any errors, which is the duty of the researchers, to inspect the data and check them against their sources in order to make sure that they are valid. Desecombe (2010) also suggests that, if the data is to be considered as valid, then the researchers must make sure that e.g., the respondents have provided the same kind of answers to similar kinds of questions and commonly provide their opinions in a consistent manner. Another important aspect for validation is to consider if other researchers would, to a large extent, arrive at similar conclusions when analysing the same set of data. Consideration also needs to be given to possible alternative explanations of the research results. Additionally, the validity of the data can also be assessed in terms of to what extent the finding from the conducted study can be generalized (Desecombe, 2010). More about the reliability, validation and the generalizability of this research is described in the Discussion chapter (*see 5.1.1 Reliability, Validation and Generalizability*).

3.5 Ethical Considerations

Darley et al. (2009) suggests that ethical considerations should be taken into consideration throughout all the research's stages. Even though ethics was a defining factor in all the decisions concerning the completion of this research, particular emphasis was given on ethics regarding the conduction of the interviews along with the management of their results. In the beginning of each interview the participants were being informed regarding the type and structure of the interviews as well as in respect of their liberty to answer as many as they feel comfortable to. Additionally, the interviews were recorded only after receiving the participants' consent and the recordings were immediately deleted after the transcription of the interviews was completed. The protection of the data from the interview participants was highly regarded throughout the interview process. Lewis-Beck et al. (2004) argues that anonymity is a crucial element of ensuring the participants' rights and the full anonymity of the participants in this study has thus been preserved. Nothing but some partial information regarding their role and experience has been mentioned in this report, only aiming to highlight the credibility of their responses.

Similarly, regarding maritime data, ethics was a matter taken into consideration. No sensitive information has been disclosed that could potentially harm the vessel, the crew, its owners or the authority providing the data. Concerning the required power provided by Traficom for the 24 sample vessels, as per FSICR, no correlation has been made between that and any individual vessel, as requested by the competent authority.

When selecting the sample vessels, ethics has been taken into consideration as well. As aforementioned, acquiring and handling all necessary information for the total population was found to be challenging and therefore emphasis has to be given on a 24-vessel sample instead. In order to create a shortlist of sample vessels, focus has been given into accurately representing the total population and setting criteria that would provide strong indications about the development of the ice-going capability of the assisted vessels in relation with their construction year. That has been achieved by identifying a DWT range that represents the majority of the population and similarly a ship type that is widely represented among the set of data.

Additionally, even though a hypothesis has been tested, particular attention has been given to not select vessels according to the degree they would affect the outcome of the analysis. For instance, the installed power of the vessels has not been taken into account when choosing the sample vessels. After ensuring that the vessels met the aforementioned set criteria, the final sample of the assisted vessels was randomly selected.

4 Results

The results presented arose from analysis of the conducted interviews and the maritime data obtained from the SMA and FTIA, referring to the period of January to April of 2018 for the Bay of Bothnia.

4.1 Interviews Results

The results of the conducted interviews with both target groups, namely authorities and non-authorities, are expressed in the topics surrounding the operating capability of the FSWNS and how it is influenced by the EEDI regulations. These topics intend to provide indications concerning what kind of influence, as well as to what extent, the EEDI regulations of Phase 1 (2015-2020) might have had so far on winter navigation in the northern Baltic Sea region.

Impact of EEDI on ice navigation in the Baltic Sea

Based on experience from several of the interviewees, there is a clear indication of a decrease in the ice-going capability of the merchant fleet operating in the Baltic Sea. Reason being e.g., the recent modifications on the ship design with reduced ice strengthening, weaker engines with reduced power output and reduced speed. All of these measures are implemented to increase the open water efficiency but as a consequence the ice-going capability has been reduced. However, a large part of the participants revealed that it's not easy to determine the extent of the impact of the EEDI regulations considering that the majority of the fleet does not have to comply with these regulations, since they have been constructed before the regulations come into force. The EEDI compliant ships will arguably remain a small minority in the Baltic Sea for the next upcoming years.

Another factor making it difficult to estimate the extent of the EEDI-impact is the fact that the authorities do not usually take the EEDI compliance of the assisted vessels into consideration when measuring and analysing the key performance indicators (KPI) of the FSWNS. One example of such KPI is the IB waiting times. Furthermore, the kind of impact vessels with less ice-going capability will have further on is also difficult to predict since the KPIs are strongly linked with the prevailing ice conditions.

Demand for IB assistance since the enforcement of the EEDI regulations

The common opinion among the participants is that there has not been any clear change in the demand for IB assistance since the enforcement of the EEDI regulations. Even though the majority has the belief that eventually the EEDI regulation will affect the ice going capability of the vessels. Moreover, the amount of time since the enforcement of the regulations that has passed was considered not sufficient in order for any conclusive results to be produced. The number of current EEDI compliant vessels is believed to be too limited to noticeably affect the demand for IB assistance. Another element to take into consideration is the severity of the ice conditions. The majority of the past winters were categorized as rather mild and as a result the actual effect of the EEDI compliant vessels in the demand of IB assistance is challenging to accurately assess.

Assessing the changes in the operating capability of the FSWNS for the past decade
As previously mentioned, a common belief according to the respondents is that the operating capability of the FSWNS is deeply affected by the severity of the winter and more precisely, its prevailing ice conditions. Major improvements have been identified in terms of the cooperation

between Finland and Sweden contributing to more efficient operations. Accordingly, the capacity of the IBs have been varying over the years. Both for the Finnish and for the Swedish side, the number and type of IBs have been altered throughout the past years. The alteration in the IB fleet is due to decision making regarding the IBs fleet renewal as well as not to renew contracts with third parties contributing with auxiliary IBs. Additionally, authorities decided to obtain IBs with different design specifications, which can contribute to a greater extent, following the trends of shipping, e.g., ships with wider hull design.

Furthermore, several viewpoints have been expressed regarding achieved improvements over a wider time frame, during the past 30-40 years, which are contributing to the increased operating capability of the FSWNS. More explicitly, the identified improvements refer to technological advancements in the field of meteorology, achieving more precise weather predictions and more accurate registration of the prevailing ice conditions. Moreover, technological advancements have been noticed in the tracking of the vessels, which have resulted in a more efficient ice navigation management as well as through the traffic restrictions. The new IBs added to the fleet tend to have better optimized hulls and to have increased energy efficiency compared to the older ones, which have resulted in reduced fuel consumption.

Current IB resources

Concerning the current amount of IBs in the Baltic Sea as well as their respective size, engine power and overall ice going capacity, it was concluded that their level of sufficiency is significantly dependent on the severity of the winter season. A really cold winter will cause a large extent of thick ice in the northern Baltic Sea that will stay for a considerably long period of time, thus putting high demands on the available IBs in the area. If the trend of frequent mild winter seasons, with short durations, continues to occur, it was suggested that it would be beneficial to invest in smaller IBs, which usually has a higher speed and overall causes less pollution. When being used they also allow for the bigger IBs to stay standby and they can even be used in the early/late stages of a more severe winter season. However, it was also stated that there might be a need for bigger IBs in the fleet, concerning the global trend of designing bigger and wider merchant vessels in order to increase the cargo capacity. Wide merchant vessels in need of assistance require wide IBs in order for the IBs to make the ice channel wide enough for them to pass through. In the worst-case scenario, only one IB will not be enough to assist a really big vessel, which then would require 2 IBs to simultaneously assist that one vessel (furthermore referred to as 2-IB operation). If this phenomenon occurs on a larger scale, it will most likely require the current IB fleet to be expanded or at least partly renewed.

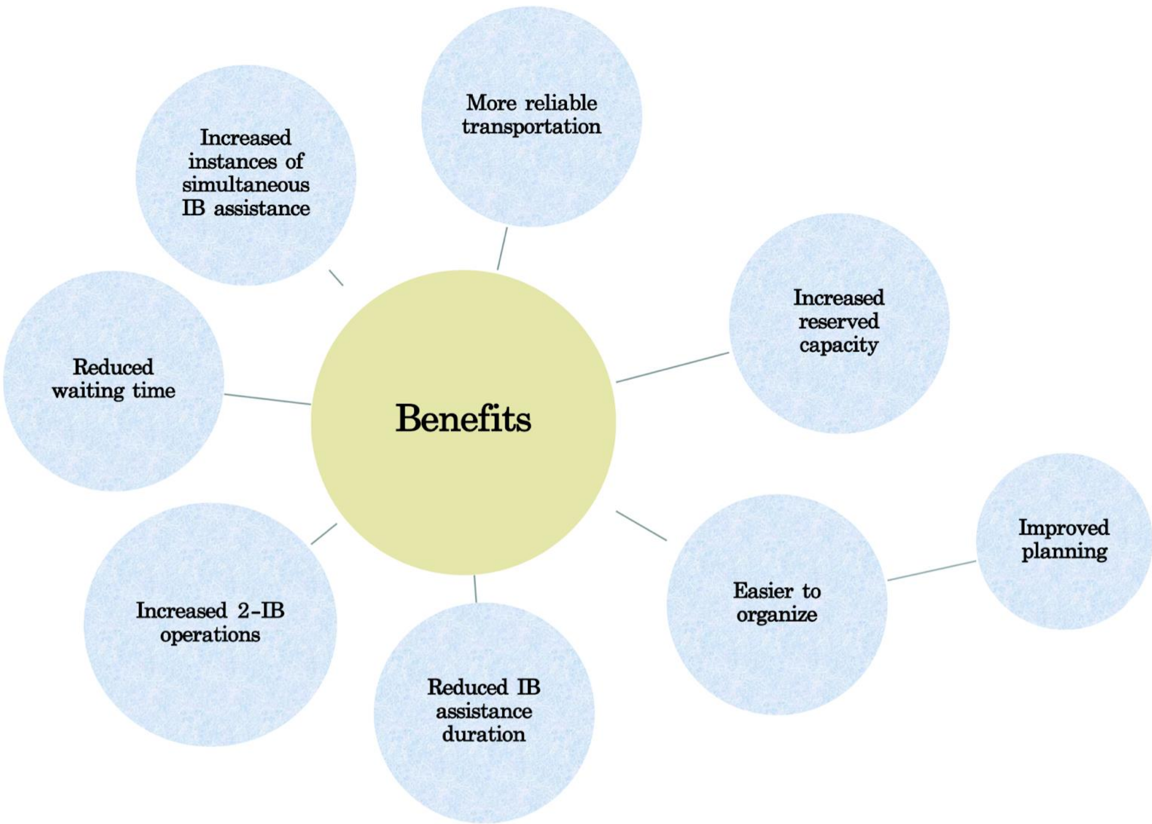
However, the IB resources currently in use are believed to be somewhat sufficient. At least they have been sufficient in the past years, taking into consideration the winter severity of the past decades, with some exceptions of a few winters that have been slightly more severe, and the fact that the authorities usually manage quite well in achieving their target of not letting the average IB waiting times to exceed 4 hours.

Additionally, it was suggested that for future investments in new IBs to seek more environmentally sustainable IBs. One of the important standpoints which determines if a ship is considered sustainable, is the type of fuel being used. As it is right now, the majority of the IB fleet in Finland and Sweden are running on diesel oil. In order to make the fleet more environmentally sustainable, by causing less emissions to the air and the ocean, it was suggested to use IBs with less polluting fuels such as LNG.

Increasement of the IBs capacity

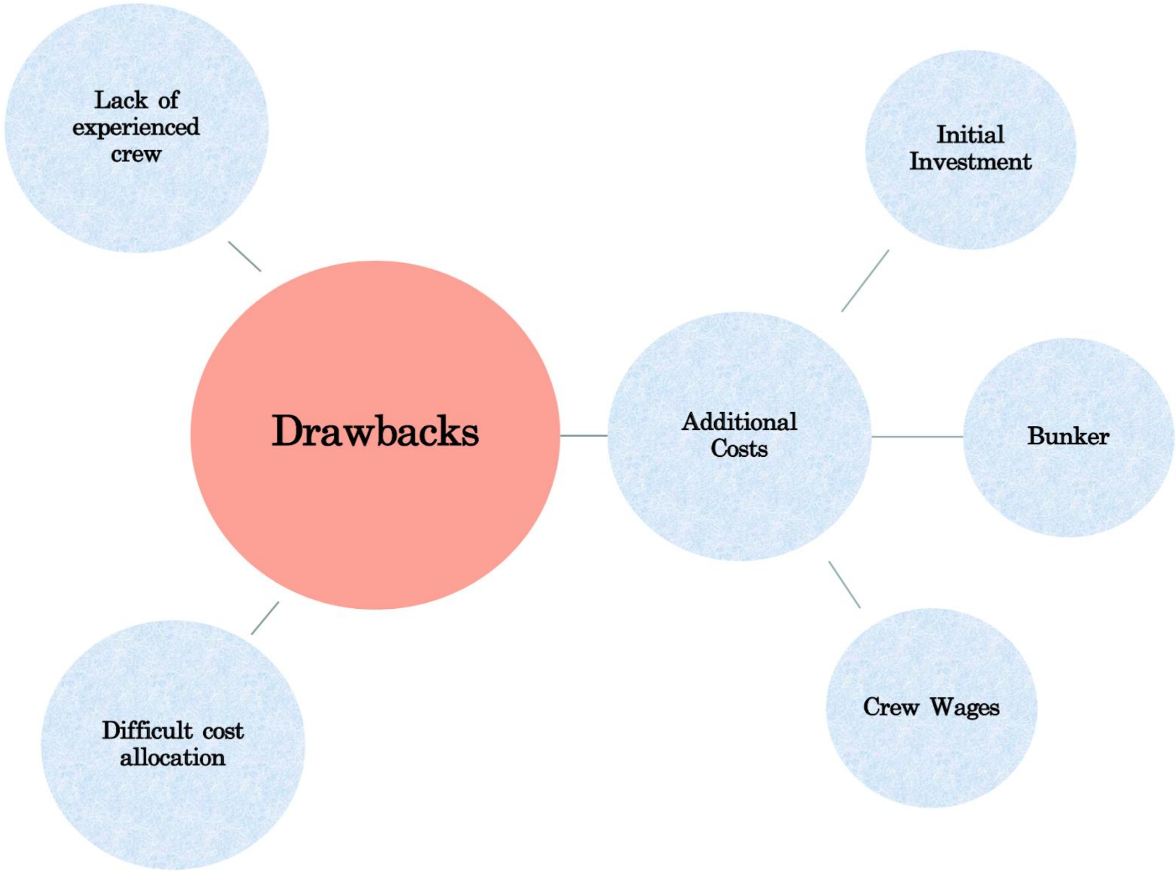
According to the conducted interviews, an increase of the IBs capacity would produce several benefits which are displayed in *figure 4*. Throughout the interviews several upsides have been identified that would be achieved by increasing the capacity of the IB assistance, such as an increase in both the reserved IB capacity and the instances of simultaneous IB assistance. At the same time, due to the increased IB capacity, the IB assistance duration would be reduced as well as its waiting time for such assistance. Following the trend of shipping for larger and wider commercial vessels, an increased IB capacity would allow the IBs to conduct 2-IB operations, for which there is an increasing demand. Furthermore, the respondents argue that the increased IB capacity will not only impact on an individual level, by reducing the individual ships' waiting time, but would also impact on a holistic level. The transportation in the area as a whole would benefit as it would be more reliable. Lastly, it has been suggested that by increasing the capacity of the IBs, the FSWNS would be able to organize its operations with less effort, which subsequently leads to improved operations planning.

Figure 4. Benefits of increasing the IBs capacity. Authors own copyright with data from the conducted interviews.



On the other hand, the participants have also expressed considerable concerns regarding that proposal as displayed in *figure 5*. In detail, the most highlighted drawback of an increase in the IBs capacity is the additional cost arising from such investment. Due to the significant initial cost of the investment, there are some expressed difficulties related with the allocation of such costs. The decision making behind any IB acquisition is a complicated and time-consuming procedure. Except for the initial cost of the investment, the additional expenses of the bunker and crew wages are also believed to be considerable. Moreover, identifying an appropriately experienced crew is regarded as challenging due to the high level of experience and skills required in an IB crew.

Figure 5. Drawbacks of increasing the IBs capacity. Authors own copyright with data from the conducted interviews.



Alternative options to secure efficient operation within the FSWNS

Apart from increasing the IBs capacity, it was found that there are other options to secure a more efficient and secure operation within the FSWNS. One of the alternatives is to reconsider and make alterations of the FSICR. The Finnish and Swedish authorities, which are responsible for developing these rules, cannot directly affect the engine power of the vessels but they could focus more on having rule requirements that affect how well the ships can be assisted. In more detail, it is believed that there is room for improvement in e.g., the requirements for what kind of towing arrangement the ice classed vessels should have, the type of bows to allow and also requirements concerning what ballast draft the ships should have. The ballast draft is important to make sure that the propellers are properly submerged in order to avoid any ice interaction as far as possible.

Another measure that was frequently mentioned was the recruitment of experienced personnel among the seafarers, and especially among the captains, to the IBs. Having personnel with experience of winter navigation in ice fields is considered as a vital component for safe navigation within the FSWNS. The reason is that the IB assistance operations are quite complex since they frequently require difficult decisions to be made, e.g., on how to assist a ship that is stuck in the ice, how to arrange different towing operations and how to establish an efficient communication and cooperation with the ships in need of assistance. It was also mentioned that having a crew with experience of difficult ice conditions is important for the merchant vessels as well, since their actions and decisions have a big impact on the execution of each assistance.

More specific routes in the Bay of Bothnia could be beneficial as well. The formation of narrow passages further down from the Gulf of Bothnia could improve the navigation system since all ships could potentially pass from almost the same point during winter time as during summer time, which is already being done to some extent. If this were to be done on a bigger scale, it would arguably decrease the demand for IB assistance.

Furthermore, it was suggested that the governments of Finland and Sweden should develop a system that supports shipowners who want to invest in ships with a high ice-going capability. It is yet unknown if it would be economically beneficial to financially support shipowners who want to invest in ships with high ice going capability compared to having a big IB fleet. One of the significant benefits of these ships was expressed as; their ability to navigate more independently in ice, which would decrease the demand for IB assistance.

Fairways fees' link with IB operations

All costs deriving from IB operations are borne by the respective governments of Sweden and Finland. One way of financially supporting these IB operations was described as collecting fairways fees by the merchant vessels when entering waters of Sweden and Finland. These fairways fees are collected by the respective governments and are intended to cover, at least partly, some of the costs that derive from the IB operations such as salaries, maintenance, fuel, rented resources and administration. The regulations concerning these fairways fees are up to the governments to be decided upon. Furthermore, it was stated that paying the fairway fees gives the merchant vessels the right to receive IB assistance and the corresponding waiting time for such assistance should on average be less than 4 hours, in accordance with SMA's goal for average IB waiting time.

Guidelines for IB assistance

Provided that the vessel requiring IB assistance is eligible for such assistance, the IBs will proceed according to the regulations and guidelines issued by the competent authorities of Finland and Sweden. The annual winter reports of both countries hold information on how the IB assistance is to take place, along with instructions displayed on the website www.baltice.org, which is a common initiative of all Baltic nations.

Nevertheless, the IB assistance often tends to be a complicated procedure as it is much dependent on several external factors. The level of experience of the IB crew and the ship requiring assistance, as well as the prevailing ice conditions are believed to be defining factors. Furthermore, the specifications of the vessel affect the extent of the offered IB assistance as for example the necessity of towing the vessel.

Moreover, some viewpoints have been expressed regarding further advancements in the IB assistance's common practice. It is believed that minimizing the IBs' fuel consumption should have a greater impact on how the assistance is to be conducted, rather than minimizing the duration of the procedure. Thus, further emphasis is suggested to be given to the environmental perspective of the IB assistance, as plenty room for improvement has been identified in that area.

Ice Conditions

From the conducted interviews it was stated that the ice conditions have generally not changed much in the past few years. For the past few decades on the other hand, it was argued that the ice conditions have decreased and the length of the winter seasons has shortened. It was also mentioned that it will take several decades before any considerable change with milder ice conditions, compared to the ones we are used to experiencing nowadays, will occur. However, even in times with reasonable light ice conditions and mild winters, every now and then severe and challenging winters are expected to take place, which will put immense pressure on the FSWNS.

4.2 Waiting times Data

The data collected during this study mainly consisted of IB waiting times in the Bay of Bothnia, meaning the amount of time a vessel that is located in the area had to wait before receiving icebreaking assistance and thus being able to carry on with its voyage. Apart from the waiting times for IB assistance, other types of waiting times that could be of interest when monitoring the activities in the Bay of Bothnia were included in the collected set of data. In detail, these additional recorded waiting times consisted of vessels waiting for a pilot to arrive, waiting to berth, waiting due to extreme weather conditions and lastly, a number of various causes which were categorized as "others".

Emphasis was primarily given on the waiting times concerning IB assistance. Reason being that the duration of the waiting time for IB as well as the efficiency of the overall IB services determine to a great extent the operating performance of the FSWNS. Furthermore, it is an area where the authorities can, to a large degree, influence via their decision making, in comparison with some unrelated to IB services waiting times, which they are unable to affect or mitigate.

4.2.1 Waiting times for IB assistance during January - April 2018

The data provided by the Icebreaking Management department of SMA, concerned the waiting times in the area of Bay of Bothnia for the winter season of 2017-2018. More specifically, the data referred to the period of January to April of 2018 where the IB assistance was provided in the area. Except for the IB waiting times recorded during the same period, there are also records unrelated to IB assistance waiting times which provide interesting information.

The season's first assistance in the area was provided on the 7th of January and the vessel only waited for 40 minutes. The vessel was associated with the Finnish port Kemi and the IB assistance was provided relatively close to it. Similarly, the second IB assistance was carried out a few days later on the 11th of January. The vessel was associated with the Finnish port Tornio and its waiting location was also close to Kemi but southern compared with the first vessel. The waiting time was 1 hour.

On the other hand, the final IB assistance of the season was provided on the 27th of April and it was associated with the Finnish port Kemi. The duration of the waiting time was 22 minutes. Additionally, the same vessel was also assisted the previous day as well on 26th of January for the same port with a waiting time of 25 minutes.

Overall, in the Bay of Bothnia during January to April 2018 there have been 969 instances of IB assistance. As displayed in *figures 4* and *5*, out of the total number of instances, 715 were associated with Finnish Ports (74%) while 254 were associated with Swedish ports (26%). In total, there were 10 associated ports, 6 were Finnish ports and more specifically the ports of Kalajoki, Kemi, Kokkola, Tornio, Oulu and Raahe. Meanwhile there were 4 Swedish associated ports, Skelleftehamn, Luleå, Haraholmen and Karlsborg. Out of the assisted vessels, the Finnish port Tornio was most frequently associated with, 219 times, while the Swedish port Karlsborg was the least associated with, 19 times as per *figure 6*.

Figure 6. Associated ports of the assisted vessels in Bay of Bothnia during January -April 2018. Authors own copyright with data provided by SMA.

Country	Associated Port	Instances
FI	KALAJOKI	29
FI	KEMI	135
FI	KOKKOLA	148
FI	TORNIO	219
FI	OULU	86
FI	RAAHE	98
SE	SKELLEFTEHAMN	74
SE	LULEÅ	101
SE	HARAHOLMEN	60
SE	KARLSBORG	19

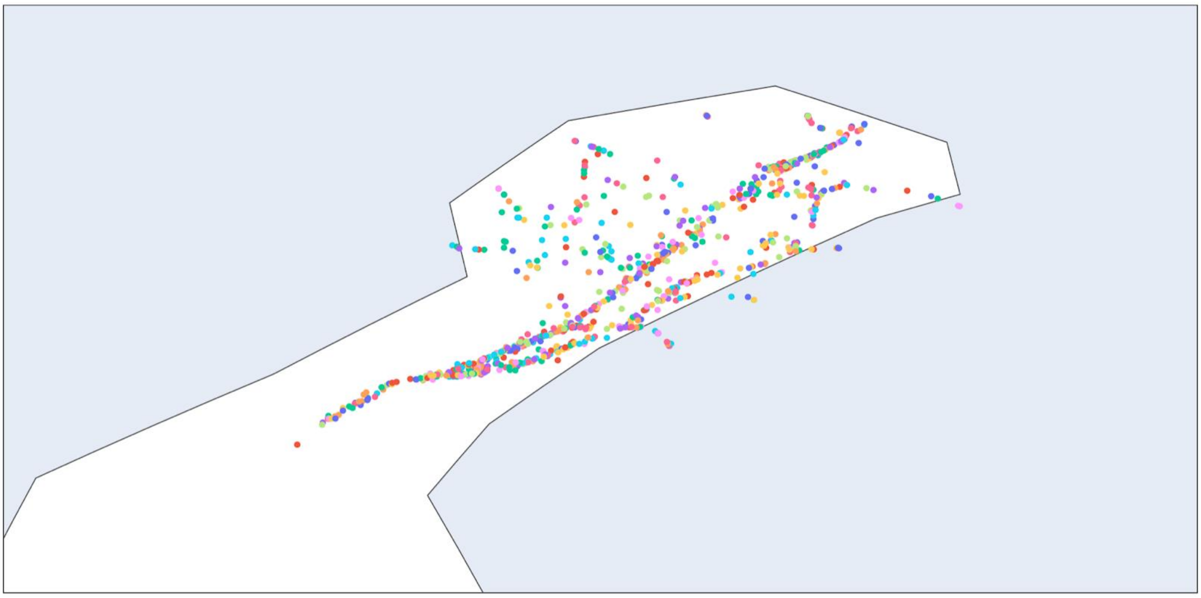
The common objective of Finland and Sweden is to maintain the IB waiting time below 4 hours. Overall, the average recorded waiting time in the Bay of Bothnia was 2 hours and 54 minutes. However, some extreme waiting times were recorded. The highest duration for IB assistance reached up to 30 hours and 36 minutes. Meanwhile, there were several cases where the minimum waiting time was theoretically zero. The standard deviation out of the total waiting time durations for all vessels was 3 hours and 30 minutes, while the median is 1 hour and 42 minutes.

Categorizing the vessels into two groups, Group A consists of the vessels where the authorities met their objective of a waiting time below 4 hours. On the other hand, Group B consists of the vessels where the waiting time exceeded the 4-hour objective.

Out of the 969 IB instances and for the majority of the vessels requiring IB assistance the FSWNS managed to keep the waiting time below 4 hours. More specifically, for 747 IB instances consisting of Group A and representing 77,1% of the vessels, the average waiting time was 1 hour and 25 minutes. The standard deviation was approximately 1 hour and the median was 1 hour and 12 minutes. Nonetheless, for Group B, concerning 222 IB instances and representing 22,9% of the total vessels, the average waiting time was 7 hours and 50 minutes with a standard deviation of 4 hours and 15 minutes and the median was 6 hours and 12 minutes.

In *figure 7* the vessels' locations are geographically represented while waiting for IB assistance. There are 969 IB instances displayed in the map chart, occurring from January to April of 2018. Somewhat closer to Finland, a formed line of instances is noticeable, where the majority of the instances took place with a shape similar to a spine. The formed line's beginning is approximately near the Finnish town Vaasa and it reaches up to the Finnish town Kemi. Several instances are visible and somewhat scattered near the Swedish coastal areas.

Figure 7. Geographical representation of the vessels' locations waiting for IB assistance in Bay of Bothnia during January -April 2018. Authors own copyright with data provided by SMA.



Even though the average waiting time in the studied geographical area was within the 4-hour target of the competent authorities, there have been several cases where the waiting time exceeded this target. Along with the aforementioned highest recorded waiting time of 30 hours and 36 minutes, there were in total 29 cases where the waiting time exceeded 12 hours. The reasoning behind such prolonged waiting times is not clear for all vessels. However, some information regarding the ships with the highest (30 hours and 36 minutes), third highest (23 hours and 30 minutes) and the fifth highest (19 hours and 42 minutes) waiting time was available. The reasoning for the highest waiting time is believed to be some strong wind power in the area which is likely to have resulted in relatively heavy ice pressure (FTIA, personal communication, June 11, 2021). When such ice conditions occur, the operating performance of the FSWNS is affected. It takes several days for the FSWNS to recover and to mitigate any delays in the IB waiting times.

For the third highest waiting time, the vessel is believed to most likely have been stuck on ice on its way out from a Finnish port towards its way to Skellefteå. The IB resources are regarded to have been far away from the vessel's location which resulted in its prolonged waiting time (SMA, personal communication, May 24, 2021). For the ship with the fifth highest waiting time, it is believed that the location of the vessel waiting for IB assistance was one the most defining factors (SMA, personal communication, May 24, 2021). The vessel's associated port was located in the port of Karlsborg, which is the northernmost Swedish port. As displayed in *figure 6*, the port of Karlsborg is the port with the most limited number of port visits. Therefore, the IBs require additional time transferring to the area from their current location in order to assist a single vessel.

4.2.2 Waiting times Unrelated to IB assistance

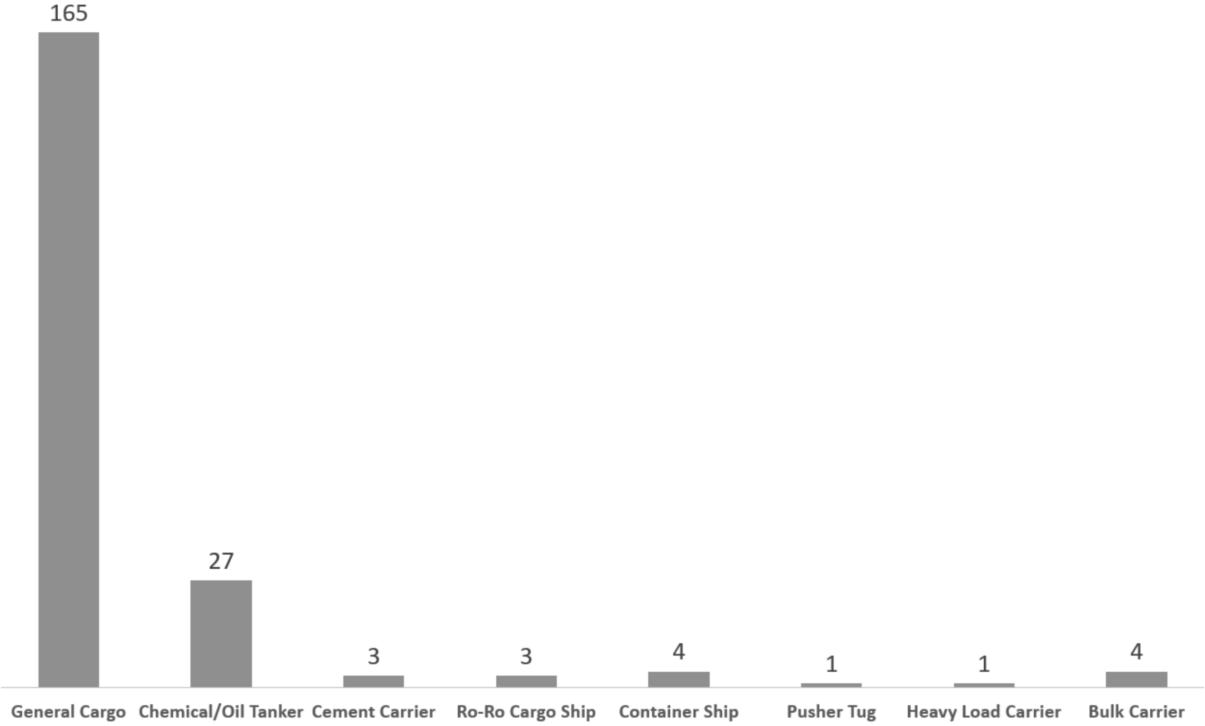
As aforementioned, among the data collected from Sjöfartsverket there were waiting times in the Bay of Bothnia during January to April of 2018 for reasons other than IB assistance. In detail, there were a total of 228 instances of waiting times unrelated to IB assistance. There were 100 instances unrelated to IB assistance waiting times due to vessels waiting for berths which was the majority, representing 44%. Accordingly, there were 77 recorded instances due to waiting for a pilot, representing 34%. Furthermore, there have been 50 instances where the vessel has been waiting for “Other” reasons, representing 22% of the total instances. Some examples of such reasons were waiting due to inadequate ballast, high traffic volumes, engine problems, not complying with IB orders and cargo operations among others.

4.3 IB Assisted Vessels’ Data

During the research period in the Bay of Bothnia 213 individual vessels have been assisted and have an average of approximately 4,5 IB instances per vessel. The minimum individual recorded IB instance per vessel was 1. There have been 40 vessels that have been assisted exactly once, while the rest 173 vessels have been assisted more than once and have an average number of 5,4 IB instances per vessel.

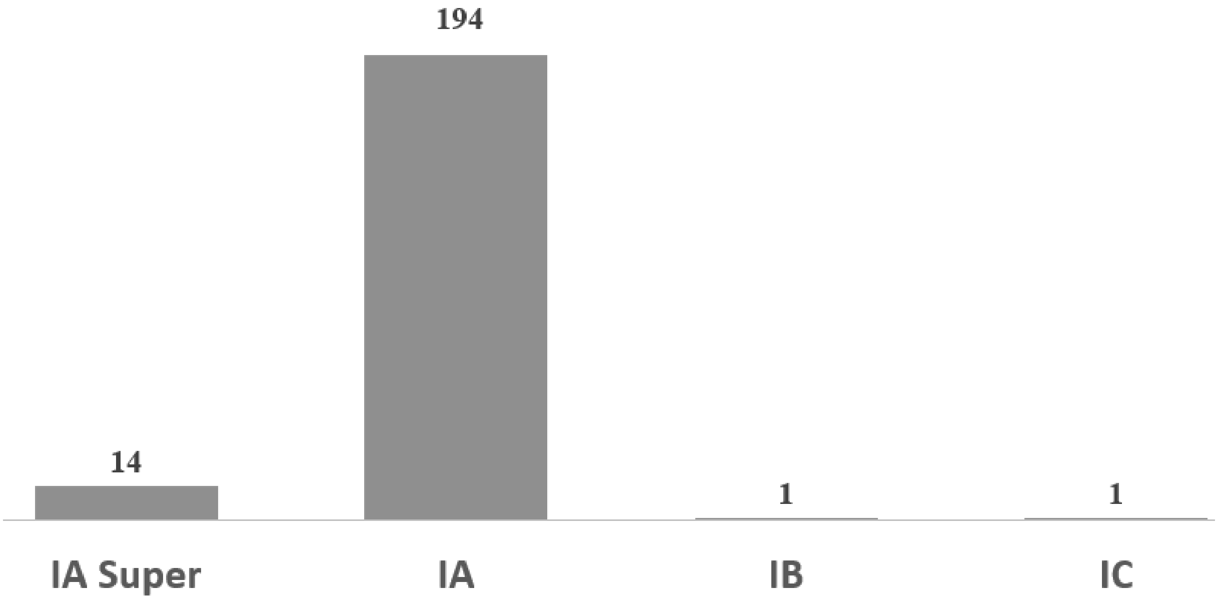
In detail and as displayed in *figure 8*, out of the 213 assisted vessels, the vast majority were general cargo ships. A small portion of the assisted ships concern chemical/oil tankers, while there is a limited presence of other various ship types.

Figure 8. The proportion of the different ship types of the assisted vessels in Bay of Bothnia during January -April 2018. Authors own copyright with data provided by SMA.



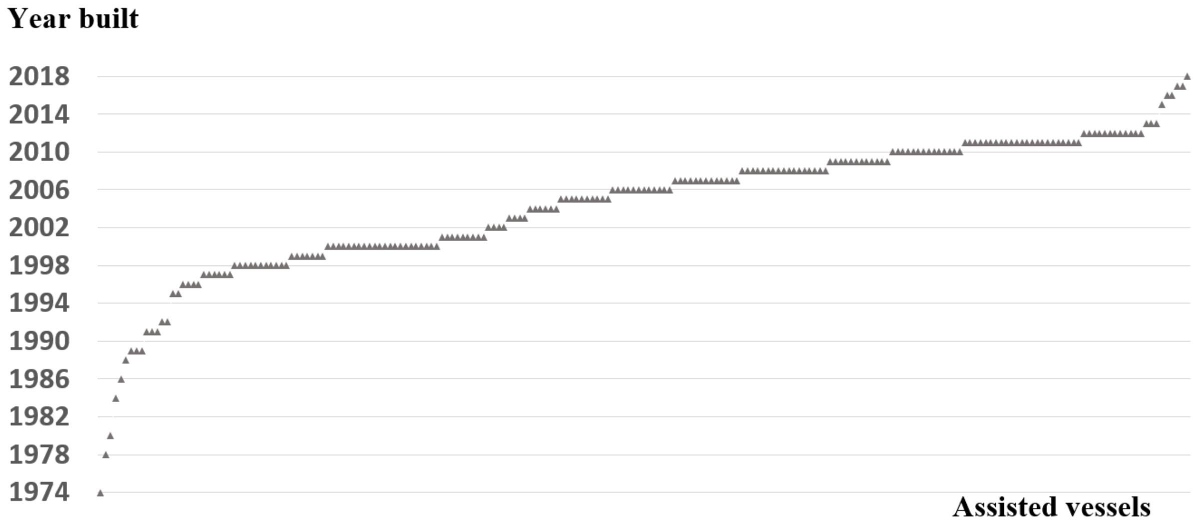
Except for the general cargo vessels dominating the ship type in the area among the IB assisted vessels, the most common FS ice class was found to be the IA as per *figure 9*. The second most attained ice class among the same population was the IA Super, with two single cases of IB and IC ice class respectively. The ice class of 3 assisted vessels was not possible to be extracted. The attained ice class for all of the EEDI vessels was IA.

Figure 9. The proportion of the different FS ice classes of the assisted vessels in Bay of Bothnia during January -April 2018. Authors own copyright with data provided by SMA.



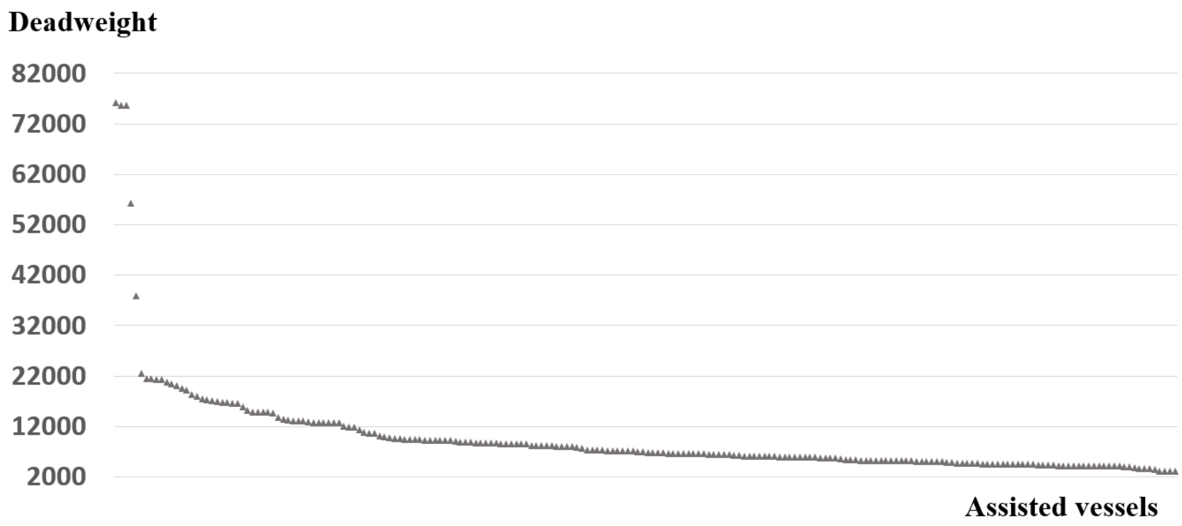
While the scope of this thesis is to investigate the impact of EEDI on the FSWNS, the results indicate only a few appearances of EEDI vessels among the whole set of data, as per *figure 10*. In detail, the vessels constructed after the enforcement of the EEDI regulations were found to be 9, representing 4.2% of the total number of assisted vessels. More specifically, the oldest vessel within the same set of data, had been constructed in 1974, while the newest vessel in 2018. In *figure 10* the vessels' construction year is displayed and the main concentration is noticeable from 1994 until 2014.

Figure 10. The construction year of the assisted vessels in Bay of Bothnia during January - April 2018. Authors own copyright with data provided by SMA.



As seen in *figure 11*, the DWT of the assisted vessels appears to be relatively low. The vast majority of the vessels have a DWT between 2.000 - 22.000. However, there are some exceptions displayed in the chart as well, reaching as high as almost 80.000 metric tonnes.

Figure 11. The DWT of the assisted vessels in Bay of Bothnia during January -April 2018. Authors own copyright with data provided by SMA.



4.4 Assessment of the Ice-going capability of the assisted vessels

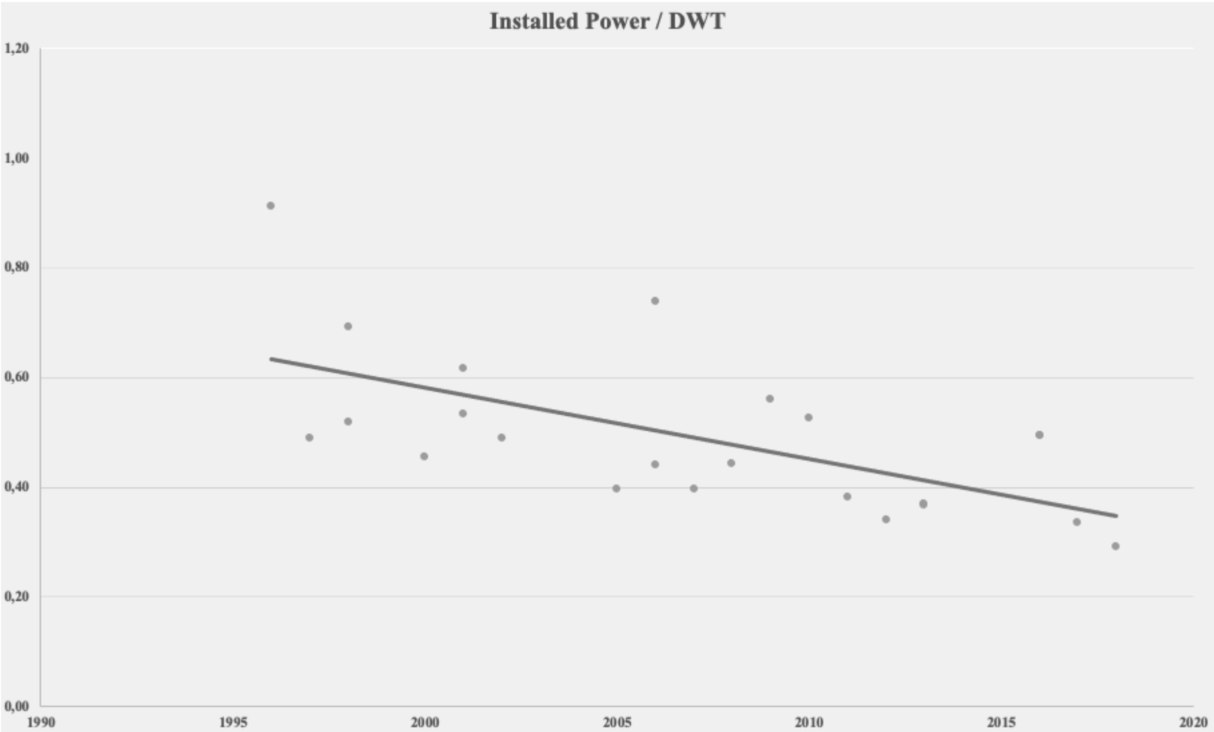
In order to assess and later on compare the ice-going capability of the assisted vessels through the years, three methods have been used. A sample of 24 vessels (named A-X) has been selected as per *figure 12*, where the construction year varied from 1996 up to the most recently constructed vessel among the set of data, in 2018.

Figure 12. The sample vessels list stated the ships' particulars, instances of IB assistance, the ice class and required power as per FSICR. Authors own copyright with data provided by SMA.

Sample Vessel	IB Instances	DWT	GT	Year Built	Total Power (kW)	Power/ dwt	Power/ GT	Ice Class	Required Power (kW)	Installed Power/ Required Power
A	1	6706	3618	2018	1950	0,29	0,54	IA	1608	1,213
B	9	5790	2990	2017	1950	0,34	0,65	IA	1650	1,182
C	24	5019	3405	2016	2484	0,49	0,73	IA	2398	1,036
D	7	5019	3405	2016	2484	0,49	0,73	IA	2398	1,036
E	3	8137	5667	2013	2995	0,37	0,53	IA	2900	1,033
F	7	8096	5751	2013	2995	0,37	0,52	IA	2900	1,033
G	4	5276	3739	2012	1800	0,34	0,48	IA	1800	1,000
H	5	5233	3500	2011	2000	0,38	0,57	IA	1900	1,053
I	5	7616	6120	2010	4000	0,53	0,65	IA	2932	1,364
J	11	7133	6046	2009	4000	0,56	0,66	IA	2932	1,364
K	1	6718	4695	2008	2970	0,44	0,63	IA	2730	1,088
L	6	6665	3990	2007	2640	0,40	0,66	IA	2549	1,036
M	8	6000	3990	2006	2640	0,44	0,66	IA	2549	1,036
N	1	7064	5257	2006	5221	0,74	0,99	IA	3839	1,360
O	3	6665	3990	2005	2640	0,40	0,66	IA	2549	1,036
P	7	5527	4211	2001	3404	0,62	0,81	IA	3345	1,018
Q	8	5880	4185	2002	2880	0,49	0,69	IA	2832	1,017
R	6	7200	4938	2001	3840	0,53	0,78	IA	2864	1,341
S	4	8700	6130	2000	3960	0,46	0,65	IA	3073	1,289
T	3	6324	4446	1998	3280	0,52	0,74	IA	2886	1,137
U	3	7049	6418	1998	4876	0,69	0,76	IA	4351	1,121
V	11	5390	2904	1997	2640	0,49	0,91	IA	2486	1,062
W	3	6410	5239	1996	5850	0,91	1,12	IA	4361	1,341
X	14	5398	2904	1996	2510	0.46	0.85	IA	2486	1,010

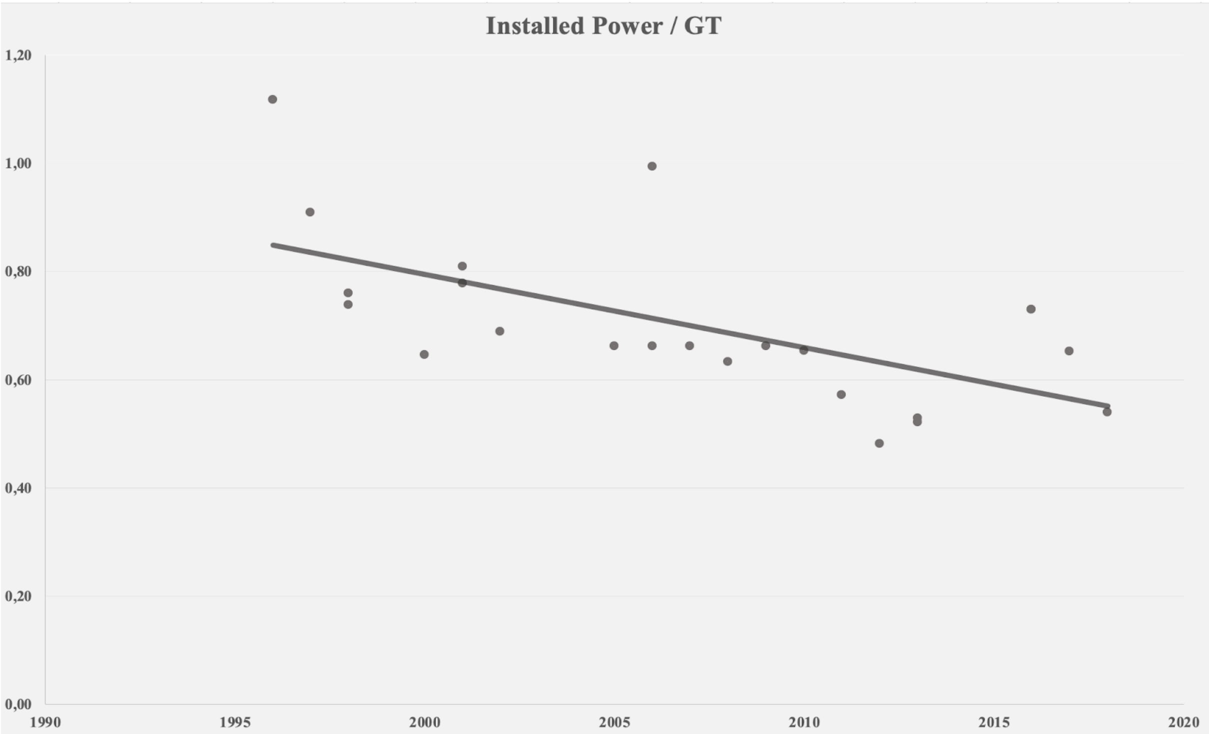
There are 6 EEDI vessels, constructed from 2013 and onwards. All vessels are of the same FS ice class (IA), type (General Cargo) and of similar DWT, ranging from 5.000 to 9.000 tonnes. The first method as seen in *figure 13* compares the installed power per vessel with its DWT (kW per tonnage). The average line in the graph represents the average ratio and a downturn is noticeable. The ratio of the average installed power per DWT is approximately 0,6 - 0,7 in 1996 while the average ratio gets reduced to below 0,3 in 2018.

Figure 13. The vessels' Installed power to DWT ratio in relation with the vessel's construction year. Authors own copyright with data provided by SMA.



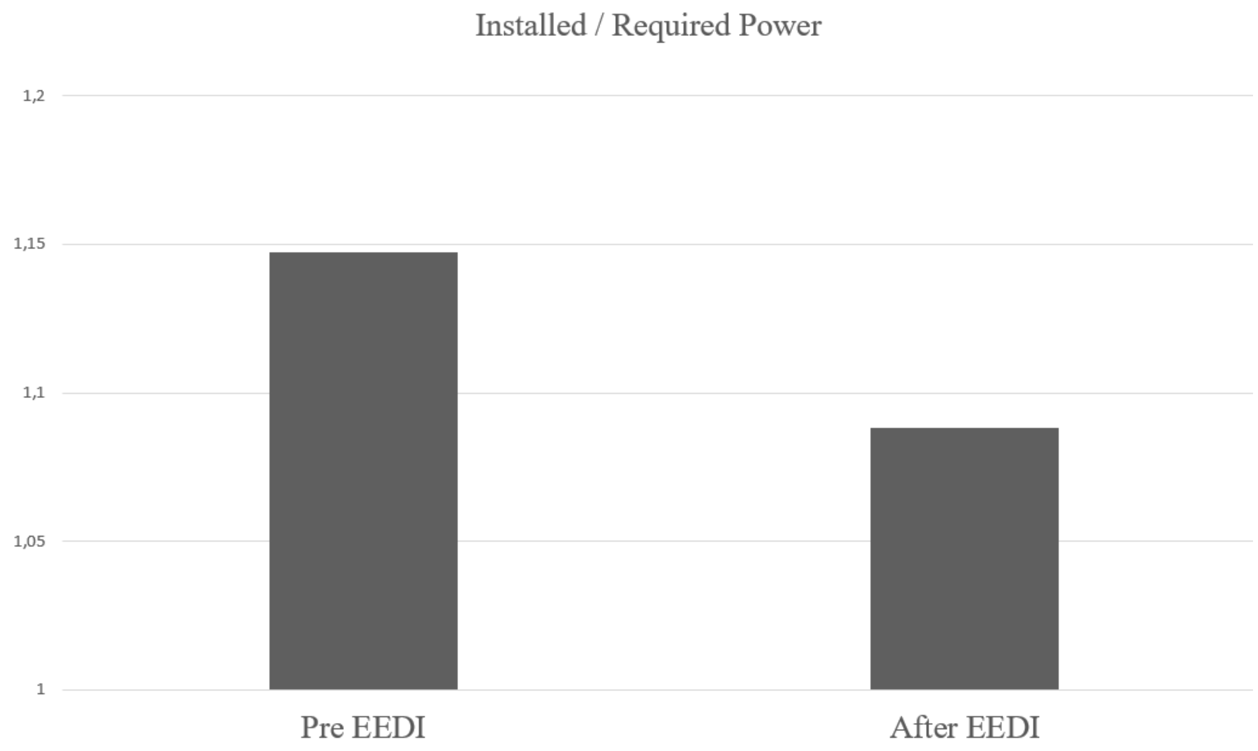
Similarly, the ratio between the installed power per vessel and the GT has been plotted in *figure 14.* There are similar indications as in *figure 13* of a downturn course which is noticeable in the average plotted line. The sample vessels are concentrated somewhat close to the average line, except for some outliers in 1996 and in 2006, where the ratio is higher than the rest, above 1. The initial average ratio of the installed power per GT is approximately 0,8 in 1996 while it gets reduced to approximately 0,6 in 2018.

Figure 14. The vessels' Installed power to GT ratio in relation to the vessel's construction year. Authors own copyright with data provided by SMA.



Lastly, the average ratio between the installed power per vessel and the required power has been plotted in *figure 15.* The required power refers to the power needed in accordance with the FSICR in order to attain a certain FS ice class. The required power can furthermore be obtained through either calculation or model tests. The comparison indicates that the ratio has slightly declined over the past years, as the ratio for the EEDI vessels is closer to 1. When the ratio is 1.0, the installed power is equal to the required power, thus no additional power has been installed compared with what was necessary. From the sample of the assisted vessels, the pre-EEDI and the EEDI vessels have approximately 15% and 8% respectively, higher installed propulsion power compared with their required power, on average.

Figure 15. A comparison of the average ratio of the Installed power to Required power of the Pre EEDI vessels and (After) EEDI vessels. Authors own copyright with data provided by SMA.


Installed / Required Power
1,2
1,15
1,1
1,05
1
Pre EEDI
After EEDI

5 Discussion

The discussion surrounding the chosen methodology with its execution and complications is displayed in this section together with viewpoints on the gathered results of the study.

5.1 Methodology

The mixed-method approach used in this research consisted of a data collection through the conductions of semi-structured interviews and collection of maritime data. An analysis of these different methods together intends to, through the utilization of the benefits arising from their different characteristics, provide an indication of the overall impact of EEDI on the operating performance of the FSWNS since the enforcement of the EEDI regulations. Throughout the conducted research with these methods used to collect data, strong efforts have been made in order to gather as reliable and valid data as possible.

5.1.1 Interview data collection

Interviewing experienced individuals operating within the FSWNS, both authorities and non-authorities, was beneficial for this research. In combination with the nature of the questions, being semi-constructed and somewhat open, it allowed the participants to narrate themselves throughout the process and discuss with a certain degree of freedom. Moreover, it provided a great chance for the authors to expand their knowledge and understanding of the stakeholders' role in a deep level, which would be unlikely in a scenario with fixed and fully structured questions.

However, due to the timeframe of this thesis colliding with the busiest period in terms of IB assistance and overall coordination within the FSWNS, the inclusion of a greater number of participants was found challenging. Additionally, the numerous interview invitations to shipping companies were unfruitful and therefore it was not found possible to include them and record their experience and perspective. Similarly, the inclusion of seafarers both from the shipping companies' side and the IBs side was unsuccessful. Furthermore, throughout the interviews some knowledge gaps were experienced among the participants mainly regarding the different components of the FSWNS. Taking all those factors into consideration it is believed that the interview findings serve more as indications rather than conclusive results.

Bearing in mind the challenges faced when scheduling and conducting the interviews as well as the possibilities for further data extraction with the inclusion of seafarers and shipping companies, a different research method could be appropriate and beneficial. More especially, replacing interviews with questionnaires is believed that perhaps would benefit the research in terms of number of participants and variety of roles. The reason behind the anticipated increase in the data is due to the fact that a questionnaire could be filled in, in time that is best suited for the participant and would also decrease the distress of the participants regarding their knowledge or experience. However, the downsides of the questionnaire as a research method have been taken into consideration and it is believed that it would not allow the researchers to get their hands on data that have been of great importance for the finding of this research.

5.1.2 IB data collection

SMA provided data for different kinds of waiting times in the Bay of Bothnia during January - April in 2018. As aforementioned, the data concerned the vessels' waiting time for IB assistance along with vessels' waiting time related to reasons other than IB service. Even though that not great focus was given in the vessels' unrelated waiting times, they still provide interesting indications regarding the traffic volume in the area and the challenges the vessels encounter except for navigating in obstructive ice conditions. These kinds of challenges arguably also have an impact on the operating capability of the FSWSN which should not be understated.

Regarding the IB waiting times, it was found that the set of data was insufficient to directly assess the EEDI's impact on the FSWNS for the winter season of 2017-2018. In detail, the lack of the vessels' specifications among the data abstracted any clear indication about the vessels' EEDI compliance. Therefore, it is hard to assess the extent of the EEDI vessels among the total number of assisted vessels and their demand for IB assistance as well as their ice-going capacity. Nonetheless, similarly with the unrelated IB assistance waiting times, the set of data provided strong indications about the traffic volume in the area. Additionally, some indications have been identified regarding the operating capability of the FSWSN in terms of its main KPIs, the IB instances and the waiting time duration except for the total port calls for the same period that would indicate the system's total capacity.

5.1.3 Reliable, Validated and Generalized data

One of the measures implemented in order to increase the reliability of this research was to record the interviews instead of taking notes during the discussions or simply trying to write from memory. Permission to record was given by the interviewees before each interview. By using this method, we could transcribe each of the interviews and carefully analyse all of the qualitative data received without the risk of losing valuable data along the process. Another measure to increase the quality of the references, which was implemented during the literature study, was to use the CRAAP test.

When conducting the literature review a large number of reports, books and other publications have been studied. Effort has been put into identifying the latest visions of the studied literature, in order to increase the *currency*. This is especially important when investigating topics that are sensitive to the passage of time since their relevance is greatly related to their publication year and vital information might not have been available at the time. For instance, one of the most reliable sources of publications has been the Winter Navigation Research Board, where the most recent reports have been prioritized when dealing with such topics as the EEDI's impact on the winter navigation. In order to focus on the *relevance* for the studied material, a comparison of different sources with similar content was made. Thereafter, the most appropriate ones to describe the subject without shifting outside of the scope of the research were selected. In terms of the *authority* component of the CRAAP test, the credibility of different authors was estimated by inspecting their previously published material. Furthermore, the number of times the articles had been cited was compared while searching through the various databases and it was one of the determining factors on the inclusion of a source in this literature study. To secure the *accuracy* of the studied material, an examination of the conclusions from each of the studied articles was made in order to see if they also could be found elsewhere, e.g., in other scientific articles. Additionally, how many times each article had been reviewed was also considered. Lastly, critical thinking has been applied when studying the relevant material in order to ensure that the statements and results of the studies have been appropriately supported by strong argumentation. Taking into account the *purpose* of the published material, only statements based on justified evidence were selected.

In order to validate the qualitative data gathered from the interviews, follow up questions were frequently asked to the interviewees in order to make sure that their arguments were interpreted correctly. The understanding of the opinions from the interviewees was rarely a problem. However, asking follow up questions was still seen as an appropriate procedure in making sure that the various arguments from the interviewees were thoroughly considered before proceeding with the qualitative data analysis.

In terms of generalizability, the findings of this research could theoretically, and to a certain degree, be implemented in areas with similar traffic volume, IBs and merchant fleet's specifications along with similar ice conditions considering that the enforcement of the EEDI regulations affect the design of the vessels on a global scale. However, due to the complexity of the cooperation between Finland and Sweden, which constitutes the FSWNS, and the involvement of a high number of different parties, the generalizability's extent is fairly limited. Therefore, the findings of this research are somewhat unique and dependent on the specifications of the FSWNS.

5.2 Results

The results of the Research are discussed in this subchapter. The discussion consists of the literature review findings, the interview findings and finally the results from the analysis of the maritime data. The different and occasionally contradictory viewpoints have been discussed, which later on led to this research's final conclusions and recommendations.

5.2.1 Theory findings

The studied literature aimed to captivate the most significant viewpoints of the scientific community for this topic. Even though the studied material differs in many ways, the viewpoint of the current and future impact of the EEDI regulations on winter navigations and as a result on the FSWNS, is common. In detail, it is suggested that the EEDI regulations will have a positive impact on the ships' open water navigation, resulting in reduced combustion emissions of CO_2 per transport work in comparison with non-EEDI compliant vessels, as well as reduced. Nonetheless, the negative impact of the EEDI regulations has been underlined and it is widely believed that it will have a negative impact on the ice-going capability of the ships. This conclusion is based on the results of different case studies that have emphasized their research in the most prevailing EEDI measures in order to assess their navigating capabilities.

The majority of the presented EEDI compliance measures are leaning towards modifications concerning the optimization of the ship's hull and its propulsion system. Case studies for these measures have been investigated and the ships' ice going capacity is portrayed as reduced in comparison with the pre-existing ships. More specifically, this portrayed negative effect in the ice-going capability of the ships is proportionally increased according to the stricter requirements set by the different EEDI phases. The particular ice conditions and extent of the IB service (navigating in open channels, direct IB assistance or towing) are considered valuable factors when identifying the total impact on the ice-going capability of the vessels. However, a certain degree of uncertainty is highlighted, due to the large number of assumptions resulting from the lack of in-depth research in this area. Therefore, even though there are many indications illustrating the negative impact of these measures on the ice-going capability of the vessels, further research is needed in order to produce conclusive results.

One of the presented measures for EEDI compliance is showing great prospects and it is focusing on increasing the energy efficiency of the engines. Bearing in mind that any kind of significant and ground-breaking produced results require long term research. Deigning engines that would achieve high-performance while at the same time would require less fuel consumption, would undeniably be a vast success. The generated problem resulting from the issuing of the EEDI regulations would be to a great extent resolved. Nonetheless, as previously mentioned, such a level of success cannot be expected in the short term but its promising outcome could serve as incentives for not only the shipping companies but for the FSWNS to invest in it as well.

Alternative measures that could theoretically achieve EEDI compliance have been presented such as biofuels, LNG and hybrid solutions with supplemented batteries. However, even though they are able to comply with the EEDI's requirements, they are considered somewhat impractical for their broad implementation in the shipping sector as well as in the area of the Baltic Sea. Any scenario where these solutions would replace the prevailing fuels, would require extensive investments and familiarization both from the side of the shipping companies and from the states' side which would only be feasible in the long term.

LNG is viewed and presented as one of the most realistic options for EEDI compliance except for the major alterations in the design of the vessel. One has to take into consideration that except for the challenges related with the infrastructure and supply of the fuel itself, the LNG's negative impact on the environment resulting from the leakage of un-combusted methane. LNG's impact, does not only concern the ethical considerations that the shipping companies should include in their decision making when selecting the appropriate measure for achieving EEDI compliance, but also the likelihood for alteration in the EEDI regulations. Lindstad et al., (2020) has argued that IMO should include all GHGs emissions in the EEDI calculations rather than only focusing on the CO_2 emissions. Apart from the above mentioned, LNG's challenges for a wide implementation as a marine fuel for EEDI compliance, its reduced power output in comparison with diesel fuel is important to be considered, which might result in reduced ice-going capabilities as well. However, there is a lack of research in this area and it is difficult to draw any conclusions on this.

Perälä & Tikanmäki (2020), claimed that the vast majority of the general cargo ships, visiting the Bay of Bothnia during the winter season of 2019, fulfil the EEDI requirements even during phase 3. The justification behind this phenomenon is due to the fleet's relatively small size, being below 15.000 DWT. The ships benefit from this since the reduction in the required EEDI is linearly interpolated between the values stated for each EEDI phase (e.g., 0- 30% for phase 3). Therefore, the smaller the ship's size is, the lower the value of the reduction factor is going to be, which results in the ships achieving EEDI compliance without putting significant effort into it.

Based on the understanding that eventually the EEDI vessels operating in the Baltic Sea will be increased, the results of the study conducted by Bergström and Kujala (2020) indicate an increase in the two out of three of the KPIs mentioned in their report. These KPIs are referring to the instances of IB assistance alongside the duration of the waiting time, according to the volume of the vessels complying with the EEDI regulations. As presented in the literature review earlier in this report, the results illustrate a clear increase of both these KPIs, which are significantly increased according to the volume of the EEDI vessels. Bearing in mind that the gradual replacement of the pre-existing vessels with EEDI vessels will take place over the next few years, it is possible that the FSWNS will be greatly benefited by taking into consideration these estimations and gradually increase its IB capacity. In that way it is likely that the FSWNS will continue to meet their objective of an average waiting time below 4-hours for IB service.

For the largest part of the investigated time frame of EEDI's phase 1 (2015-2020), the number of newly constructed EEDI vessels is presented to be rather low and therefore it is unlikely to largely affect the operating capability of the FSWNS. Additionally, for the same time period the indicated increased demand for IB assistance for EEDI vessels was calculated to be between 20-30%. The vessels' average life span is presumed to be approximately 25 years as aforementioned. Taking that into consideration, any major effects on the demands for IB assistance will most likely be noticed with a degree of certainty, several years after the enforcement of the last EEDI phase. As things stand at the moment, phase 3 is the most demanding phase yet, in terms of the ship's designed energy efficiency levels. Nonetheless, it is possible that the indicated increased demand for IB services will continue to rise, as the EEDI regulations are getting stricter and stricter. It is likely that when a large portion of the world merchant's fleet will be replaced by newly constructed energy efficient vessels the increase in the demand for IB services will reach even higher numbers.

Another significant and highly influential factor regarding the impact of EEDI on the FSWNS are the ice correction factors. Results illustrate the positive impact of the ice correction factors, allowing the vessels to simultaneously comply with the EEDI requirements and achieve a high ice class notation, which is much needed when navigating in the Baltic Sea during the winter season. In addition, the suggested solution presented by Westerber (2014), arguing that increasing the ice correction factors is more beneficial rather than increasing the IBs capacity, appears to be very promising in terms of energy efficiency, overall financial costs and coordination efficiency. The independent ice-going capability is regarded of high importance in the Baltic Sea and a possible increase in the ice correction factors could theoretically contribute to a larger number of vessels being allowed to increase their installed engine power. However, as mentioned in the literature review, there is a trend to reduce the ships' power output, in order to minimize the fuel consumption and the overall costs. Therefore, it is likely that regardless of any alteration on the ice correction factors, shipowners will still select vessels with increased open water performance rather than ice-going capabilities, since that results in increased fuel consumption. The overall market's conditions will possibly affect to a great extent the specifications of the future constructed ships and their abilities to navigate in ice conditions.

The cost of IB services is undeniably one of the most influential factors when debating about needed changes in the capacity of the offered IB services. Sweden's total net cost for IB services was calculated to be approximately over 300 million SEK. The Swedish authorities along with the Finnish authorities for which the costs of IB services were not available, are therefore responsible for allocating such funds in order to allow trading to take place even during different ice conditions. Following the indications for a future increase in the demand for IB assistance, the competent authorities might come to the realization that further investment is necessary in order to ensure secure and reliable transportation in the Baltic Sea. As a result, the cost for IB services would further increase and therefore the authorities are required to investigate how to support any upcoming investments.

5.2.2 Interview findings

The findings of the conducted interviews indicate that there has been a decrease in the overall ice-going capability of the merchant fleet operating in the Baltic Sea in the past few years. A couple of the major reasons for this are argued to be a result of the different measures used to comply with the EEDI regulations, as well as initiatives by shipowners to increase the open water efficiency of the fleet. Increasing open water efficiency results in decreased fuel consumption and thus saves money for the shipowners. One of the measures being implemented in order to comply with the EEDI regulations consists of modifications on the ship design, which as with all of the EEDI related measures, intends to reduce the CO_2 per transport work. These kinds of modifications have taken a toll on the average ice strengthening of the vessels, the average power output from the propulsion engines as well as the average ship speed, all of which reduce the ice going capacity of the vessels. However, it was also revealed that it's not easy to determine the extent of the impact of the EEDI regulations considering that the majority of the fleet operating in the Baltic Sea does not have to comply with these regulations, since the majority of them was constructed before 2013, i.e., before the regulations even came into force. It is also believed that the EEDI compliant ships will arguably remain a small minority in the Baltic Sea for the next upcoming years.

Another aspect which makes it difficult to estimate the extent of the EEDI-impact is the fact that the authorities do not usually take the EEDI compliance of the assisted vessels into consideration when measuring and analysing the KPIs of the FSWNS, such as the IB waiting times, amount of IB instances and the number of port arrivals. The kind of impact vessels with less ice going capability will have further on in the future is also difficult to predict since the mentioned KPIs are strongly linked with the prevailing ice conditions.

It was suggested that one way of improving the reliability of importing/exporting from/to Sweden and Finland is to increase the overall ice-going capability of the fleet operating in the Baltic Sea in general, and the Bay of Bothnia in particular. In order to achieve that, the merchant vessels should arguably implement measures to be more independently capable of operating in different ice conditions. However, this suggestion is difficult to turn into reality since basically all measures to improve the ice going capability has a direct negative effect on the vessel's open water efficiency, since they usually result in a reduced carrying capacity and/or decreased fuel efficiency. Basically, it will cause increased costs for the shipowners, such as increased fuel costs and the cost of lost opportunity, which certainly is in the opposite interest of the shipowners. One way to incentivise shipowners to invest in increased ice going capacity, could be for the governments of Sweden and Finland to financially support, to a certain extent, such positive initiatives for the FSWNS. This option could potentially, in the longer run, reduce the operating cost for IB assistance since its demand would likely decrease if the overall ice going capacity increases. However, it is believed that identifying, selecting and financially supporting the shipping companies it concerns, is somewhat challenging. Coordinating such an initiative would most likely be as equally complicated as finding the capital to fund it.

Another interesting finding from the interviews was the importance of experienced crews onboard the IBs, and more specifically, having experience from navigation in various ice conditions which present different kinds of challenges and different kinds of IB operations. Throughout the recent years, the IB fleets of Sweden and Finland have lost plenty of valuable ice navigation experience which is immensely difficult to fully replace. It was found that one way of improving the expertise of how to deal with different conditions and the respective challenges, except for recruiting experienced seafarers, is to implement more training and education for the IB personnel. It's also considered important for the merchant vessels, which operate in the Bay of Bothnia during the winter season, to have crews with experience from IB assistance and various ice conditions. This is important in order for the future instances of IB operations to be as efficient as possible in terms of cooperation, communication and ability to take urgent actions with safety and damage minimization in consideration.

5.2.3 IB data findings

The type of data analysed in this study was e.g., the IB waiting times & IB instances, both of which are important KPIs for the FSWNS. Additionally, data concerning the ice-going capability of the assisted vessels has been investigated. The parameters for measuring the ice-going capability consisted of the ratios for installed power to DWT, installed power to GT and finally, installed power to the required (ice class IA) power.

The FSWNS appeared to operate in an efficient manner for the winter season of 2017-2018. The vast majority of the assisted vessels had to wait for less than 4 hours for an IB and therefore the authorities managed to achieve their target for a waiting time below 4 hours. It is also important to take into account the type of winter, which was rather normal in relation to records of the last 60 years. Its intensity was not as mild as the ones in the previous years and yet the FSWNS performed well. Assessing the system in conditions that were not optimal was one of the reasons behind the selection of the winter season of 2017-2018.

This indicates that even though the winter's severity was worse than the previous years, the FSWNS performed well and the majority of the assisted vessels experienced no difficulties arriving at or departing from their destination. Nonetheless, the extreme recorded waiting times reaching up to even over 30 hours are believed to be a result of various factors combined together. Even though such instances are unfortunate and undesirable, they are believed to be possible and likely to happen under challenging circumstances that are difficult to completely mitigate. Examples are e.g., unpredicted change in the weather conditions, strong wind power causing heavy ice pressure or due to the location of the assisted vessel or the IB being remote.

The season's first assistance in the area was provided on the 7th of January, while the last one was on the 27th of April. Thus, the IB season lasted for 111 days. The intensity of this winter season in terms of the ice extent was rather normal. Therefore, it is assumed that the duration of the IB season for a mild winter, which is more common in the last few years, would be even shorter. Moreover, it is evident that the majority of the assisted vessels were associated with Finnish ports and thus, it is assumed that the traffic volumes are higher in Finland. In accordance with this is the geographical representation of the assisted vessels' location which is closer to Finland for the majority of the instances. The difference in the traffic volumes between the associated ports of the assisted vessels could to an extent influence the operations of the IBs and result in extended waiting times in areas where the traffic volumes are less.

The assessment of the ice-going capability has been performed through a sample of the assisted vessels. The criteria for the selection of the 24 sample vessels were primarily set by the characteristics of the assisted vessels. Considering that 165 out of the total 213 assisted ships were general cargo ships, along with the fact that 7 out of total 9 EEDI ships were general cargo ships, combined with several previously mentioned factors, they have contributed to that selection. Nonetheless, the description of a general cargo ship is somewhat broad. General cargo ships do not necessarily share many similarities, which results in this ship type being heterogenous. Despite that, there is a certain degree of complexity in acquiring detailed ships' specifications. Taking that into consideration, as well as the criteria that shaped up the sample vessels, having a similar DWT, ice class (IA) and the importance of including ships with different construction years, it is therefore assumed that the outcome can provide reasonable and justified indications. Additionally, the sample number is considered relatively low, when aiming to produce definite and conclusive results. However, it is believed that the sample vessels, having carefully been selected, can provide strong indications about the ice-going capabilities of the EEDI vessels as well as in comparison with the rest of the assisted vessels.

The ice-going capability of the sample vessels was measured and assessed in three manners. By calculating the vessels' ratios of the installed power to DWT, the installed power to GT and lastly the installed power to the FS ice class calculated required power. The three ratios have been put in relation to the construction year of the ships. As displayed in both *figure 13* (Installed power to DWT) and *figure 14* (Installed power to GT) there is an evident downturn in the average ratios over the passage of time. A decrease is noticeable throughout the whole-studies time frame, including the years that the EEDI vessels had been constructed. Meanwhile both graphs illustrate a decrease in the ice-going capability of the assisted vessels; there is no apparent and definite correlation with the EEDI regulations. It is believed that the decrease could be a result of measures aiming to increase the ships open water capabilities, overall performance and reduce their fuel consumption. By the implementation of such measures, the shipowners would decrease their overall operating costs. Consequently, it has resulted in a reduced installed power per vessel, which furthermore negatively affects the vessels' ice going capability.

In *figure 12* the comparison between the average ratio of the Installed power to Required power of the Pre EEDI vessels and EEDI vessels is illustrated. The difference in the ratios is not significant. The EEDI vessels' ratio decreased approximately 5% in comparison with the pre-EEDI vessels. Taking into account that the closer a vessel's ratio is to 1, as in the case of the EEDI vessels, the less additional power has been installed. This indication points to a somewhat decreased ice-going capability in comparison with the pre-EEDI vessels. Therefore, it is considered that the impact of EEDI as of yet to the ice-going capability of the vessels is relatively low. Additionally, the reasoning behind the evident reduced ice-going capability is not definitely linked with the EEDI regulations but could be an effect of other factors, such as financial incentives of a reduced fuel consumption.

6. Conclusion

The EEDI regulations are likely to have an impact on a global scale and it will lead to a chain reaction throughout the shipping industry as well as, to a certain extent, benefit the environment in terms of decreasing overall CO_2 emissions. Addressing this study's research question which was "*what has been the impact of EEDI on the operating performance of the FSWNS since the enforcement of the regulations?*", the researchers reached to the conclusion that up until this point in time the impact has not been significant and not majorly noticeable. The regulations do not apply for the vast majority of the fleet operating in the Bay of Bothnia, since they have been constructed prior to its enforcement. As a result, the regulations have not so far had any considerable impact on the operating capability of the FSWNS.

The severity of the ice conditions appears to have become milder in the last few years in relation to the previous 60 years. This furthermore results in the likelihood of EEDI having a significant impact on the FSWNS being relatively low since the KPIs of the FSWNS are strongly linked with the prevailing ice conditions.

During the research's time frame (January - April 2018), and to what is considered a normal winter, the FSWNS appeared to operate efficiently. The vast majority of the vessels requiring IB assistance, the waiting time was within the 4-hour target. The average waiting time was well below the target, being 2 hours and 54 minutes. The undesirable instances of extreme waiting times for IB assistance are believed to be the result of several factors combined together which are unlikely to be completely mitigated and they seem not to have a correlation with the EEDI regulations.

When assessing the progress of the ice-going capability of the assisted vessels over the passage of time for the past decades, a gradual downturn has been identified. The installed power to the required power ratios of the investigated EEDI vessels appear to have a reduced ice-going capability in comparison with the pre-EEDI vessels. The installed power to the required power ratio of the EEDI vessel is closer to 1, which points out that the vessels have an installed engine power somewhat closer to what they are required to as per FSICR.

However, based on the findings of installed power to DWT ratio and installed power to GT ratio, a decrease in the ice-going capability is evident throughout the whole construction-year time frame set by the sample vessels. These indications point out that even though EEDI is likely to have impacted on that reduction in their ice-going capability, it is not the defining factor. The gradual reductions in the abovementioned ratios over time designate that additional external factor affected the vessels' ice-going capability.

The reason for the reduced ice-going capability of the assisted vessels is mainly due to measures being implemented in order to increase the open water efficiency (e.g., design modifications) in order to decrease fuel consumption and thus reduce overall operating costs. Another reason is the measure of reducing the engine power in order to comply with EEDI but since the majority of the current General Cargo ships in the Bay of Bothnia are quite small in size (> 15.000 DWT), they seem to fulfil even the EEDI phase 3 regulations quite easily. This further implies that mainly the vessels above 15.000 DWT will be influenced by the regulations as it seems at the moment unless there are any alterations that would lead smaller vessels to make alterations in order to comply as well.

6.1 Recommendations

As aforementioned, the inclusion of certain individuals, which was a part of the principal target groups, was not feasible for this research. The research's conduction time period collided with the busiest time period for the professionals within the FSWNS. These principal participants were the merchant vessels' seafarers with the appropriate experience navigating in the Baltic Sea during the winter months, as well as seafarers operating aboard the assisting IBs. In addition, the inclusion of a part of the shipping companies operating all year around in the Baltic Sea would be beneficial for the research. It would provide the opportunity for the shipping companies to express their viewpoints and concerns about EEDI's impact on their operations and their future plans for ship purchases. Therefore, it is recommended that, should a future research take place, the time period for such should be taken into consideration alongside the inclusion of the recommended principal participants. It is suggested to conduct such research after the IB season comes to an end which will allow these aforementioned principal participants to be included and offer their inputs.

Additionally, the simulation model aiming to captivate the operating performance of the FSWNS under different operating scenarios, which was included in the theory was found of great significance. However, according to the authors of that paper, a number of assumptions have been made in order to carry out the simulation, resulting from the lack of real maritime data that was unavailable to the researchers. It is recommended to carry out similar simulations, provided that additional data would have been collected, which would minimize the extent of assumptions. Subsequently, the simulation's results would increase their validity and would produce more conclusive results, which could arguably benefit to a great extent the operating capability of the FSWNS and its ability to respond to the future demand

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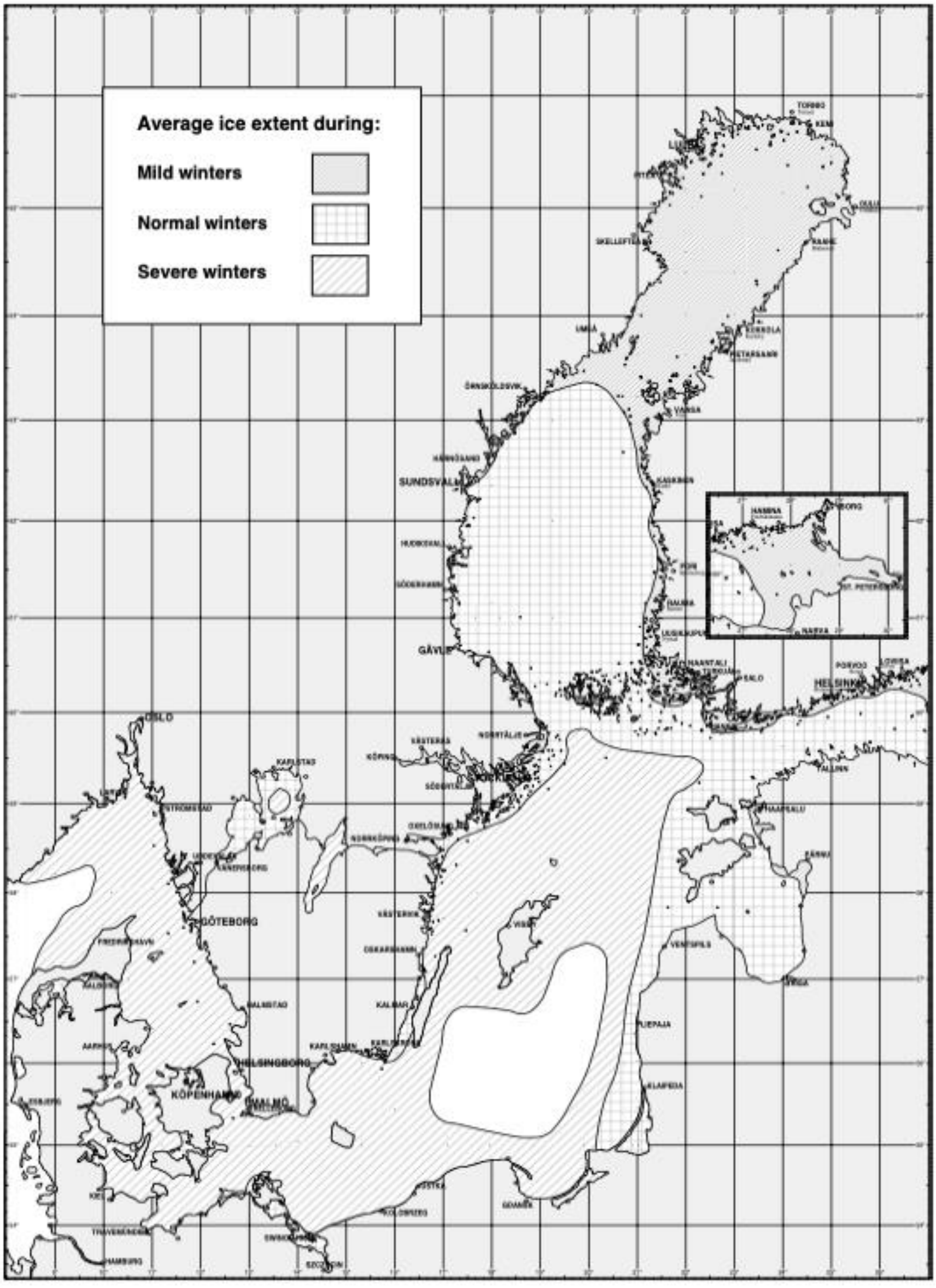
Appendix

Appendix 1. The average ice extent in the Baltic Sea during different types of winter



Appendix 2. Baltic Sea ice chart from 5th of March 2018