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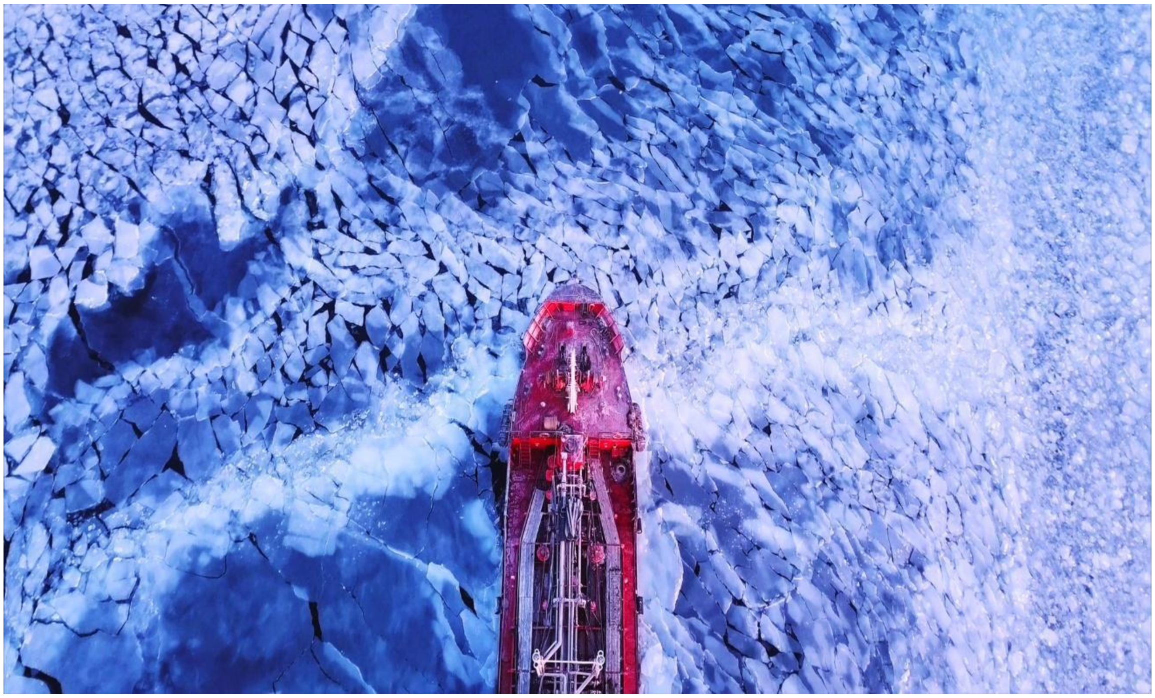

# Feasibility Study on Commercial Shipping in the Northern Sea Route

Master's thesis in the Master's Programme ***Maritime Management***


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# Abstract

The constant mitigation of ice extent in Arctic region enables the Northern Sea Route (NSR) becoming an attractive shipping lane with numerous trading opportunities between Europe and Asia. The benefits of the shortening NSR can be related to its substantial savings in voyage time and fuel consumption compared to the conventional Suez Canal Route (SCR). However, the shorter distance itself cannot guarantee the cost-efficiency due to harsh condition, in which remoteness and ice conditions raise the questions about safety challenges and extra operational cost. In particular, the ship-ice resistance likely increases the fuel consumption and reliance on ice-breakers may constrains the transit time. Dissimilar from normal open water routes, an average assumption of constant speed should not be applied in the NSR. Therefore, this research aims at computing fuel consumption in Arctic waters by using real-time data of ship's position, the corresponding speed, ice concentration and ice thickness. The cost analyses from two case study vessels in three different ice scenarios provide a cost comparison between the NSR and the SCR. Furthermore, interviews and surveys with various actors in the shipping industry were conducted to further assess the feasibility of the full transit in the NSR, the potential cargo in this niche market, as well as their major concerns towards possible challenges. The main conclusion of the thesis is that, thanks to the cutting voyage time up to 34% for the full transit Shanghai - Gothenburg, the NSR can save up to 40% of the cost in ice-free condition in comparison with the SCR. When the ice occurs, the percentage of cost reduction declines to around 20% and 5%, depending on the severity of ice. However, as the cost performance is sensitive to market factor such as RUB-USD exchange rate, the NSR is no longer cost-beneficial because of the expensive ice-breaker fee in ice scenarios. Besides the cost factors, the majority of surveyed shipping companies expressed their hesitance due to technical obstacle for ice-class vessels and the safety challenges for search and rescue activities.

**Keywords: Northern Sea Route (NSR), Arctic shipping, cost analysis, feasibility study, ice resistance, fuel consumption.**

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Thi Bich Van Pham and Aravopoulos Miltiadis

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# List of Abbreviations

| Abbreviation | Description |
|---|---|
| **ESIMO** | ЕСИМО (English: Unified State System of Information on the Global Ocean) |
| **FOM** | Fuel Oil Mass |
| **GPS** | Global Positioning System |
| **GUNiO** | ГУНиО (English: Head Department of Navigation and Oceanography, or HDNO) |
| **HFO** | Heavy Fuel Oil |
| **H&M** | Hull and Machinery |
| **IACS** | International Association of Classification Societies |
| **IBCAO** | International Bathymetric Chart of the Arctic Ocean |
| **NEP** | Northeast Passage |
| **NSR/P** | Northern Sea Route/Passage |
| **NSRA** | Northern Sea Route Administration |
| **NSDIC** | National Snow and Ice Data Centre |
| **PESTEL** | Political, Economical, Social, Technological, Environmental, Legal |
| **PC** | Polar Class |
| **P&I** | Protection and Indemnity |
| **RoRo** | Roll-on-Roll-off |
| **SAR** | Search and Rescue |
| **SCR** | Suez Canal Route |
| **SFOC** | Specific Fuel Oil Consumption |
| **WMO** | World Meteorological Organization |

# Chapter 1: Introduction

This chapter points out the current situation and the trends of the Northern Sea Route. Additionally, the research questions will be presented in order to provide the scope of the research to the reader.

## 1.1 Background

Global warming has led to the melting of the ice in the Nordic pole region. The Northern Sea Route (NSR) connecting Eastern Asia with Northern Europe is an emerging concept lately, which brings new trading opportunities for the upcoming decades. The NSR offers one third distance reduction for full transit from Eastern Asia to Northern Europe. Significantly, China is one of the emerging superpower economies in the world. It is estimated that China will acquire or operate 1/4 of the global commercial maritime fleet by 2030 (Global Marine, 2015). Henceforth, increasing demand in coal oil and natural gas are expected, followed by fleet increasing capacity for bulk carriers, tankers and LNG carriers. Meanwhile, the Suez Canal Route (SCR) is suffering massive delays due to the increased traffic and waiting times. The NSR is considered as an alternative to avoid waiting times and probable political conflicts, piracy or terrorism in the district of Suez Canal. Moreover, the NSR is compelling to the maritime industry because it is a shipping lane for transporting hydrocarbons and natural resources deposits that have been extracted recently in the Arctic region.

However, from the shipowners' perspective, there are several factors to take under consideration before proceeding into investing in such a niche market. Reliable feasibility studies have been already conducted for proving the efficiency and reliability of the passage, measuring costs, regulatory alignment, including safety and security considerations and also sensitivity analyses. The outcomes can be divided into the optimistic ones, supporting that there is a bright future in the Arctic Shipping and pessimistic ones, that it is not feasible and there are a lot of barriers to overcome. Because of this, even shipowners have been divided into the conservatives who avoid risks and the ones willing to undertake risks for enhancing the company's reputation, for research purposes or further cost benefits. It is worth to mention that the shipping companies' effort to conduct the full transit, has enhanced the research and sometimes proven the researchers pessimistic about the potentials of the NSR. Since 2013, COSCO has been one of the greatest non-Russian operators within the NSR, with primary interest on trading construction materials for the Yamal LNG plant placed in Sabetta Port. According to Chi Mei Zhang, vice president of COSCO shipping, with total 12 to 15 days average days of savings in sailing times and 9,000 tons of fuel in total, the NSR seems a good business opportunity for the company to enhance its activity in this niche market (Zhang, 2019). Furthermore, in September 2018, the first container ship owned by Maersk conducted the full transit (Busan to Bremerhaven). Still, after severe ice conditions faced in the East

Siberian Sea and the necessity of icebreaking escort, the reduced distance limited the voyage duration into ten days compared to the SCR. Even though Maersk acknowledges the long-term benefits of the NSR, they believe it is not a viable commercial alternative since it is only feasible currently for a three months duration. On the other hand, COSCO intends to enhance its activity within the transit during the year 2019.

The controversial roles of shipowners regarding the NSR motivated this thesis to estimate the costs and feasibility of transit voyage through the NSR. The aim is to assess (1) the recognition of the passage throughout the years from the industry, (2) its current situation and (3) its potential prospects. The importance of analysing the NSR benefits and spread knowledge to public research can expand trading activities in the region. This research follows specific economic models, real cases from actors involved, neutrally involved actors' perception, data retrieved from model simulations about weather forecasting services and also calculations of costs for assessing the feasibility of the NSR.

## 1.2 Research purpose and research questions

There are three main fields of interest in this study. Firstly, it is focusing on the assessment of the economic potentials of the NSR as an alternative compared to the SCR, by considering all possible factors that can affect the benefits of undergoing the full transit. Further on, from the shipping companies' perspective, it aims to identify what possible challenges prevent them from being active actors in this market. Finally, it would be interesting to identify the demands and the prospective cargos for the near future; emerging opportunities for investments by the shipowners.

Thus, the purpose of this study is to calculate the fuel consumption and fuel cost from real data, then compare the total voyage cost of the NSR with the SCR. Furthermore, The multi-perspectives about the challenges and market potential were examined from actors in shipping industry.
Based on the stated purpose, the following three research questions have been formed:

- How much is the time and cost for using the NSR compared to the Suez Canal for cargo transportation between Northern Europe and Asia during the navigational season?
- What are the challenges for shipping companies to operate across the NSR?
- What are the promising cargo types to be transported via the NSR?

## 1.3 Limitations

In this thesis, the primary emphasis of the feasibility study is on the economic aspect. Firstly, for the business decision making, further and deeper steps on other aspects in PESTEL (Political – Economic – Social – Technological – Environmental – Legal) analysis is needed for a well-rounded perspective on the viability of commercial shipping in the NSR. Secondly, for the sake of simplification, each scenario handles only a single type of ice; however, in real condition, several ice types may occur at the same time. For example, the continuous formation of brash ice creates level ice that enables the presence of both ice types in the early phase of the winter period.

On the other hand, some data limitations have emerged. First, reaching as many actors in the shipping industry as possible would provide a multi-perspective view of the shipping industry regarding the NSR. However, this was limited to only three actors contributing to the interviews due to high workload or intimacy issues. Furthermore, all the survey respondents are representatives of organizations in Europe. Future research would get a more balanced view if the opinions can be collected from a broader scope of Asian maritime companies as they are important actors on the other side of the NSR. Moreover, the real coordinates are only available for the NSR sections, the route planning for the open-water sections outside the NSR was assumed that leads to the variations in distance measurement. Finally, the calculation model was applied for merely Handysize bulk carrier and Sub-Paramax container vessel in the case study, which means the result cannot be generalized to all types of vessels. The cost-benefit analysis in real-life business should be carried by case-on-case basis. However, the study suggested an NSR-SCR comparable approach for total voyage cost and fuel consumption computation that can be used with various vessel types and sizes.

## 1.4 Ethical Considerations

This thesis has been fully concerned about the Ethical Considerations in Research, compatible with the Chalmers requirements upon this aspect. Furthermore, the research was conducted under The European Code of Conduct for Research Integrity (ECCRI) about honesty in research communications and reporting, fairness in providing references as reliable as possible (ECCRI, 2017). During this study, the interviewees have fully consent into providing their perspectives by the conditions of keeping full enclosure of personal information and their companies. Thus, they will remain anonymous due to confidentiality reasons. Likewise, the anonymity of the survey replicants will be applied. Finally, it is essential to note that any included literature statements, data and images who subject to copyrights, have been treated with citing the authors and the owners accordingly.

# Chapter 2: Frame of reference

This chapter presents the fundamental background on the NSR such as its development and concerns for cargo transportation. Furthermore, the regulatory framework regrading to commercial shipping in the NSR will be examined. Several economic feasibility models to estimate the shipping costs and ice type conditions will also mentioned.

## 2.1 The North Sea Route (NSR)

According to the Russian Government, the Northern Sea Route (NSR) officially is the shipping pathway connecting Northern Europe with Asia from the Kara Sea across the Siberian Sea up to The Bering Strait. The overall route on Russia's side of the Arctic between North Cape and the Bering Strait has been called the Northeast Passage (Russian Legislation, 2018), as shown in Figure 2.1.

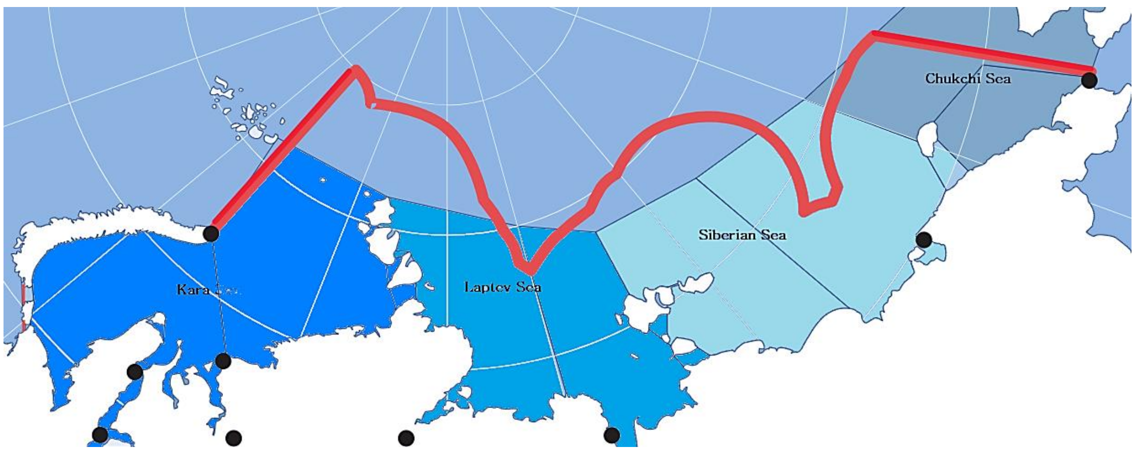


Figure 2.1 The Subregions of the NSR, retrieved from NSRA (www.nsra.ru)

During the last decades, global warming has led to the melting of the ice in the Arctic region. As Suez Canal is suffering long delays (Verny, 2007), all actors in the shipping industry are interested in an alternative trading network passage between Asia and Northern Europe. Competitiveness in the shipping industry can be significant by reducing operational, voyage and capital costs. Therefore, the NSR has emerged as a compelling alternative due to its reduced distance; approximately 40% compared to the SCR (Liu & Kronbak, 2010). Studies have been conducted to testify the Arctic Shipping feasibility, cost expenditures, the trading demand, current infrastructures, legislative and regulatory system as well as ice-classed vessels and maintenance needed. It is proven that the changing climate conditions have decreased the ice levels of the Arctic within the last 40 years (NSIDC, 2017) and destinational traffic has been increased significantly (Humpert, 2017). The primary responsibility for the NSR was delegated to a non-profit Russian State corporation with main interest in Nuclear Energy, named Rosatom. Its subsidiary, Rosatomflot manages the Russian nuclear-powered icebreaker fleet based in Murmansk (Nilsen, 2018). The main activities of Rosatomflot are piloting, towing vessels, Search and

Rescue (SAR) operations on ice conditions, research and transporting cargo out of ports near Russia's Arctic coastline (Nilsen, 2018).
According to Emmerson (2011), in the 1930s Josef Stalin established settlements along the Arctic coastal borders of the current Russian areas, in order to secure northern perimeters from invasions of enemy troupes and exploit the natural resources. The lack of transportation methods resulted into making shipping the most viable option. Consequently, the NSR was established after route administration facilities, construction of ports and icebreakers (Armstrong, 1955). The route was mainly restricted to only Soviet vessels due to political controversies. According to Brubaker and Ragner (2010) after the collapse of the Soviet Union in 1991, the passage opened for international commercial shipping mainly as an alternative to the conventional SCR.

### 2.1.1 Development of the NSR

According to Clarkson's Report (2014), the NSR is considered as a niche market since it cannot compete with the tonnage of trading goods through the SCR. The main products traded in 2013 were oil products, LNG, natural resources, mainly iron ore and coal, whereas 52% of westbound vessels and 1% of eastbound vessels were in ballast conditions (Humpert, 2014) significantly not favourable compared to oil tankers transited through SCR the same year.

In his research, Kiiski (2016) claims that the sparsely populated and lacking facilitation ports in Russia, makes it difficult to absorb containerized cargo or to import a large volume of bulk cargo. Potentiality though, can be identified on exporting cargo from natural resources or being a transcontinental shortcut. Five Asian countries (China, Japan, South Korea, India and Singapore) granted a permanent observer status on the Arctic Council. Notably, China, as it contains a high shipping activity globally, finds potentials on the NSR regarding energy trading and its independence from Malacca Straits (Zhang, 2011). On a different perspective, South Korea relies on a strategic plan of reduced port fees (Kim, 2015) and Japan is aiming at research purposes (Tonami, 2014). The Arctic holds a 30% of natural gas and 13% of oil of the world's total undiscovered resources, mostly in Russian territories. Raza et al. (2016) expect that Russia and Northern America to sell their output to the Asian market (LNG supplies). Also, NSR brings Norway and especially Russia (5 days away) closer to Asia explaining Russia's plan of investment in the LNG plant of Yamal with 20% share of Chinese National Oil Company (CNOC) (Falck, 2013). The cost efficiency potential of the NSR over the Suez Canal is 42%, enough to attract the industry players to make the required investments and CO2 emission reduction up to 52%. A higher charter rate increases the cost efficiency for the transit shipping of LNG.

The maritime trend is shifting into offshore activities (Peters et al., 2011); however, sub-zero conditions raise awareness for environmental concerns (Sander et al., 2014). There is a maritime and population interdependency in the Arctic, requiring a mass of labour to function properly. Nuclear powered vessels and azimuth propulsion systems provided capabilities, manoeuvrability, improved safety and environmental footprint. However, there is doubt of reducing $CO_2$ emissions even with cleaner fuels, since the additional impact of emissions more than offsets the effect of shorter voyages. IMO designed a Polar Code as lean policy guidance. Icebreakers fleet will expand if further ice melting will take place that will change the charges, since greater volumes can lead to reduced tariff prices. The reason for high tariff pricing is the nuclear icebreaker fleet to operate on tariff-based income (Arctic Council, 2009). Additional to insurance, there are concerns as wreck removal, pollution salvage and towage cargo and crew claims. A pricing policy could significantly reduce costs but seems to be time consuming, uncertain and discriminative (Moe, 2014).

Fedi et al. (2018) claim 19 times higher incident rate in the Arctic compared to open waters, mainly due to human factor mainly due to crew inexperience, inattentions, heavy weather conditions and lack of communication. Second reasoning is collisions and groundings. Humpert (2018) writes about Mikhail Belkin, assistant to the Director General of Rosatomflot, the rapidly changing scenery of the NSR, cargo volume and future trends.

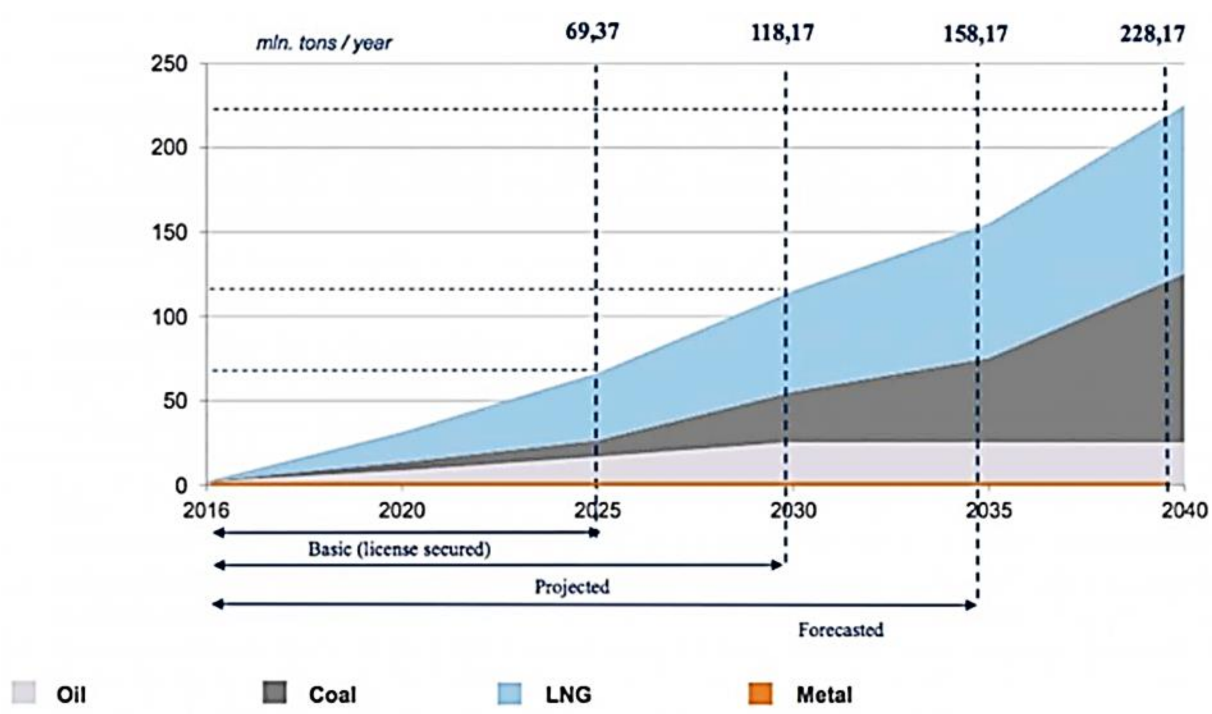


Figure 2.2 Cargo Forecast for NSR (Belkin, 2018)

Belkin (2018) claimed that Rosatomflot was about to face enormous challenges since marine traffic is expected to tenfold within the upcoming decade, as can be seen from

Figure 2.2. Based on the cargo volumes transported and the high anticipation rate for the future combined, we present them in Table 2.1.

Table 2.1 Tonnage shipped annually through the NSR (annual data Rosatomflot, 2018)

| ***Year*** | ***Tonnage Shipped (tons/ year)*** |
|---|---|
| 2010 | 111.000 |
| 2011 | 820.789 |
| 2012 | 1.261.545 |
| 2013 | 3.900.00 |
| 2016 | ~7.300.000 |
| 2018 | ~18.000.000 |
| 2020 | ~40.000.000 |
| 2030 | ~115.000.000 |

Based on Rosatom records, the transported cargo along the NSR in 2018 was 18 million tonnes. Belkin states that because of the rising number the corporation invested on three new built icebreakers of a new generation double-draft LK-60Ya. According to the contract, they are expected to be completed by 2020. In more details, these icebreakers keep a more efficient profile because of the increased capacity of the nuclear reactors from 53 MW to 60 MW. Their wider beam of 34 meters will open channels ideal for escorting larger commercial vessels, compared to the previous generation of icebreakers with a beam of 29 meters wide. Limited draught (8.55-10.5 m) will help to navigate within shallow waters (Humpert, 2018).

Operational cost reduction is also in the plan since automated systems will be applied, reducing the crew by almost 50 per cent (53 crew members).

### 2.1.2 Barriers in the use of NSR for goods transport

Even though NSR concept is continuously emerging, factors as fuel consumption due to increased resistance, environmental concerns, vastly costly ice breaking fee and insurances, extreme weather conditions, communication problems, specific navigational paths due to swallow sea waters, lack of repairing and Safety and Rescue (SAR) infrastructures are some of the reasons leading to its feasibility uncertainty.

Brubaker and Ragner (2010) explain that feasibility tests have been conducted to testify the feasibility and compatibility of the route in an international context. However, not only climate issues, political and economic instability raised concerns, but also operational and safety risks lead to hesitance in the NSR (Granberg, 1998) while in parallel global shipping was flourishing.

The aforementioned concerns lead the shipowners into being hesitant into investing in the NSR. The vessels travelling across the NSR are mainly for research purposes and fulfilling high demands cargo within this niche market. More specifically, one major concern is the initial investment on an ice classed vessel. In order to withstand the ice damage, there is an enhancing on the structure of the fore hull followed by an increased capital cost of 20–40% (Lasserre, 2014). Moreover, this leads to diminishing of the available cargo capacity. Harsher navigational conditions suggest more damage to vessels, thus higher Repairs and Maintenance (R&M) costs (Schøyen & Bråthen, 2011).

Transarctic routes have a high risk of delays because vessels might stack in ice, and the intervention of ice breaker assistance is required. Therefore, the shipowners might face financial penalties due to delays and credibility damage (Lasserre, 2014). Furthermore, the poor repair conditions of the facilities across the route (Xu et al., 2011; Lasserre, 2014) rise limitations regarding service and repair (Ho, 2010; Kitagawa, 2008) and also high uncertainty concerns regarding safety and rescue availability. Sarrabezoles et al. (2016) claim that the uncertainty and risk result in higher insurance costs due to the limited international experience for ice-classed ships undertaking trans-Arctic voyages. Moreover, the ice-breaking fee is one of the main voyage costs (Novikov, 2014), in addition to fuel costs (Rahman et al., 2014).

Shipping lines keep a cautious position towards the Russian policy system because of the various uncertainties. Furthermore, a good alternative as involving European countries like Norway, Sweden or Finland would help investments on the concept of the NSR.

Shipping companies consider the potential benefits, of shorter sailing distances, reduced fuels costs, and increased productivity. There is the assumption of Schøyen and Bråthen (2011) that air emissions from ships primarily correlate to travel distances and since the NSR is shorter, will equally result in less $CO2$ footprint. Studies indicate lesser fuel consumed (Liu & Kronbak, 2010), implying the tolerance of fuel prices, due to NSR attractiveness, to rise as predicted by the International Energy Agency (Rapier, 2016).

## 2.2 Regulatory framework

### 2.2.1 International regulations

The vast majority of international maritime conventions are developed by the International Maritime Organization (IMO), which is a body of the United Nation (IMO, 2013). Besides all the international regulations applied for vessels in standard sea areas, there are some additional clauses in IMO Conventions, separated codes and multi-national agreements that specifically indicate for Arctic shipping.

**United Nations Convention on the Law of the Sea (UNCLOS)**

UNCLOS is known as the most significant international convention regulating activities at sea (Freestone et al., 2006). Regarding the commercial navigation through Arctic region, UNCLOS - Article 234 presents "Ice-covered waters" on which coastal nations have rights to request additional requirements for ships passing through ice-infested sea within their jurisdictional area (Nordquist et al., 2010). According to this article, coastal states adjacent to ice-covered sea possess the full right over additional regulations which are applicable within EEZ zone – Exclusive Economic Zone 200 nautical miles from the baseline – aiming at protecting the marine environment, preventing dangerous accidents caused by shipping activities (Churchill & Lowe, 1999). Coastal countries can adopt and enforce non-discriminatory laws to control marine pollution and conserve ecological balance in ice-covered areas (IMO, 2014).

**International Code for Ships Operating in Polar Waters - Polar Code**

Polar Code presents IMO's Guidelines for specific requirements to ensure maritime safety, manning competency and environmental protection in Arctic and Antarctic (IMO, 2010). Polar Code has been developed to complement existing IMO instruments with the objective of *"increasing the safety of ships' operation and mitigate the impact on the people and the environment in the remote, vulnerable and potentially harsh polar waters"* (Lloyd's Register, 2016). Despite the development over 25 years as recommended guidelines, Polar Code entered into force quite recently: 1 January 2017 for new-building vessels; 1 January 2018 for existing vessels; 1 July 2018 for crew training requirements (Grandinetti, 2017).
Polar Code includes two main parts for Safety of ships and Environmental protection; each consists both obligated and advisory sections (Mauger, 2017). Both parts are in accordance with their parent Conventions that had become compulsory by the amendments to existing SOLAS, STCW, and MARPOL Conventions (Lynch, 2018). Safety measures were adopted in November 2014 by resolution MSC.385(94) and dealt with vessels' safe design, construction and operation. It obeys SOLAS, applying to international cargo vessels, which is larger than 500 GT and passenger ships carrying over 12 passengers on international voyages (Kendrick, 2016). Additionally, Part I-A, Chapter 12 adopted an amendment to the STCW Convention by resolution MSC.416 (97), entered into force on 1 July 2018. The provision establishes obligated minimum requirements for both ships design and manning. It demands training and qualifications of the crew on ships sailing in polar waters. The requirements consider the unique risks that arose with operating in hash polar regions like darkness, ice collision, low temperatures, remoteness (Kendrick, 2016). The Code requires ships to apply for a Polar Ship Certificate (PSC) which became a condition for passing the NSR after January 2019 (IMO, 2018). In addition, to provide instructive information to crew members about the ships' operational characteristics and limitations, the Polar Code demands the ships to carry a Polar Water Operational Manual (PWOM) which can assist their decision-making process in critical circumstances (IMO, 2018). Every master, chief mate and officer would be well-understanding their appointed duties in various functions mentioned in PWOM. The training requirements are different depending on the ice and weather conditions. Basic training is required for the manning responsible for navigational

watch onboard when passing through open-sea or in water area with ice concentration no more than 10%. For other more intensive ice-covered areas, advanced training is mandatory (Grandinetti, 2017).

Additionally, Pollution prevention measures was adopted in May 2015 by resolution MEPC.264(68) and focused on environmental protection. It follows the Annexes I, II, IV and V of MARPOL, which apply to broader categories of vessels (IMO, 2018). However, the Energy Efficiency Design Index (EEDI) is the only exception. As outlined in MARPOL Annex VI Chapter 4, there is a targeted index for each ship design except ice-breakers and ships under category A in the Polar Code as these ships are not able to satisfy fuel efficiency requirements because of their unique hull shape and engine (Tsuchiya & Vroegrijk, 2018).

### 2.2.2 Arctic Council

The Arctic Council is not an institutional body established by neither a formal international convention, nor under the direct control of IMO. The active Arctic Council provides scientific reports and practical guidelines for better acts in Arctic waters (Grandinetti, 2017). Arctic Council consists of the eight Arctic States: Canada, United States, Russia, Norway, Sweden, Iceland, Finland, Denmark (including Greenland and the Faroe Islands). Additionally, twelve non-arctic countries have been admitted as observers to the Arctic Council: France, Germany, Netherlands, Poland, Spain, United Kingdom, China, Italy, Japan, South Korea, Singapore, India (Arctic Council, 2011).

International cooperation in the Arctic Council with six specialized working groups has concentrated on various issues regarding shipping activities, environmental protection, polar research and studies although sovereignty claims and disputes over natural resources remain (Tonami, 2014). Apart from Arctic coastal states, many non-Arctic states have paid attention to interest in the region, especially from those in Asia, proving the general attractiveness of this unique area over recent decades (Kiiski, 2017).

### 2.2.3 Northern Sea Route Administration

Russia claims its full authorization of controlling the international navigation over the NSR within its 200 nautical miles EEZ water (Ulstein, 2014). According to Russian regulations, all foreign vessels desiring to use the NSR have to apply for permission and give notification to Russian authorities prior to entering the area. In 2013, the Russian government approved the "Rules of Navigation in the Water Area of the Northern Sea Route" and simultaneously formed the Administration of the Northern Sea Route (NSRA) with the objectives to organize safe navigation and ensure environmental protection in the NSR area (Transport Ministry of Russia, 2013). The NSRA is under supervision of Ministry of Transport of Russian Federation and Federal Agency for Maritime and River Transport.

The foreign ships are permitted to sail through the NSR only when having the approval of NSRA. Besides issuing navigational permissions, NSRA also manages the instruction for applying ice-breaker service, ice pilotage, weather forecast services, and operating search and rescue assistance along the route (Eide & Endresen, 2010). The NSRA website provides information on how to apply for the navigational permission and added services; the cost of ice-breaker is also available. Shipmaster or ship owner can fill in an online form, then NSRA will announce their results of approval or refusal (NSRA, 2018).

According to NSRA, ships are required to have ice classification higher than Arc 3 based on the Russian Classification Rules or reference categories. However, there is an exception for lower ice-classed vessels to have permission to navigate via NSR during summer period when the route is ice-free or under favourable weather conditions (Transport Ministry of Russia, 2013). The exceptions are assessed on the case-by-case basis depending on vessels' ice-class and the actual ice condition in a particular period of time.

There are technical requirements that all ships must install a closed sewage treatment system either biologically or chemically clearing methods. The total capacity of storage tank must be sufficient for one-month navigation. Also, residuals from fuel separation and rinse water must be either treated or stored in tanks with a volume sufficient for 30 days. Furthermore, devices to collect petroleum waste are required (Centre for High North Logistics, n.d.). On 9 January 2017, the NSRA aligned its terminology use in regulations with ones in the Polar Code However, it should be noted that there is no direct correlation between Polar Class and Russian “Arc” ice classes (Transport Ministry of Russia, 2017). The ice-class equivalence assessment is decided by the NSRA on every single case.

### 2.2.4 Regulations on classification of ice-class vessels

Ships navigating in ice-covered waters need different design compared with standard ships due to the unique shape and technological requirements. Requirements such as the strengthening of the hull and powerful machinery are reflected in ships' ice class that demands valid certification issued by an authorized classification society or a maritime institution (IACS, 2014). There are several standards for vessel's ice classification, organizations such as Finnish-Swedish rules, Russian rules, Polar Class (Zhang et al., 2016). The approximate equivalences between ice classes of different societies are presented in Table 2.2.

Table 2.2 Approximate equivalences between ice classes of FSICR, Russian Rules and Polar Class (Zhang et al. 2016)

| Russian Maritime Register of Shipping | Finnish-Swedish Ice Class Rules | Polar Class |
|---|---|---|
| Arc 9 | - | PC1 |
| Arc 8 | - | PC2 |
| Arc 7 | - | PC3 |
| Arc 6 | - | PC4 |
| Arc 5 | IAS | PC5 |
| Arc 4 | IA | PC6 |
| Ice 3 | IB | PC7 |
| Ice 2 | IC | - |
| Ice 1 | Category II | - |

Polar Code (2016) categorises vessels into three main groups:

"*Category A ship - ships designed for operation in polar waters at least in medium first-year ice, which may include old ice inclusions*
*Category B ship - a ship not included in category A, designed for operation in polar waters in at least thin first-year ice, which may include old ice inclusions*
*Category C ship - a ship designed to operate in open water or in ice conditions less severe than those included in Categories A and B.*"

The IACS classification ranges from the lowest PC7 to the highest PC1. All IACS polar classes are above the Category C of the Polar Code (IACS, 2007).

The Finnish-Swedish Ice Class Rules (FSICR) were introduced since 1971, commonly used especially for vessels in the Baltic Sea (Riska, 2011). The purpose of this system is to facilitate the year-round operation of shipping activities in the ice waters. FSICR's standards are incorporated with the rules of several classification societies despite the difference in notations. A recognized ship can be classified as IA Super (IAS), IA, IB, IC, II and III, ranging from the highest to the lowest class accordingly (Finnish Transport Safety Agency, 2010).

Russian Maritime Register of Shipping (2019) classifies polar vessels in "Arc" notations which range from the highest-class Arc 9 to Arc 4, Ice 3, Ice 2, Ice 1 as the lowest class.

## 2.3 Economic Feasibility models

According to Kiiski (2017) Feasibility" often combines with prefixes presenting scope that research topic focuses on. In a broad view, feasibility covers PESTEL contexts, which are Political, Economic, Social, Technological, Environmental, Legal.

According to Graaskamp (1972), feasibility refers to *"identifying and measuring the adequacy of fit between context which defines the problem and the form of the proposed solution".* It is also defined as *"... a reasonable likelihood of satisfying explicit objectives when a selected course of action is tested for fit to a context of specific constraints and limited resources".*

Majone (1975) defines feasibility being a realistic objective for policy analysis that can be further mentioned in terms of the relevant constraints such as administrative, economic, institutional. Meanwhile, Gilabert & Lawford-Smith (2012) that feasibility enables comparative assessment of various proposals and eliminates ones that are not beneficial to proceed in practice.

Economic feasibility is also known as cost-benefit analysis in order to determine the expected benefits and advantages from a proposing option and compare them with costs and expenses. The project is called feasible if benefits surpass costs. A similar concept with "economic feasibility" is "economic viability" which is described by Lin (2002) as a possibility that continuously generates cashflows which surmount estimated costs.

### 2.3.1 Economic models without ice considerations

Natsuhiko et al. (2013), Kiiski (2017), Zhu et al. (2018), Zhang et al. (2016), Raza and Scoyen (2014) focus on components of cost itself and impacts of economic elements such as fuel cost, load factor, tariff on cost-benefit analysis without or with rather little considerations of ship resistance in ice-infested water. These studies often assume the average ship speed during the entire voyage.

Natsuhiko et al. (2013) presented shipping cost estimation model using the actual NSR shipping cases of transporting iron ore, LNG and frozen fish with the constant speed assumed along the voyage. On the two methods of computing depreciation cost, the straight-line method is used instead of a declining balance method because of its simplicity. The authors concluded that if the ice continues melting, summer sea ice enables lower ice class vessel to transit into the NSR. Due to the shortened distance, NSR shipping is time-saving and cost-efficient since expenses for fuel, operation and overhead all decrease.

Kiiski (2017), in his PhD thesis, provided a holistic PESTEL analysis on the feasibility of commercial shipping along the NSR. The author pointed out that the daily cost along the NSR is higher than in the SCR. However, on average shorter distances by one-third in the NSR is sufficient to fill the gap of unfavourable cost discrepancies. From shipowners' viewpoint, the NSR remains a niche market. In short-run till 2030, the NSR can be viable for certain shipping sectors under the right conditions of market and climate. There is an extremely modest potential for container shipping in the NSR, in contrast with the promising potential of energy bulk especially for destinational voyages than transiting voyages. In long-run, the feasibility of commercial shipping of the NSR remains a high level of uncertainty in which infrastructure and ice breaker service are decisive factors.

Zhu et al. (2018) supported Kiiski's conclusion that NSR can be a feasible choice under the status quo and that the route is more appealing to ports in the northern countries. The research showed that the environmental costs for container shipping tend to be higher than the conventional route because of small ship size and limited cargo-capacity that causes greater environmental impact per TEU. If bigger vessels with higher load factors can be sailed in the NSR, both operational and environmental costs could be mitigated.

The model of Zhang et al. (2016) suggested that both container and oil shipping regularly save around ten days for a transit compared to the SCR. The increase in bunker prices leads to the rise in market share of the NSR. However, despite the time-saving benefit, container shipping earns less profit per unit when sailing along the NSR. Meanwhile, oil shipping can only save cost if the average-ranged tankers are deployed. Thus, NSR is not economically appealing in container shipping compared to the conventional route but attractive to small or medium-size tanker operators.

A comparative study of Raza and Scoyen (2014) showed that even though global LNG demand has been increasing quickly, the NSR may not emerge as a threatening competitor to the SCR in the future. The result revealed that the NSR is 42 per cent cost-efficient for LNG carrier over the traditional route by offering half reduction in the sailing distance between the ports in Northern Europe and Northeast Asia. The NSR is an appealing option when the charter rate increases; meanwhile, the insurance cost seems not to have a significant impact on the total shipping cost structure. The authors agree with many other studies to conclude that a reduced tariff would enhance the competitiveness of the NSR significantly as an alternative over the southern one.

### 2.3.2 Economic models with ice considerations

Besides computing fundamental economic factors, studies of Grandinetti (2017), Xu et al. (2018), Solakivi et al. (2018) consider the variability of ship velocity in different ice conditions or use ship-ice transit simulation.

In the Master's thesis, Grandinetti (2017) developed a cost-benefit model depicts the effects of ice conditions on the vessels' resistance, speed and fuel consumption. The model enables the use of real-time ice data and POLARIS assessment. The study pointed out that the feasibility of NSR as an alternative seaway requires the right combination of ship parameters and variables. In summer months, ice-classed vessels are economic beneficial option to operate in the NSR compared to the SCR. On the other hand, in the winter time the ships are not economically feasible but more time-saving in comparison with the Suez route.

In the study of Xu et al. (2018) authors also considered the effect of ice condition in the cost model of the NSR/SCR-combined container services for ice-classed ships. The paper concluded that if the NSR tariffs decrease sufficiently, especially when down to zero, the route becomes more competitive. If the NSR tariffs are more than 0.8 times as the Suez Canal tolls, the NSR/SCR-combined service is less economical than the SCR. The second result of the research is about the two-sided effect of the bunker price. On the one hand, an increased bunker price will facilitate the use of NSR thanks to the shortened distance and fuel saving. On the other hand, when bunker price is significantly high, shipowners desire slow steaming that requires more ships in circulation. As the ice-classed vessels are capital-intensive, the fuel saving cannot compensate for the capital burden. Thus, the medium level of the bunker will benefit the most for the use of the NSR/SCR-combined service. Four months corresponding to 30 voyages, is the number of minimum operating time that makes NSR/SCR-combined service economical.

Research on the influences of Polar Class on the economics of bulk carriers in icy water, Solakivi et al. (2018) revealed that constructing ice-classed vessels could be up to three times more costly than non ice-classed vessels of the same category. Vessels with more powerful engines and heavier structure lead up to 1.5 times more fuel consumption. On the other hand, the load factor decreases 20 per cent compared to those without an ice class. Polar Class compliant vessels are not suitable for slow steaming, so the economic implications of ice-classed bulk shipping in the Arctic seems not to be an attractive option.

### 2.4 Shipping costs

According to Ostreng (2012), there are three primary methods for the economic feasibility comparison and analysis. The first approach is the calculation for total shipping cost in each route to estimate cost per units. The second approach mainly compares the cost differences among the alternative routes. The third method assumes the yearly capacity of transported cargo to compute the total cost of starting up a regular annual service.

As being stated by Lasserre (2014), there is no consensus on the optimal choice of models, assumptions and parameters to estimate shipping time and cost on the NSR route. The results are varied depending on the market sectors, selected ports and market conditions. The majority of studies divided the shipping cost into three main costs; capital, voyage and operational costs, as shown in Table 2.3 (Stopford, 2009).

Table 2.3 Shipping cash-flow composition

| **Capital Cost** | **Operational Cost** | **Voyage Cost** | **Earnings** |
|---|---|---|---|
| - Initial investment<br>- Depreciation<br>- Interest rate | - Repair and maintenance<br>- Insurance<br>- P&I<br>- H&M<br>- Cargo insurance<br>- Piracy<br>- Crew:<br>- Salary<br>- Training<br>-Others:<br>– Administration<br>– Added equipment against ice | - Fuel cost<br>- Canal tolls<br>- NSR fee:<br>- Ice-breaker<br>- Pilotage<br>- Weather forecast service<br>- Port fee | - Freight rate<br>- Cargo carrying capacity<br>- Productivity (load factor, speed, utilization rate, port time) |
| **Total cost = Capital cost + Operational cost + Voyage cost** | | | |
| **Profit/Lost = Total earning – Total cost** | | | |

### 2.4.1 Capital costs

The capital costs of a vessel depend on how it is financed. The capital costs can be computed in the forms of initial investment for a new building, depreciation cost, and interest rate if any (Stopford, 2009).

Ice-classed vessels require a more substantial initial investment due to the strengthen hull and powerful engine (Grandinetti, 2017). Polar Code (2016) introduces several additional requirements on ships to be sailed in the Arctic waters. That was written in Part II and was adopted as a mandatory regulation under the MARPOL Convention. The restrictions set up by the Polar Code and Russian Rules require vessels to have a large storage tank. An accurate number of the increase in investment cost is difficult to acquire (Lasserre, 2015). Based on 17 studies, Lasserre (2015) concluded that capital cost increases about 20% for IB vessels and 30-40% for ice-classed vessels above IAS standards, compared to normal vessels.

The depreciation cost of a vessel could be calculated by two methods; the straight-line depreciation and the declining balance. The first is widely used by many shipowners thanks to its simplicity. The life span for a ship's depreciation varies by countries. Natsuhiko et al. (2013) estimated that the depreciation cost of ship’s operational life is counted by the straight-line method of 10 years, accordingly the annual depreciation is set to 10% of the new-building price tag. Differently, Zanne (2014) based the argument on accounting standards that the economic life of a vessel for 25 years in average, 350 operational days per year.

Residual value, also known as a salvable value, is calculated as the price of scrap metal multiplied by lightweight tonnage of a vessel (Zanne, 2014).
Hence, the residual value equals to the ship's lightweight tonnage multiplied with the price of scrap metal.

$$\text{Yearly depreciation cost} = \frac{\text{Initial investment} - \text{Residual Value}}{\text{Economic Lifetime (years)}}$$

### 2.4.2 Operational costs

**Repair and Maintenance Cost**
This cost section includes costs for dry docking, supply, lubricant, spare parts and all expenses regarding repairing the faulty parts. It appears that harsh conditions in Arctic water cause ice-hull confrontation, propeller dysfunction and negative impacts on the engine, which all increase ship maintenance and repair cost. Based on the study of Jalonen et al. (2005) the most likely damages to incur on the hull are the scratching of paint due to floating ice with a lower likelihood of damage on the frames of the vessel. Additionally, the propeller blades can be damaged due to hammering on ice chunks, or the shaft because of concentrated ice mass between the hull and propeller blades. It must be noted that there is a high possibility that growlers can be formed during ice breaking and flow between ice breaker and the vessel escorted. These small icebergs can cause severe damage to the hull; however, due to their double hull nature, it will be superficial with no leakage.

The cost may surge up to 20-150% extra maintenance expenses for ice-classed ships navigating in Polar waters than regular ships on usual routes. The other way to calculate the maintenance expenses in cost estimation, is by setting the cost proportional to 1.095%/year of the new building price (Natsuhiko et al., 2013).

**Insurance cost**
Maritime insurance is significantly essential in Arctic shipping to mitigate the associated risks. The vessels need to be assured by three different types of insurance, namely Protection and Indemnity (P&I), Hull and Machinery (H&M) and cargo insurance. Each insurance component assures separated risk categories: P&I covers protected clauses for third-party liabilities whereas H&M protects against damage for the ship itself, its machinery and equipment. Furthermore, cargo insurance solely covers possible lost to the cargo carried on the ships (Schelin & Tiberg, 2007).

Liu and Kronbak (2010) assumed a 25 per cent increased P&I insurance premium for the ice-classed ships. Furuichi and Otsuka (2013) in their studies used 10USD/GT/year as additional H&M and P&I coverage for the trans-arctic vessels. Meanwhile, Hino (2011) estimated a lump sum 120,000 USD/year for both insurances. In stark contrast, other research proposed different views, the study by Sarrabezoles et al. (2016) argued that actual insurance costs might not be as high as stated by the many previous study reports. Skuld (2013) and Gard (2013) agreed that insurance companies do not increase P&I premium but charge extra for H&M insurance and additional equipment on board. The insurance fees estimation varies in literature studies, but most of them agreed that ordinary hull and machinery insurance does not cover navigation in ice-covered waters. Underwriters likely charge a supplement to assure these risks (Sarrabezoles et al. 2016; Skuld, 2013; Gard, 2013).

Besides insurance costs for Arctic shipping, it is important to mention the piracy risk along the Suez Canal, which may add the insurance cost for vessels to choose this traditional route. Falck (2013) showed that piracy in the Gulf of Aden bottleneck makes the insurance cost for transit shipping through the canal increases. Shipowners may need coverage for armed guards and kidnap and ransom (K&R) premium.

Erikstad and Ehlers (2012) claimed that the NSR now has comparable insurance level concerning the SCR, as the fact that *"most damages are left below the deductible limit and thus not claimed"*. Furthermore, the arm guard fee along the Somalian coast is considered as *"offsetting the differential"* (Raza & Scoyen, 2014).

They pointed out that during 2011-2013, high piracy risks along the SCR led to extra premium fees for armed guards. Thus, the NSR was an affordable choice to insurance cost savings (Kiiski, 2017).

**Crew cost**

Pursuant to the Polar Code (2016) and STCW Convention, for vessels navigating in ice-infested waters, ship's master, chief mates and navigational watchkeeping officers are obliged to ice training. Ice training's objective is to enhance crews' ability to confront physical and psychological obstacles like fatigue, darkness and remoteness, which can lead to human errors (Sakhuja, 2013). The training requirements are divided into two levels in accordance with various ice conditions. When the ice concentration is less than 10%, the necessary level of ice training is requested for the officers, applying for tankers and passenger vessels. However, for higher ice concentrations rate, all ships are required an advanced ice training level for the ship's master and chief mate and basic level for navigational watch officers (Polar Code, 2016).

### 2.4.3 Voyage cost

**Fuel costs**

According to Lasserre (2015), fuel costs are the most significant cost component in total voyage cost. Fuel costs directly affect the decision-making on operating in the NSR as Li (2018) showed the correlation between fuel price and the traffic in the NSR.

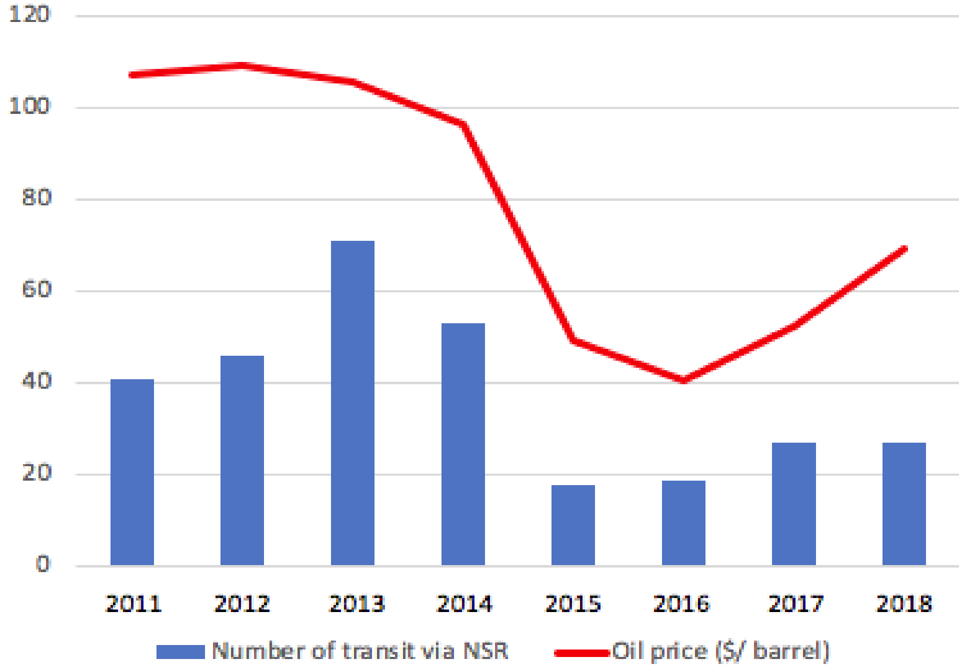


Figure 2.3 The number of transits through NSR and oil price 2011-2018 (Center for High North Logistics, 2018)

As can be seen from Figure 2.3 about the development of bunker price in comparison with the NSR transit number from 2011-2018, when the oil price increased, the considerable fuel costs became a decisive factor. This fact facilitated shipowners to operate via the NSR because the shorten distance saves considerable fuel cost.

The fuel costs are defined by fuel consumption of the entire voyage multiplied by the fuel price. On the one hand, fuel price is dependent on the type of fuel used and the market rate. The choice of fuel directly affects the fuel cost due to the considerable range cost for various fuel types. For example, Naval Distillate Fuel (NDF) is more expensive compared to the widely available Marine Diesel Oil (MDO) or Intermediate Fuel Oil (IFO) because it has a lower freezing point (Grandinetti, 2017). On the other hand, fuel consumption is affected by distance, speed, engine power, weather conditions (ice, winds, spray).

### Canal tolls

The Suez Canal fee is calculated based on several factors, including ship type, northbound or southbound, laden or ballast, Suez Canal Net Tonnage (SCNT) (Suez Canal Authority, 2019b). Additionally, tugs, mooring, pilotage and disbursements services will charge extra. The SCNT is computed as the exact measurement of all spaces below the upper deck, as well as the permanently covered and closed-in spaces on that deck (Suez Canal Authority, 2019a). The Suez Canal queuing system is created to decrease the entire canal transit time. The transit time accounts from the time of arrival, the actual transit time through the canal and the time of exiting. The arrival time at the canal to the time of departure is estimated to be about 40 hours, and the actual transit time through the canal itself takes 11.4 hours on average (Grifths, 1995).

### Icebreaking and Pilotage fee

Unlike the Suez Canal, no passage fees are incurred for passing the NSR (Transport Ministry of Russia, 2013). NSR fee primarily refers to the cost of ice-breaker assistance. According to NSRA (2018), only icebreakers under Russian flag may escort vessels through the NSR. The applied ships must be compatible with the required technical limitations, most importantly, the requirements of ice-class (Transport Ministry of Russia, 2017).

In general, the vessels should be at least IA classed. However, in some favourable ice conditions during summer time, ships with lower ice-class are permitted to pass the route and even can sail independently without ice breaking escort.

The Federal State Unitary Enterprise (FSUE) Atomflot is the dominant player among six organizations providing ice-breaking service. If the ship is allowed to enter the route, the next step is to contact Atomflot to request the icebreaker assistance and negotiate the icebreaking fee. The charge is dependent on gross tonnage, ice class, navigation period, and quantity of transit zones. In general, the tariff is more expensive for larger ships, lower ice class, transiting through many zones (Lasserre, 2015).

Under the NSRA law, ice pilotage onboard is mandatory if the shipmaster is not experienced in ice-covered waters (NSRIO, 2016). The NSR pilot fee is calculated on vessel size, ice class, pilotage distance and the navigation time. The ice pilotage fee is about $1,000 per day, plus $5,000 for other associated travel expenses (Grandinetti, 2017).

### Other voyage costs

Besides the aforementioned costs, additional expenses may occur during the voyage. According to Liu and Kronbak (2010), service of route recommendation based on meteorological and ice data accounts for $90/ day and $231 for three days. Additionally, the bunker filling fee is $6.3/ton, fresh water supply is around $1-2/ton, telephone costs $4.5/minute. The total expenses for maps, guidebooks, signals book can be up to $700-900 for the route. Another cost is the additional expenses for winter clothing, lifeboats, protective equipment and tools.

**2.5 Ice types**

According to Shokr and Sinha (2015), there are specific criteria to identify ice types. The most important characteristics are their thickness and age. The authors suggest additionally classification ice types based on the World Meteorological Organization (WMO, 1985). More specifically, there are three additional scales; fast ice over floating ice, level ice over deformed ice, and seasonal ice over perennial ice (Shokr & Sinha, 2015). This thesis focuses on two main ice types, brash and broken ice. Brash ice is formed mostly during November in the region of Arctic by ice floes or broken parts of pack ice leading to smaller floating chunks. Shokr and Sinha (2015) define brash ice as the *“accumulation of floating ice made up of fragments; the wreckage of other forms of ice"*. The authors additionally, defined pancake ice-considered as broken ice for this research as the formation of *“breaking Nilas or even grey ice sheet under agitated conditions of ocean gravity waves or swell”*. Therefore, such ice formations will lead to some additional resistance, augmented with the usual open water resistance based on the ship hull formation.

According to Shokr and Sinha (2015) and Pastusiak (2016), ice concentration defines the ice coverage in the ocean. It is measured in ranging of tenths for the entire surface of the ice-covered waters. The authors state that *“each point on the scale corresponds to the percentage of the sea’s surface covered by ice (WMO, 2004b). A general classification of degrees of ice extent used in shipping (CIS 2005) identifies an open water classification, which describes water with an ice cover of 0–1/10 (to 1/8; to 10–12 %)”.* Furthermore, the authors claim that full operating speeds in these ice conditions and avoidance of ice floes without significant change on the speed, are possible. For the route planning within the icy waters, the sea ice extent plays a crucial role. The running speeds are mainly affected by two primary factors (Arikaynen, 1990); ice concentration and thickness. Ice concentration determines the area of ice-free waters and the adjustments on the operating speed needed. For instance, (Pastusiak, 2016; Shokr & Sinha, 2015) 4/10 of ice concentration can lead to a 75 per cent of the route carried out on operating speed and for the remaining 25 per cent some reductions to speed, due to necessary manoeuvrability in ice. Vessels can sail in waters with 4/10 ice concentration, without ice classification (Arikaynen, 1990). Not the case for higher ice floating extend, whereas corresponding ice class and appropriate displacement to first engine output ratio are needed. Especially for ice concentrations of 7/10-9/10, icebreaking escort is essential even for certified high ice-classed vessels.

Ice thickness determines the age of the ice. Shokr and Sinha (2015) remark that newly formed ice can be a thin layer of 5 cm up to 30 cm. If the ice thickness exceeds these limits, then it is considered as first-year ice. Moreover, its ability to survive the summer melting period, it can transform into three different ice types. Old ice, or second-year ice, in case of thickness less than 250 cm and multi-year ice in case of a thickness exceeding 300 cm.

The navigational season in the Arctic is conditional to the ice extent and the vessel's ability to traverse through ice, considering their ice class strength.

According to Office of The Federal Register (1999), the navigational season is defined as *"an annual period designated by the Corporation and the Authority, that is appropriate to weather and ice conditions or vessel traffic demands, during which the Seaway is open for navigation".*

# Chapter 3: Research Methodology

This chapter presents the research approach, the methods used and how the data were collected. Furthermore, the case study in the study with three different scenarios are explained.

## 3.1 Research approach

According to Leedy and Ormrod (2005, p. 3), research can be defined as *“the systematic process of collecting and analyzing information (data) in order to increase our understanding of the phenomenon about which we are concerned or interested”*.

This thesis follows mixed methods and a deductive approach. Based on Creswell (2014), mixed methods approach is the collection of both quantitative and qualitative data for the research purposes following a statistical and textual analysis pattern, including both open and closed-ended questions.

According to Wilson, J. (2010, p.7) deductive reasoning is concerned with *"developing a hypothesis (or hypotheses) based on existing theory, and then designing a research strategy to test the hypothesis"*. More specifically, the thesis aims to use the assumptions in the literature supporting the feasibility of the NSR and apply them on simulations and a set of calculations for different case scenarios.

Furthermore, primary data is gathered by the researchers to acquire the research's objective. Secondary data is collected by other persons than the authors conducting the research (Bryman and Bell, 2015). To approach the mixed method, both primary data and secondary data were used in the study. The following sections will present further detail on the data collection techniques and data analysis methods.

## 3.2 Data Collection

### 3.2.1 Secondary data

A literature review through books, peer-reviewed articles, scientific journals, and referencing materials to create the frame of reference. Literature was searched on databases: ScienceDirect, Elsevier, Business Source Premier, Scopus, Chalmers' library. Combination of the keyword "*The Northern Sea Route*” was used together with one of following selected keywords: *feasibility study; laws and regulations framework; safety and security; ice resistance; fuel consumption; cost-benefit models* to narrow down the scope of search results. Advanced search tool helped to select literature that was published from 1970 onwards to ensure the validity and updating information used in the research. Besides books and peer-reviewed articles, reports and guidelines on the webpages of both NGO and governmental organizations such as IMO, Arctic Council, Northern Sea Route Administration also support to form theoretical framework. The initial literature selection including journals, articles, books and websites, was 120 in total. After filtering of the literature, the most relative stands for selecting 99 in total.

### 3.2.2 Primary data

Primary data was collected through interviews with various actors in shipping industry and a questionnaire to shipping companies.

According to Yin (2014), there are six viable sources of data, namely documents, archive records, interviews, direct observation, participant-observation and physical artefacts. In this research, internal documents, interview , and survey are the three primary sources for collection of primary data .

**Interviews**

Besides the quantitative method to calculate the cost, primary data was collected through interviews in order to achieve multiple-perspectives and comprehension on the topic. There are three types of interviews in scientific research; structured, semi-structured and unstructured (Harrell & Bradley, 2009).

In the study, a semi-structured interview was found as the optimal option since it does not limit the responses within predefined questions, which often happens in the structured method (Kvale, 2007). The semi-structured interview allows respondents express opinions comfortably in accordance with their expertise and enables further discussion. However, Johannesson and Perjons (2014) pointed out that the process requires flexible skills from interviewers to elaborate towards the studied objectives.

The selection of interviewees derived from purposive sampling (Patton, 1990) to serve specific inquiry of the research. Respondents were selected based on their relevant knowledge and adequate experience on Arctic shipping and the NSR. The interviewees taking part in the research included actors from a diverse background within the shipping field and different professional positions that enable to shape well-rounded opinions on the feasibility of commercial shipping in the NSR. Communication with prospective participants occurred via emails and LinkedIn. Eventually, three interviews were conducted in English between 27th March 2019 - 3rd April 2019. One was carried out through Skype and the other two by interpersonal meetings; each last approximately 30-50 minutes. To bring a holistic view from various stakeholders, the interviews were contributed by respondents at managerial level from a shipping company having a business on the NSR, port authority, and three representatives from an insurance company. The positions of the interviewees are shown in Table 3.1.

Table 3.1 Interviewees and professional positions

| Organization | Position of the Interviewee |
|---|---|
| Shipping Company | Operations Manager |
| Port authority | Senior Manager of Market Intelligence |
| Insurance Company | Senior Underwriting Manager |
| | Underwriter |
| | Reinsurance Officer |

The semi-structured interview consists of six open-ended questions (Appendix-E). Apart from predetermined questions, some have been designed exclusively based on the different fields of interest regarding interviewees' expertise. The information retrieved from predefined questions enables authors to compare and contrast the opinions under the same spectrum; meanwhile opened questions facilitate the comprehensive knowledge in depth. All the interviews were transcribed and cross-checked to ensure the accuracy of the information.

**Questionnaires**

Survey is a time-saving and inexpensive substitute to approach a broader range of respondents, albeit it constrains the possibility of collecting opinions outside the pre-formulated options (Kelley, Clark, Brown, & Sitzia, 2003).

According to Johannesson and Perjons (2014), there are two main survey structures, namely open-ended questions and closed-ended questions. Bryman and Bell (2015) claims that closed-ended question facilitates time-saving and precise responses. Furthermore, they assist in comparing and processing answers. Opened-ended questions create an opportunity to explore thorough opinions on each answer. In the study, both types of question are used. The respondents were selected by a combination of purposive and convenience sampling (Gray, 2014; Patton, 1990). Respondents need to satisfy the criteria about relevant knowledge on the topic; meanwhile, convenience sampling mentions non-random sampling of respondents' availability and accessibility (Gray, 2014). The survey was carried out from 21st March 2019 till 12th April 2019. Due to the time constraints and availability of participants, the number of interviews is limited. In total, the study got nine responses (response rate: 75%), including three participants mentioned above in interviews. Questionnaires were used as pre-phase before formal oral interviews, which helps to save time and enables interviewees to elaborate their answers further. All remaining respondents are from shipping companies either have a business on the NSR or lack of experience relating the route. The purpose was to spot the opinions of shipowners on the viability of commercial shipping in terms of potential cargo types, cost, challenges, future engagement.

A web-based survey was created on Google Forms and sent via emails to the participants. The survey includes 11 multiple choice questions with optional follow up comments section (Appendix-F).

### 3.2.3 Validity and Reliability

In order to provide the readers with further transparency, validity and reliability of the research will be discussed. Without these two elements, it would be hard to measure the errors along the research process (Forza, 2002). In order to enhance the validity and reliability of the data collected, it is important to undergo various sources and multiple research methods. Triangulation encompasses the credibility and dependability of the findings (Moon, 2019, p.113). The thesis validity and reliability will be further discussed in Chapter 5.

## 3.3 Case Study

A case study was carried out to explore the potential cost savings that the shipowners can have by transiting through the NSR in different ice formations. Two study vessels were chosen for three scenarios sailing along the NSR: completely ice-free scenario, broken ice scenario and brash ice scenario. The purpose is to calculate the fuel consumption and total cost, then to compare with the SCR.

The first scenario focuses on ice-free conditions enable open water sailing during September. A second scenario represents broken ice conditions, usually occurring in October with almost negligible ice concentration and thickness sea ice in the initial phase of shaping. Finally, a brash ice scenario in November can lead to harsh operating conditions. Matlab was used to read real-time data of the ice for every corresponding coordinate. The inputs are ice data of the entire NSR area at a specific time, longitude and latitude from ship's GPS; the outputs are ice concentration and ice thickness for the coordinates (Appendix-D). The following step is to calculate ship resistance in open water, broken ice, and brash ice by applying the codes and relevant equations in Matlab.

Google My Maps tool was used to plot the route from the actual set of coordinates in the NSR area and to measure the distance. Also, the possibility of alternative route planning was examined by analyzing the bathymetry map.

Model design to calculate fuel consumption is shown in Figure 3.1 and explained as follows:

**Step 1:** The set of 217 actual coordinates with the corresponding speed of vessel Vessel Y navigating on the NSR was collected from Chukchi to the Kara Sea. The ships' speed was recorded every hour. Meanwhile, the real-time data for ice was extracted in the period of 15-23 October and 15-23 November 2018.

**Step 2:** Coding in Matlab, the purpose is to input real coordinates (longitudes and latitudes in decimal format) of ships to extract corresponding ice concentration and ice thickness of each position in real time.

**Step 3:** Calculating ship resistance. Depends on the scenario and ice situation to apply equations of either open water resistance or broken ice resistance or brash ice resistance in each ship’s position.

**Step 4:** Calculating power needed for the ship to overcome the ice (if any) and to sail the ship in a specific velocity.

**Step 5:** Calculating fuel consumption for the NSR sections. For the legs outside the NSR, the open water equation is applied.

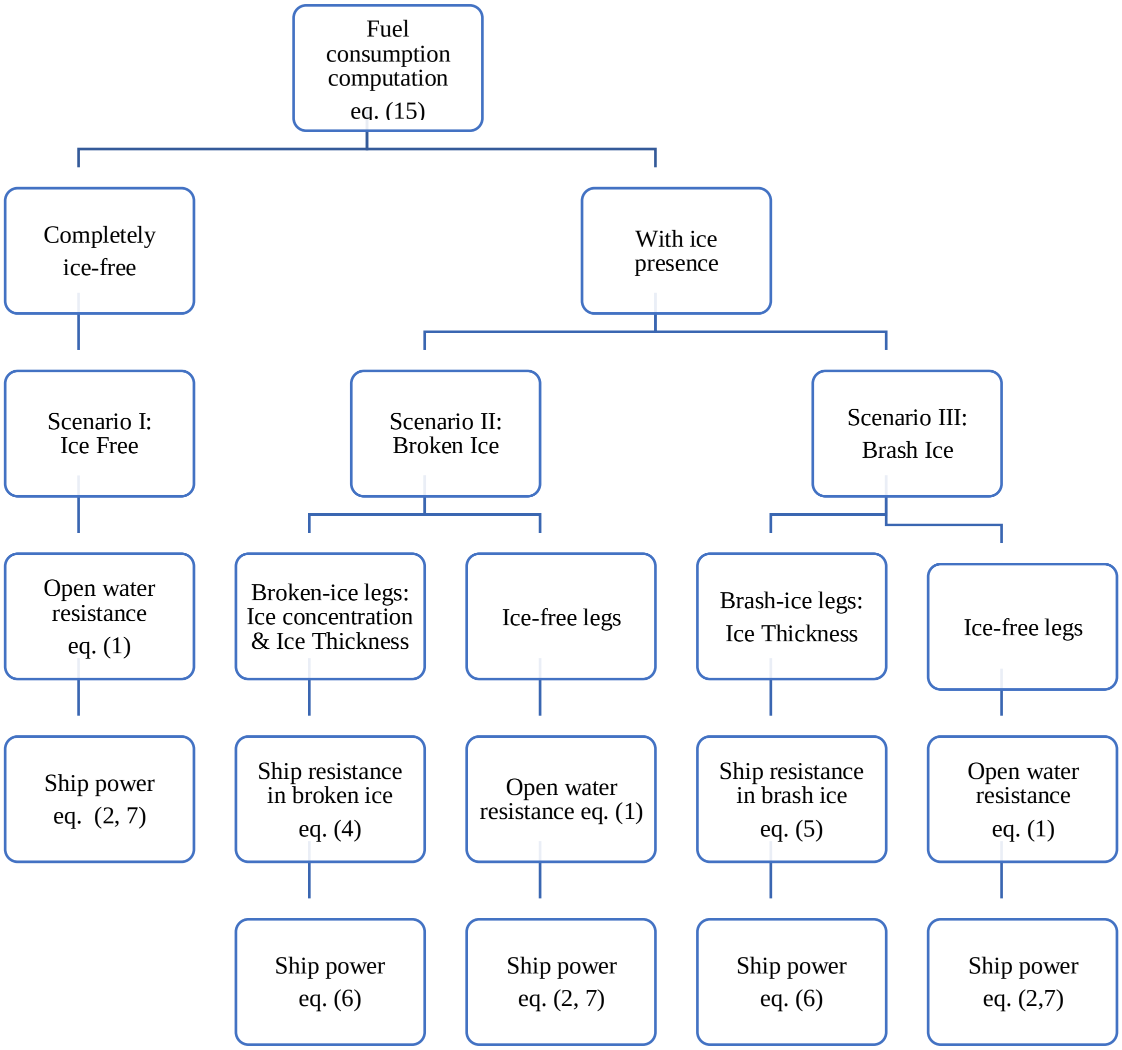


Figure 3.1 Fuel consumption computation model

Fuel consumption is dependent on weather conditions, hereby mainly refers to ice conditions. Ship resistance in any ice-free water is calculated by equation (1). The same open water resistance equation is used for the SCR and Scenario I of the NSR where the route is entirely ice-free. Meanwhile, in case of either broken ice or brash ice occur, the route is divided into ice-free legs and ice-covered legs. For broken-ice legs, the data of ice thickness and ice concentration is needed to calculate the ship resistance, whereas, for brash-ice legs, only ice thickness is required for resistance computation. Ice-free legs in both cases are treated as normal open water area.

**Scenario I: Ice-free**

The ice-free conditions in the NEP are assumed to occur in September. During this time, seawater conditions are practically similar to the SCR. To calculate the open water resistance and the power consumption, the Holtrop and Mennen (1982) method has been used thoroughly by inserting and treating the data on Matlab (Appendix-D). By calculating the propulsion power requirements, the SFOC rate has to be estimated by the specifications of Vessel Y's Main Engine, which is Wind GD RTflex50-E, six cylinders with a maximum power output of 10.470 kW with SFOC 161.2 g/kWh on 85%-100% load conditions (Appendix-C). However, it has been noticed that the power required to overcome ice resistance needs to be higher than the current engine capabilities. Therefore, a stronger engine of 8 cylinders should be applied and the power output of 13.960kW. Then, the total fuel consumption for the full transit can be estimated. For the hypothetical Vessel X, the same process has been followed. On the contrary, since Vessel X is a container ship, it is estimated to operate with higher speeds compared to Vessel Y. The Vessel X's main engine based on the same manufacturer is WindGDX72, with eight cylinders with a maximum power output of 28.880 kW with SFOC 161.2 g/kWh on not fully loaded conditions (Appendix-C). It is essential to mention that during the voyage, Vessel Y had to remain idle for eleven hours due to the waiting of icebreaker for pilotage throughout the route. The same has been assumed for Vessel X for all ice scenarios. In this case, the only cost that could be omitted is the main engine's, substituted by auxiliary engines which are considered as 10% of the engine's FOM based on Germán de Melo (2014).

**Ship resistance in open water**

Two most reliable and popular methods to estimate the ship resistance in open water are ITTC-1957 method and Holtrop and Mennen (1982) method. The total ship resistance in open area where there is no ice presence can be subdivided into:

$$R_{Total} = R_F (1+k_1) + R_{APP} + R_W + R_B + R_{TR} + R_A \tag{1}$$

Where:

$R_F$ is frictional resistance

$1+k_1$ is form factor for the viscous resistance of the hull form

$R_{APP}$ is the resistance of appendages

$R_W$ is wave-making and wave-breaking resistance

$R_B$ is additional pressure resistance of bulbous bow near the water surface

$R_{TR}$ is additional pressure resistance of immersed transom stern

$R_A$ is model-ship correlation resistance

**Form factor**

$1+k_1 = c_{13}\ \{0.93 + c_{12} \left(\frac{B}{LR}\right)^{0.92497}(0.95–C_p)^{-0.521448}(1–C_p+0.0225\ lcb)^{0.6906}$ (1a)

Where:

$C_p$ is the prismatic coefficient

lcb is the longitudinal position of the centre of buoyancy forward of 0.5L

$c_{12} = (\frac{T}{L})^{0.2228446}$ , when $\frac{T}{L} > 0.05$

$c_{12} = 48.20(\frac{T}{L} – 0.02)^{2.078} + 0.479948$, when $0.02 < \frac{T}{L} < 0.05$

$c_{12} = 0.479948$, when $\frac{T}{L}<0.02$

$c_{13} = 1 + 0.003\ C_{stern}$ for U-shaped sections with Hogner stern $C_{stern} = +10$

**Frictional Resistance $R_F$**

According to the equation of ITTC-1957 method

$$R_F = C_F\ \frac{1}{2}\ \rho_i V^2 S \quad (1b)$$

Frictional resistance coefficient $C_F = \frac{0.075}{(log10Rn - 2)2}$

Reynold number $R_n = \frac{V\ L}{v}$

Wetted surface area $S = 1.025\ L\ (C_pB + 1.7T)$

**Appendage Resistance $R_{APP}$**

$$R_{APP} = 0.5\rho_i V^2 S_{APP}(1+k_2)C_F \quad (1c)$$

Where:

$S_{APP}$ is the wetted surface area of the appendages

$1 + k_2$ the appendage resistance factor

**Wave resistance $R_W$**

$$R_W = c_1c_2c_5\nabla\rho_i g\ \exp\{m_1F_n^{\,d} + m_2\cos(\lfloor F_n^{-2})\} \quad (1d)$$

$c_{1,}\ c_{2,}\ c_5$ is influenced factors on wave resistance

$\lfloor = 1.446C_p – 0.03\ \frac{L}{B}$ when $\frac{L}{B}$ <12 and $\lfloor = 1.446C_p – 0.36$ when $\frac{L}{B}$ >12

d= - 0.9

$m_1$, $m_2$ are dependent on $C_p$ and ship parameters

**Additional pressure resistance of bulbous bow near the water surface $R_B$**

$$R_B = 0.11\ \exp(-3P_B^{-2})F_{ni}^{\,3}A_{BT}^{\,1.5}p_i g/(1 + F_{ni}^{\,2}) \quad (1e)$$

$P_B$ is a measure for emerged of the bow

$F_{ni}$ is the Froude number based on $P_B$ immersion

$A_{BT}$ is the transverse area of the bulb at forward perpendicular ($m^2$)

**Additional pressure resistance of immersed transom stern $R_{TR}$**

$$R_{TR} = 0.5\ \rho_i V^2 A_T c_6 \quad (1f)$$

Where:
$A_T$ is wetted transom area at rest ($m^2$)
$c_6$ is related to the Froude number based on the transom immersion

**Model-ship correlation resistance $R_A$**

$$R_A = 0.5\ \rho_i V^2 S C_A \tag{1g}$$

With $C_A$ is correlation allowance coefficient

**Ship power required to exceed open water resistance**

Required Effective Horsepower in open water is calculated as

$$EHP_{OW} = R_{total} V \tag{2}$$

Where
V is the speed (m/s)

**Scenario II: Broken Ice**

During October, ice is started to shape at the region of the Arctic. Broken ice is frequently met during the voyage at this time. For calculating the resistance, Guo et al. (2017) method is followed. Real ice data have been extracted from Vessel Y 's coordinates. Since most of the voyage has been carried out in ice-free waters, open water resistance is taken under consideration. Only for the small region in the Siberian Sea that broken ice had been encountered, it is necessary to include broken ice resistance. Ice data have been retrieved from the Copernicus database using the weather forecasting code (Appendix-D).

**Ship resistance in Broken ice**

Ship resistance in broken ice, which is assumed for the scenario in October followed by Guo et al. (2017) method. The total ship resistance in the areas under the broken ice condition comprises two parts, namely open water resistance $R_{OW}$ and broken ice resistance $R_{BI}$, which can be computed as follows:

$$R_{Broken} = R_{OW} + R_{BI} \tag{3}$$

$$R_{OW} = C_{OW} V^2 \tag{3a}$$

$$R_{BI} = C_{BI}\, \rho_i\, B\, h_i\, V^2\, C^2 \tag{3b}$$

Where:
$R_{broken}$ is the total resistance considering broken ice conditions and ice-free waters,
$R_{ow}$ is the resistance occurring in open water conditions,
$R_{BI}$ is the resistance occurring in the parts of the route where broken ice occurs,
$C_{OW}$ is the coefficient of the open water resistance ,
$C_{BI}$ is the coefficient of the broken ice resistance
$\rho_i$ is the density of the ice,
B is the vessel's width,
hi is the thickness of the ice,
V is the ship's velocity,
C is the concentration of the ice, and *n* is the power of the concentration.

In this equation, the ship resistance depends on both ice thickness and ice concentration.

$$C_{BI} = 4.4\ F_{rp}^{-0.8267} \quad (3c)$$

$$F_{rp} = \frac{V}{\sqrt{g\ hi\ C}} \quad (3d)$$

Thus, equation (3) can be described as following:

$$R_{broken} = C_{OW}V^2 + 4.4 \left(\frac{V}{\sqrt{ghiC}}\right)^{-0.8267} \rho_i B h_i V^2 C^2 \quad (4)$$

**Scenario III: Brash Ice**

For Brash ice conditions occurring mainly in November, it is observed that the amount of ice concentration and thickness is in significantly higher rates. Riska and Juva (2002) method was applied to calculate the resistance in brash ice conditions.

**Ship resistance in Brash ice**

Ship resistance in brash ice, which is assumed for a scenario in November followed by Riska and Juva (2002) method:

$$R_{Brash} = C_1 + C_2 + C_3\ (H_F + H_M)^2\ (B + 0.658\ H_F) + C_4\ L\ H_F^2 + \rho\Delta\ g\ \left(\frac{LT}{B^2}\right)^3 H_M\ A_{WF}\ F_n^2 \quad (5)$$

Where:

$R_{brash}$ is the ship resistance in brash ice (N)

$H_F$ is the thickness of the brash ice layer displaced by the bow and moved to the side of the canal. It is approximated to $0.26 + (BH_M)^{0.5}$

$H_M$ the thickness of the brash ice in the middle of the channel

$\rho_\Delta$ is the difference between the densities of water and ice

$A_{WF} = \frac{LB}{4}$ is the waterline area of the foreship

$F_n = \frac{V}{\sqrt{gL}}$ is the Froude number

$C_3 = 459.993\ kg/m^2s^2$, $C_4 = 18.783\ kg/m^2s^2$

$C_1$ and $C_2$ apply only for ice class IA Super with a bulbous bow:

$$C_1 = f_1 \frac{BL}{\frac{2T}{B}+1} + 2.89(f_2\ B + f_3\ L + f_4\ B\ L)$$

$$C_2 = 6.67(g_1 + g_2\ B) + g_3(1 + 1.2\ \frac{T}{B})\ \frac{B^2}{\sqrt{L}}$$

Coefficients are presented in Table 3.2.

Table 3.2 Coefficients in Brash ice equations

| | | | | | |
|---|---|---|---|---|---|
| f1 | 10.35 | $N/m^2$ | g1 | 1537.3 | N |
| f2 | 45.8 | N/m | g2 | 172.3 | N/m |
| f3 | 2.94 | N/m | g3 | 398.7 | $N/m^{1.5}$ |
| f4 | 5.8 | $N/m^2$ | | | |

The equation is applied with simplifications, however, still keeps

$$p\, \Delta g\, (LT/B^2)^3\, H_M\, A_{WF}\, F_n^2$$

for the dependences on the ship's velocity and particulars with the Froude number as a part of the equation. This equation is dependents on ice thickness rather than ice concentration.

**Ship power required to exceed ice resistance**

In ice water, applying for both brash ice and broken ice, the required propulsion power is the power that gives high enough thrust to exceed the ice resistance in the design ice conditions at the design speed. Under Finnish-Swedish ice-class rules and the Riska and Juva (2002) study, the required power $P_{ice}$ (kW) is calculated as:

$$P_{ice} = K_p\, R_{ice} \frac{1,5}{Dp} \qquad (6)$$

Where:

$R_{ice}$ is the ice resistance (kN) computed either by equation (10) or (12)

$K_p$ is a coefficient differing with the number of propellers and propeller type or machinery in Ice Class Rules. For controllable pitch propellers or electric or hydraulic propulsion machinery, $K_p$ = 2.03 for one propeller, 1.44 for two propellers, and 1.18 for three propellers; for fixed pitch propellers, $K_p$ = 2.26 for one propeller, 1.6 for two propellers, and 1.31 for three propellers.

**Calculating Fuel Consumption**

For the sake of simplification, the Effective Horsepower is estimated as 85% of the Breaking Horsepower Service Continuous Rating $BHP_{mcr}$ according to Siegl et al. (2018) is formed as following:

$$BHP_{mcr} = EHP_{OW} / 0.85 \qquad (7)$$

Fuel consumption is calculated as follows:

$$\text{Fuel Oil Mass} = BHP_{mcr} \times SFOC \times t \times C_e \times 10^{-6} \text{ (tons)} \qquad (8)$$

Where:

$BHP_{mcr}$ is Breaking Horsepower Service Continuous Rating (kW)

SFOC is Specific Fuel Oil Consumption (g/kWh)

t is the time (hours)

$C_e$ is the coefficient of ship fuel consumption

# Chapter 4: Results and Analysis

This chapter presents our main findings for case study of two ships in three scenarios. The cost components and total voyage costs are calculated in both NSR and SCR. Furthermore, the sensitivity analysis of market factors and results from interviews and survey support a thorough analysis for feasibility study.

## 4.1 Ship Particulars

Table 4.1 presents two vessels used in this study; one sub-Panamax bulk carrier named Vessel Y owned and operated by COSCO Shipping, followed by a set of data tracking the exact coordinates and ice conditions of the vessel during the voyage. The other vessel named Vessel X is assumed. Its particulars are similar to Ottawa Express owned and operated by Hapag Lloyd. The vessel data were retrieved from Thorsen (2012) Master's thesis. Both ships are ice-classed.

Table 4.1 Ship Particulars

| Factors | Units | Vessel Y | Vessel X |
|---|---|---|---|
| | | | |
| Vessel type | - | General-Cargo Handymax | Container-ship Sub-Panamax |
| TEU | - | - | 2808 |
| Ice class | - | IA | IA Super |
| DWT | tons | 37,130 | 40,882 |
| Light ship | tons | 12,082 | 17,669 |
| Length Overall (LOA) | m | 190 | 232 |
| Length between Perpendiculars (Lpp) | m | 186.4 | 230 |
| Breadth (B) | m | 28.5 | 32.2 |
| Draft (T) | m | 10.7 | 10.8 |
| Displacement volume ($\nabla$) | $m^3$ | 49,159 | 52,030 |
| Design speed | knots | 14.8 | 24 |
| Main engine power | kW | 10,470 | 25,426 |

The studied route is from Shanghai – China to Gothenburg – Sweden. Vessel X stops at three intermediate ports along the SCR route (Singapore, Rotterdam, Hamburg) and the NSR route (Busan, Pevek, Hammerfest). Vessel Y goes directly to the destination port without any port calls in between.

## 4.2 The Northern Sea Route

### 4.2.1 Route Planning

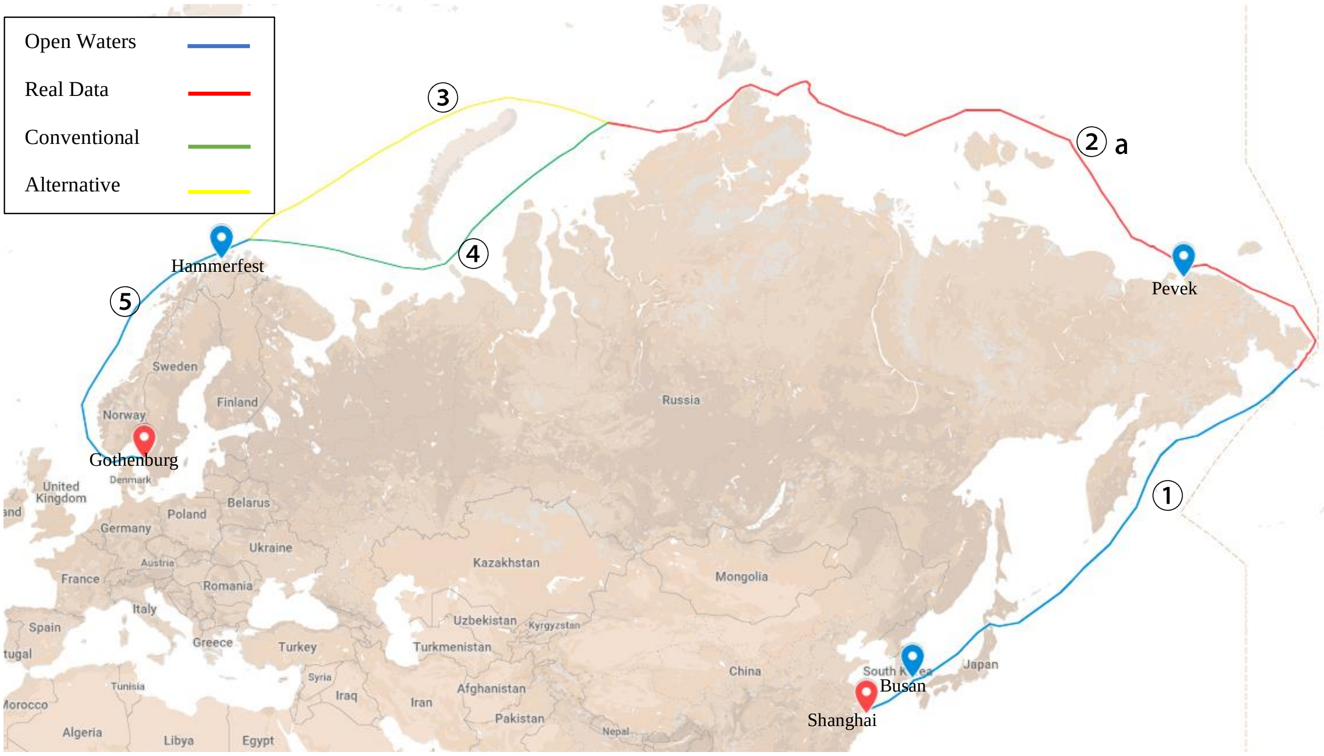


Figure 4.1 The North East Passage with real data marked with the red line (designed by authors on Google MyMaps)

Figure 4.1 presents the route planning for studied vessels in broken ice waters (Scenario II) and brash ice waters (Scenario III). Bathymetry and ice conditions are the major factors affecting the route planning. The full transit Shanghai – Gothenburg is divided into three sections. The NSR section of approximately 2,580 nm, is illustrated with the red line and is plotted from real-time coordinates. The blue lines illustrate the conventional route planning in the open waters.

The two legs (depicted with yellow and green line) represent the alternative paths of the remaining NSR voyage. The two routing options have been compared: Yellow line above Yuzhny island is 232 nm shorter than Green line below it. Moreover, in all scenarios, the Barents Sea area is ice-free, and there is no draft restriction. Hence, the route 1-2a-4-5 is used. Three port calls for container ship in the case study are Busan, Pevek, Hammerfest. The total distance has been measured on Google My Maps, counting 7,656 nm.


Figure 4.2 The NSR in ice-free scenario marked with the orange line
(designed by authors on Google MyMaps)

In the ice-free period (Scenario I), the route in the NSR section is marked by the orange line in Figure 4.2. The ice-free waters allow vessels to sail freely. Comparing to the route 1-2a-3-5 presented above, the route 1-2b-4-5 can shorten the distance by 116 nm in total, which helps to save fuel consumption in the end.

The route estimation was based on the shallowness of the sea waters in the region of Laptev Sea, especially on the Southern part. According to Pastusiak (2016), the Dmirty Laptev Strait shows a variety of shallow waters less than 10 m, making impossible for vessels for the case study of this research to pass through. Furthermore, the Kara Sea needs of special treatment, with an average depth of 111 m, but 40 per cent of it is less than 50 m deep (Majewski, 1992). Numerous abnormalities on the seabed have been observed, with varying depths between 14 to 150 m followed by small islands with shallow waters surroundings. Therefore, proper route planning is necessary based on the Russian sailing directions for Kara, Laptev, Siberian and Chukchi Seas. These guidelines suggested reliable and experienced paths along the sea waters of each sea region. Figure 4.3 is a bathymetric map further demonstrating the water depths in the Russian coastline.

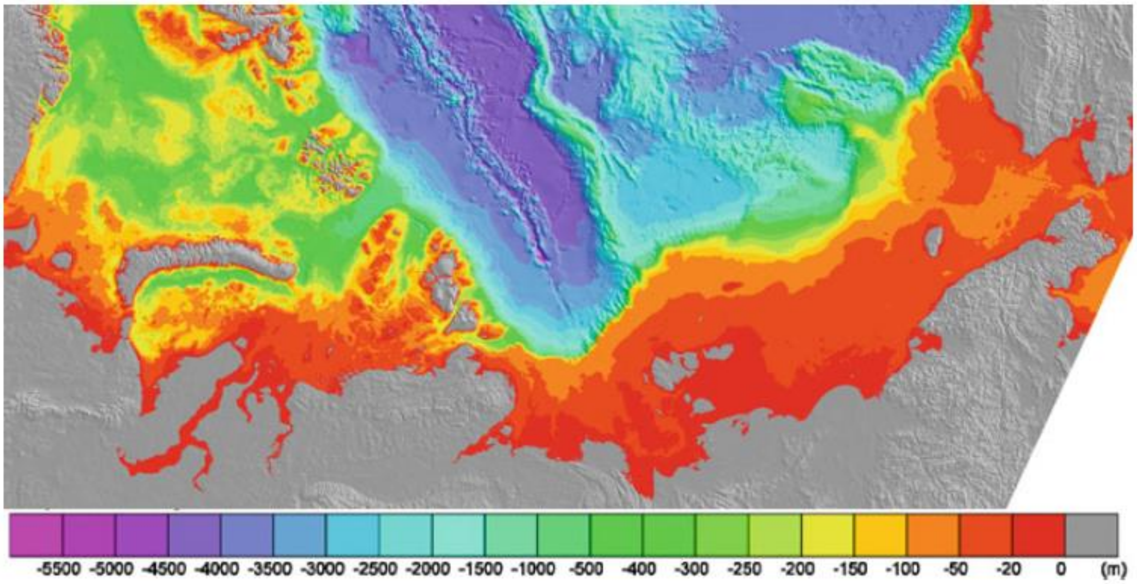


Figure 4.3 Shallow Waters approximation along the Russian Coastline
(Jakobsson et al., 2012)

Furthermore, taking under consideration the insurance company's rescue plan, the optimal route has been designed to be as close to rescue stations and ice breaker bases as possible. This ports and rescue stations are provided in Figure 4.4, retrieved from Pastusiak (2016).

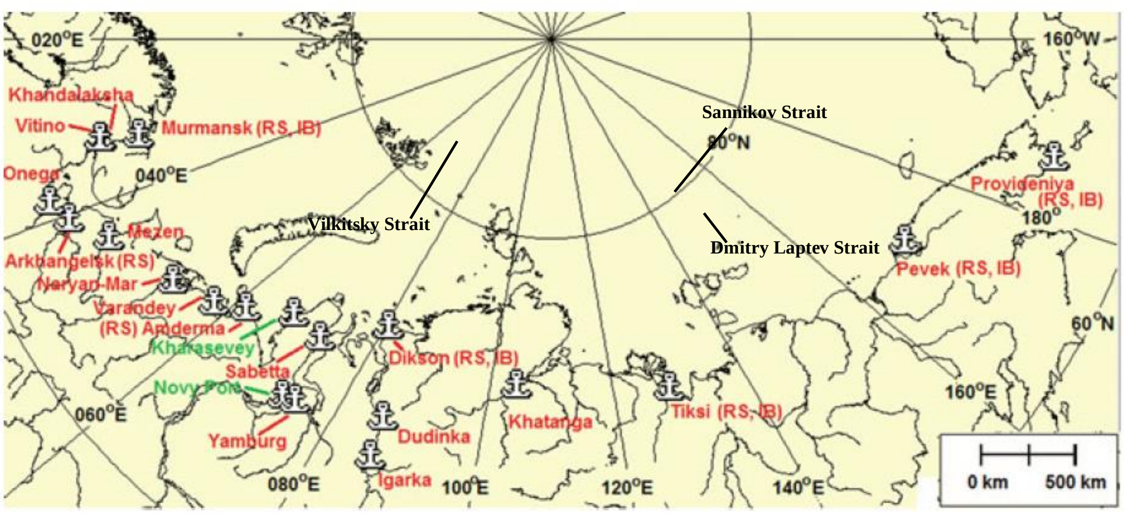


*Figure 4.4 Rescue Stations (RS) and Ice Breakers Bases (IB), in the year 2013. Retrieved from T. Pastusiak (2016)*

In the ice-free period (Scenario I), the route in the NSR section marked by the orange line in Figure 4.2 is smoother due to lack of manoeuvring to avoid ice like in the previous scenarios. The average speed in each section and respective voyage time are presented in Table 4.2.

Table 4.2 Average speed and voyage time between Shanghai – Gothenburg via the NSR

| | Section | Name | Distance (nm) | Time (days) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Vessel Y | | | Vessel X | | |
| | | Port time | | 1 | | | 4 | | |
| Open water | I | Shanghai - Dezhneva Cape | 3,125 | 9.3 | | | 6.5 | | |
| | II | Pechora Sea (Zhelaniya Cape) – Port of Gothenburg | 1,951 | 5.8 | | | 4.1 | | |
| | Average speed (knots) | | | 14 | | | 20 | | |
| | | | | Sep | Oct | Nov | Sep | Oct | Nov |
| NSR | Average speed in NSR section (knots) | | | 14 | 11.4 | 8.7 | 20 | 18.4 | 12.5 |
| | III | NSR sections | 2,580 | 7.7 | 9.4 | 12.4 | 5.4 | 5.8 | 8.6 |
| | | **Total** | 7,656 | 23.8 | 25.5 | 28.5 | 20 | 20.4 | 23.2 |

According to the ice extent data of NSIDC (2019), all stages outside the NSR are open-water in all scenarios in this study. Furthermore, the entire route is ice-free in September in the three latest years (NSIDC, 2019), which motivates the assumption that the vessels can travel at a constant speed as in open water. In open water of all circumstances, Vessel Y and Vessel X are assumed to operate at 14 knots and 20 knots based on the reference of Masahiko and Natsuhiko (2018). However, due to the varied ice conditions in Scenario II and Scenario III, the vessels' speed and ship's velocity following ice breaker ranging from 6 to 10 knots.

### 4.2.2 Ice data

Organisations have dedicated their studies on observing and monitoring the daily ice behaviour within the Arctic Region. Major actors contribute to this coordinated action, such as Technological Universities, Meteorological Institutions, even Governmental Services. The primary purposes of this effort are the provision of climatic changes and their impact on the Arctic cryosphere since the temperature in the Northern Pole has increased twice than the global average (Arctic Report Card, 2018). Therefore, proper monitoring of the situation is necessary to perceptualize and encounter the issue. Arctic Pole ice trend is vital to be provided as public information and being accessible for research purposes.

In this thesis, a series of simulations has been followed in order to retrieve the ice data. More specifically, the Chalmers Research Team has developed coding methods using Matlab to calculate and retrieve the ice data in collaboration with the weather forecast and ice condition services. The code used has retrieved the ice data from Copernicus. In order to testify the accuracy of the code outcomes, ice concentration was compared with the National Snow and Ice Data Center (NSDIC) maps in Figure 4.5 and ice thickness with Polar Portal, a collaboration between Danish Meteorological Institute, the Geological Survey of Denmark and Greenland and DTU University in Figure 4.6.

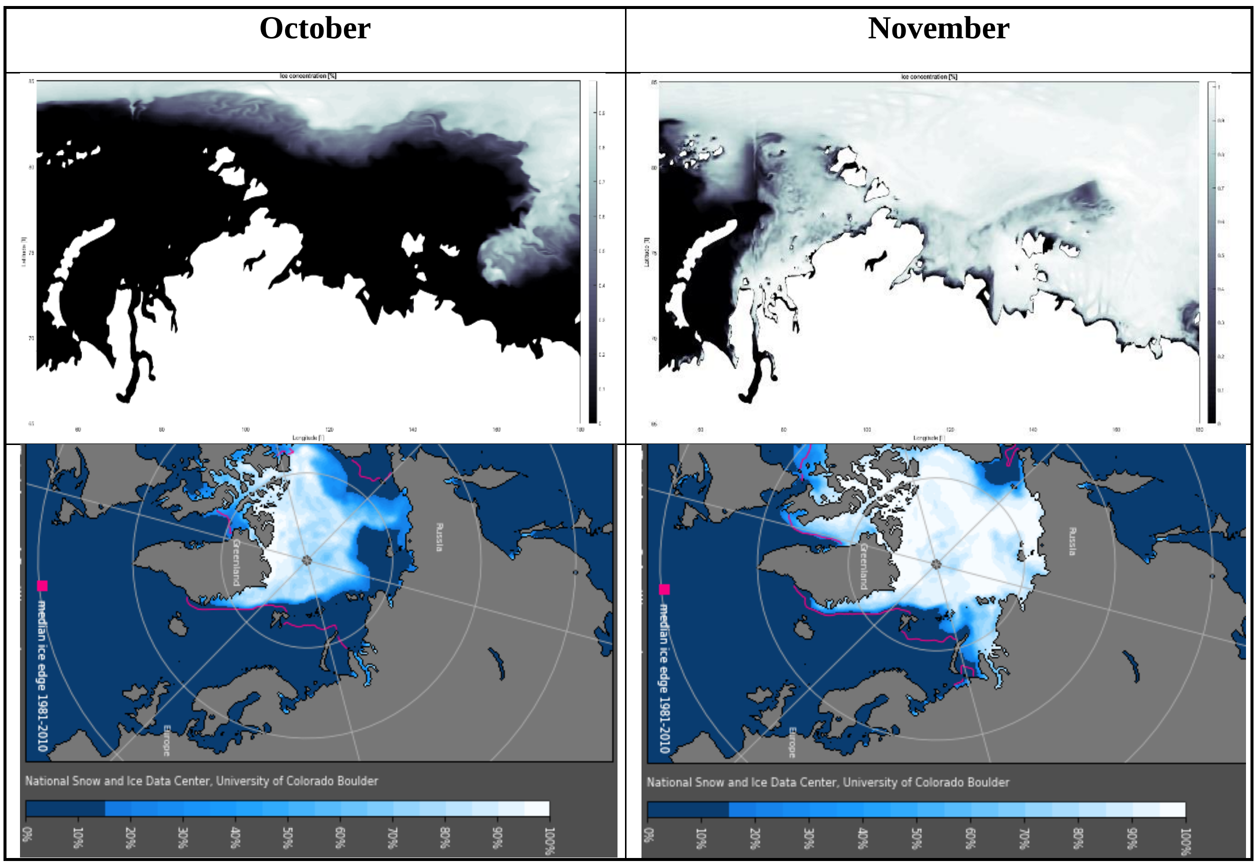


Figure 4.5 Ice Concentration, from Matlab (above) and NSIDC (below)

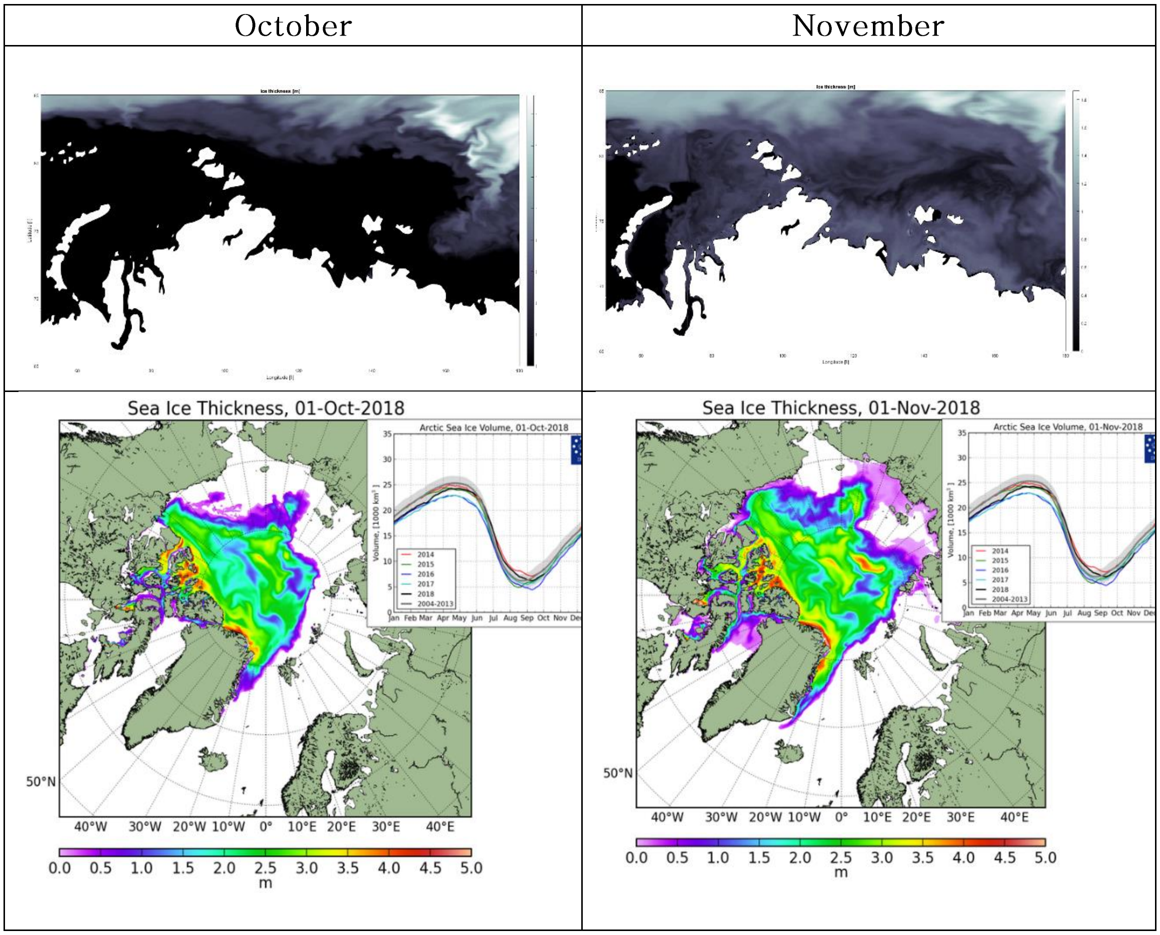


Figure 4.6 Ice thickness from Matlab (above) and from Polar Portal (below)

The length of the navigational season in the NSR depends on the vessels ice capabilities determined by the ice class and the weather conditions. According to Pastusiak (2016), the warm season defined by the Russian Sailing Directions (GUNiO), applies from July to October-4.5 months of smooth operations. However, GUNiO guidelines support that the ice decay occurs in August. Liu and Kronbak (2010) support that when ice concentration is less than 15%, the waters are considered as ice-free suitable for vessels with low or no ice class to sail. In his study, Pastusiak (2016) points out that it is better to prefer the lightest ice conditions because of voyage cost mitigation. Furthermore, the risk of damaging the hull, the propulsion system, the steering, the cargo can be reduced; even the total ship loss can be avoided. In this study, the navigational period is considered the ice-free waters and icebreaker escorting activity along the route.

## 4.2 The Suez Canal Route

The Suez Canal Route is established as a dominant seaborne trading passage connecting Asia with Europe. It is important to include the SCR in this study in order to compare the costs of the full transit, compared to the NSR. The SCR is presented in Figure 4.7.

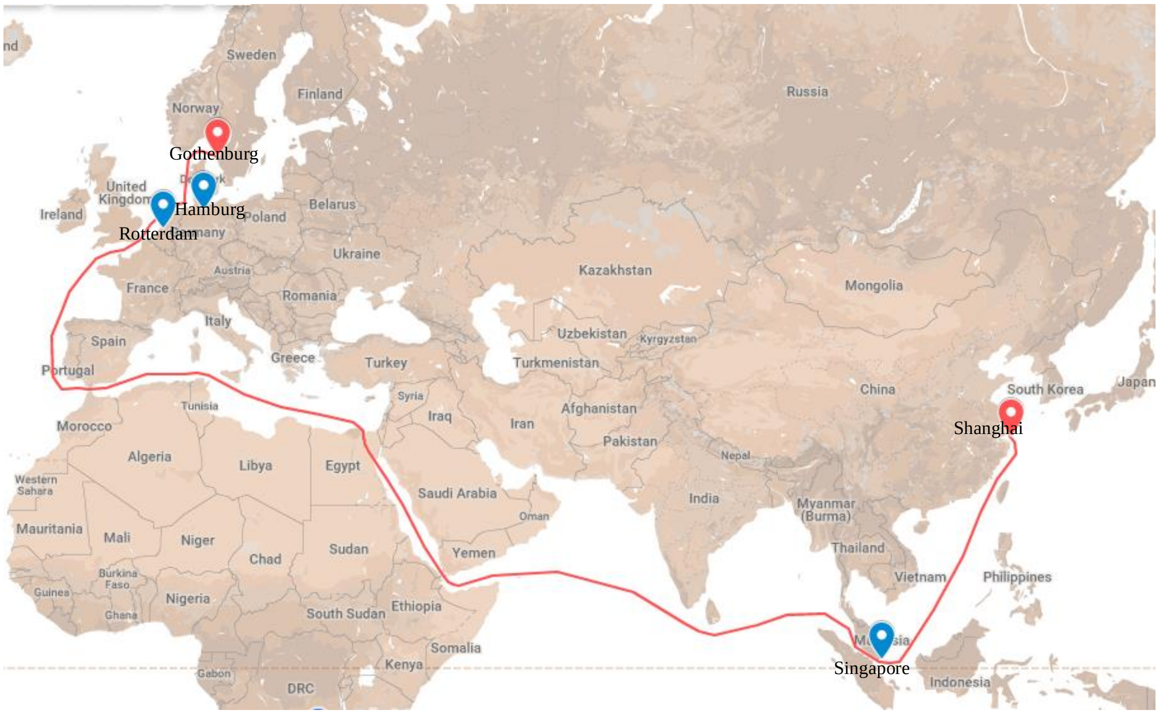


Figure 4.7 The Conventional Suez Canal Route (designed by the authors on Google MyMaps)

Figure 4.7 demonstrates the sailing route from Shanghai to Gothenburg through conventional Suez Canal. The SCR is divided into three sections: from Shanghai to the Gulf of Suez, the Suez Canal itself from Port of Tewfik to Port Said with a total of 193.3 km (Suez Canal Authority, 2018) and from exiting point of the canal to Gothenburg. The Suez Canal authority limits ship velocity inside the canal to 14km/h (Suez Canal Authority, 2018) to ensure the safety requirements in the area.

Table 4.3 Average speed and voyage time between Shanghai – Gothenburg via the SCR

| Sections | Name | Distance (nm) | Vessel Y | | Vessel X | |
|---|---|---|---|---|---|---|
| | | | Speed (knots) | Time (days) | Speed (knots) | Time (days) |
| I | Shanghai – Port of Tewfik | 7,512 | 14 | 22.4 | 20 | 15.7 |
| II | Suez Canal | 104 | 7.5 | 0.6 | 7.5 | 0.6 |
| III | Port Said – Port of Gothenburg | 3,721 | 14 | 11.1 | 20 | 7.8 |
| | Canal waiting time | | - | 0.8 | - | 0.8 |
| | Port time | | - | 1 | - | 4 |
| | **Total** | 11,337 | | 35.8 | | 28.8 |

Table 4.3 shows the speed and total voyage time of the case vessels along the SCR. Three port calls for container ship along the SCR in the case study are Singapore, Rotterdam, Hamburg. The average waiting time on the Suez Canal is 20 hours and port time for loading and unloading the cargo is about 24 hours for each port call (Lasserre, 2014). In open water area, Vessel Y and Vessel X keep the constant speed at 14 knots and 20 knots correspondingly in SCR. The 11,337 nm voyage for the entire SCR, takes 35.8 days for Vessel Y and 28.8 days for Vessel X accordingly.

## 4.3 Economic feasibility

Figure 4.8 illustrates the cost components that will be analysed in the case study.

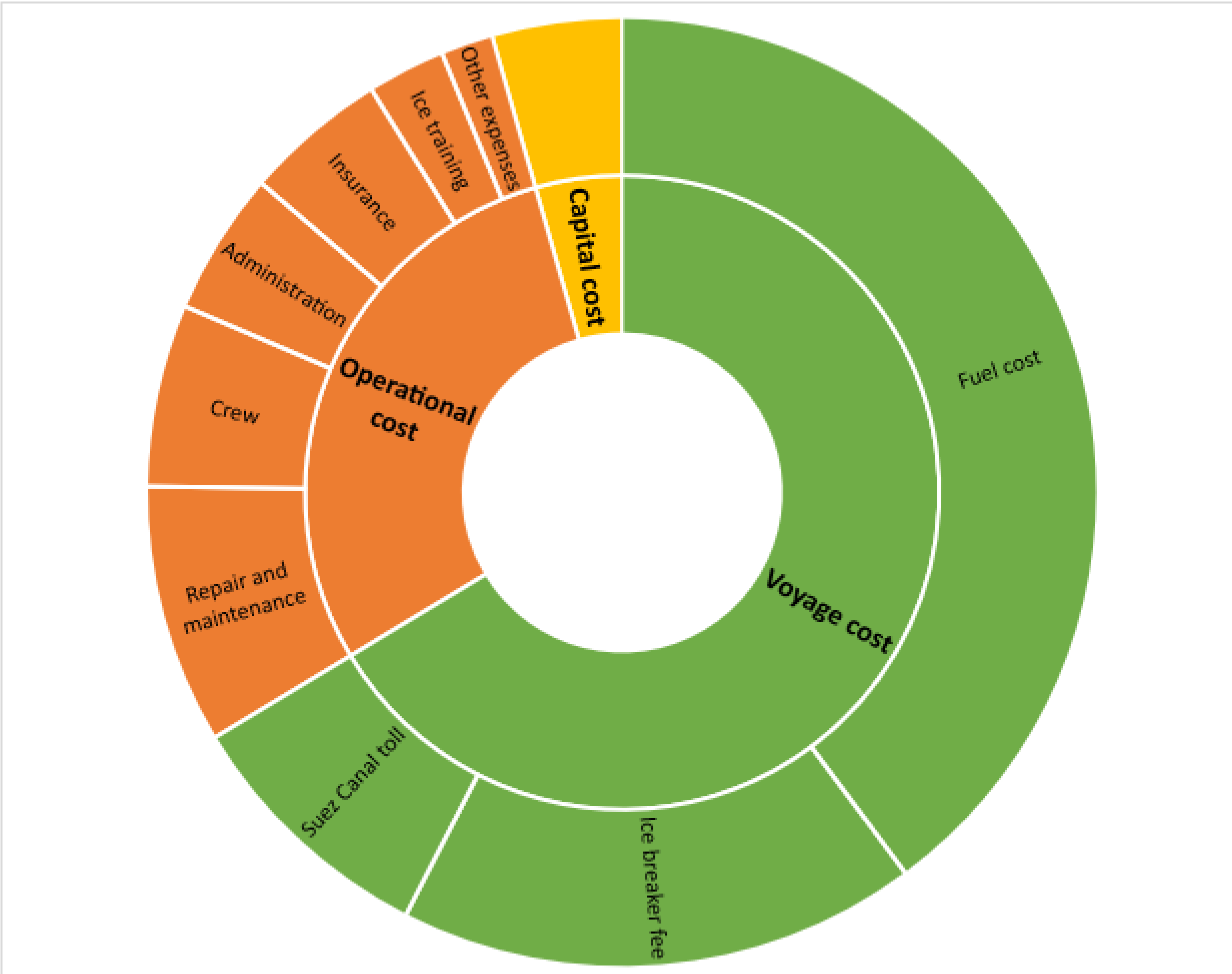


Figure 4.8 Cost components in total cost for a single voyage

### 4.3.1 Capital cost

In the case study, the assumption is that both vessels are entirely financed in a lump sum by the owners themselves. Therefore, there is purely depreciation cost without interest rate from the bank loan. As the construction prices of the two ships are ambiguous, the initial investment is estimated based on statistics of Clarkson's fleet database (Drewry Maritime Research, 2013). In this study, the additional investment cost for the ice-class vessel IA and IAS in the corresponding category is set as 25 per cent higher than the non-ice-classed vessels.

The residual value of the ships is counted by taking lightweight tonnage multiplied by the demolition market price of 446 USD/ton (Compass Maritime, 2019).

The straight-line depreciation method (Natsuhiko et al., 2013) is applied with the average life span of 25 years and 350 exploitation days yearly for both ships (Zanne, 2014). The estimated capital cost of the two studied vessels is shown in Table 4.4.

$$\text{Daily depreciation cost} = \frac{\text{New building cost} - \text{Residual value}}{25 \times 350}$$

Table 4.4 Estimated capital cost of Vessel Y and Vessel X

| | Units | Vessel Y | **Vessel X** |
|---|---|---|---|
| New building cost | USD | 30,000,000 | 50,000,000 |
| Light weight | tons | 12,082 | 17,669 |
| Demolition price | USD/ton | 446 | 446 |
| Residual value | USD | 5,388,572 | 7,880,374 |
| Exploitation life span | days | 8,750 | 8,750 |
| Daily depreciation | USD/day | 2,813 | 4,814 |

The interview with a shipping company operating in the NSR, reflected that increased investment for ice-strengthened vessels is not a challenge for organizations that own ice-classed fleet. Polar Code has a negligible influence on their operational practice. Since ice classed vessels already comply with the IMO's Guidelines, called Ships Operating in Arctic Ice-Covered Waters. However, it would be a financial burden for newcomers, meanwhile the earning potential is still unsure.

### 4.3.2 Operational costs

**Repair and maintenance cost**

The annual repair and maintenance cost shown in Table 4.5 is counted as 1.095% of the new building cost, according to Natsuhiko et al. (2013).

Table 4.5 The estimated repair and maintenance cost

| Repair and maintenance cost (USD) | Vessel Y | Vessel X |
|---|---|---|
| Per year | 328,500 | 547,500 |
| Average per day | 939 | 1,564 |

In the study, the economic analysis is estimated for a single voyage, so the expense is divided into the daily cost for the convenient calculation in the following steps. The number of exploitation days is 350 days per year. The repair and maintenance costs are estimated to increase by 20% for the voyages in icy water.

**Insurance cost**
The study disregards the cargo insurance as usually it is taken care of by cargo owners, not by the ship owners.

The interview with an insurance company brought exciting insights about how the insurance premium works in general and in the Arctic area in particular. Insurance companies assure the P&I and H&M for one year, neither for one single voyage nor for one separated route. There are several considerations to estimate insurance premium for a vessel in the NSR. The first factor is the ice class. The higher the ice-class vessels pay the lower premium. Insurance companies would rely on ice class certificates and documents relating to ship operations. Secondly, the experience of the crew, as well as ice training certification, are significantly important because minor personnel negligence may cause devastating consequences. During significant parts of the area the crew should be able to handle the weather difficulties with or without the assistance of ice breaker and pilotage. Another factor is sailing time, which aligns with the risks caused by severe weather conditions and the presence of ice.

Furthermore, insurance companies assure the ships navigating within International Navigation Limits (INL). INL determines the geographical restrictions that ships can navigate without requiring additional H&M premium and other relevant underwriters. As Arctic region is outside the INL, extra premium beyond P&I insurance would be added. Unlike the standardized systems for standard premium calculations on traditional routes, insurance coverage for Arctic voyage remains a wide range of ambiguous predictions.

The basic insurance cost is estimated by one per cent of the new building cost for non-ice class vessel and add about fifty per cent of the value more for the NSR. An interviewed insurance company suggested the yearly insurance cost in Table 4.6. They revealed that additional premium between mid-July and September, or Scenario I, is 200 per cent of annual H&M premium. For Scenarios II and III to November is on a case by case basis, but the estimation would be at 300 per cent.

Table 4.6 Estimated Yearly Insurance Cost

| Insurance cost (USD/year) | Vessel Y | | Vessel X | |
|---|---|---|---|---|
| P&I premium | 45,000 | | 50,000 | |
| Regular H&M premium | 55,000 | | 60,000 | |
| Addition insurance premium in the NSR | 165,000 | | 180,000 | |
| Additional premium for piracy and armed guard in SCR | 100,000 | | 100,000 | |
| Total annual insurance cost | SCR | NSR | SCR | NSR |
| | 200,000 | 265,000 | 210,000 | 290,000 |

Regarding the SCR, according to the interviewee from insurance company and shipping company, the route implies the risk of maritime piracy that requires the additional insurance for war risk cover in the form of Piracy Loss of Hire in P&I clauses. The war risk cover includes coverage for liabilities and expenses that would have been covered under the standard P&I insurance (Gard, 2002). The cost of that protection can reach up to $134,000 per transit (Bowden et al., 2010). In this study, we assume $100,000 per transit. As can be seen from Table 4.8, the total insurance cost of the two routes does not show a vast difference.

**Crew cost**

Crew cost is divided into two main components, namely salary (shown in Table 4.7) and ice training cost (shown in Table 4.8). The average monthly salary is $5,500/person, which roughly based on an estimation of Lasserre (2014). The representative from a shipping company shared in the interview that they pay ten per cent extra for seamen who work in the NSR voyages, depending on the Union agreement. However, the interviewee claimed that the crew cost is rather negligible, accounting for not even one per cent, compared to the total cost.

Table 4.7 The salary for crew

| | | Vessel Y | Vessel X |
|---|---|---|---|
| Number of crew (people) | | 17 | 19 |
| Salary for entire crew (USD/month) | SCR | 93,500 | 104,500 |
| | NSR | 102,850 | 114,950 |

Addition to basic salary for the crew, the operation in the NSR requires the ice training for the crew as being obligated in STCW from 1 July 2018 (IMO, 2018).

Table 4.8 The ice training cost

| | Basic training | | Advanced training | |
|---|---|---|---|---|
| Course fee (USD/person/course) | 1,860 | | 3,100 | |
| | Vessel Y | Vessel X | Vessel Y | Vessel X |
| Number of training people | 15 | 17 | 2 | 2 |
| Total (USD) | 27,900 | 31,620 | 6,200 | 6,200 |

Individual course in 5 days for operating in ice-covered waters, cold climate and darkness have two types; advanced training for ship's master and chief mate and basic training for the rest of the crew (Aboa Mare Maritime Academy and Training Center, 2019). Total training cost for Vessel Y is $34,100 and for Vessel X is $37,820.; assuming the ice training certificates validity is averagely sustained for 10 Arctic voyages.

**Other operational costs**

Besides all the mentioned major costs, there are additional expenditures such as documentation cost for maps, guidebooks, signals book to navigate through the NSR is set at $700.

Administration cost is $100,000 per vessel per year, which is around $10,000-$20,000 on average for a single voyage, depending on the exploitation level of each vessel. Usually, as the navigational period in the NSR is around five months, a vessel can operate five Asian – Europe voyages per year in maximum.

### 4.3.3 Voyage cost

**Fuel cost**

**SCR and Scenario I: Fuel consumption in open water**

The computation of fuel consumption in open water was conducted in Matlab (Appendix-D). The result of key values is presented in Table 4.9. The auxiliary power of these vessels ranges from 1.000 kW to 2.500 kW, which means between 5% and 11.6 % of the propulsion power (Rodríguez, 2014). In this study, auxiliary power equals to 10% of the main engine's propulsion power. During the port, canal and ice breaker waiting time, it is supposed that only auxiliary power is used. In the open water area, the speed of Vessel Y and Vessel X is kept constantly at 14 knots and 20 knots respectively.

Table 4.9 Fuel consumption in open water area, results from Matlab

| Values | Units | Vessel Y | Vessel X |
|---|---|---|---|
| $V_S$ | knots | 14 | 20 |
| lcb | - | -4 | -4 |
| $h_B$ | m | 4.3 | 4 |
| $A_T$ | $m^2$ | 15 | 16 |
| $A_{BT}$ | $m^2$ | 18.5 | 20 |
| $C_{WP}$ | - | 0.75 | 0.75 |
| $C_M$ | - | 0.98 | 0.98 |
| $C_{stern}$ | - | 10 | 10 |
| $S_{APP}$ | $m^2$ | 50 | 50 |
| $F_n$ | - | 0.1668 | 0.2152 |
| $C_p$ | - | 0.8658 | 0.6552 |
| $c_{12}$ | - | 0.5267 | 0.5052 |
| $c_{13}$ | - | 1.03 | 1.03 |
| $1 + k_1$ | - | 1.4855 | 1.1952 |
| S | - | 7,709 | 9,052 |
| $C_F$ | - | 0.0015 | 0.0014 |
| $1 + k_2$ | - | 1.49 | 1.49 |
| $c_7$ | - | 0.15 | 0.1382 |
| $i_E$ | degrees | 42.6549 | 12.7782 |
| $c_1$ | - | 2.9 | 0.96 |
| $c_3$ | - | 0.0189 | 0.0176 |
| $c_2$ | - | 0.7712 | 0.7783 |
| $c_5$ | - | 0.9598 | 0.9624 |
| $m_1$ | - | -1.9259 | -1.9456 |
| $c_{15}$ | - | -1.6939 | -1.6939 |
| $m_2$ | - | -0.0349 | -0.1522 |
| $\lambda$ | - | 1.0519 | 0.7304 |

| | | | |
|---|---|---|---|
| $P_B$ | - | 0.5667 | 0.5217 |
| $F_{ni}$ | - | 0.9297 | 1.2158 |
| $F_{nT}$ | - | 2.9649 | 4.3592 |
| $c_4$ | - | 0.04 | 0.04 |
| $C_A$ | - | 0.00037 | 0.00032 |
| $R_F$ | N | 308,260 | 690,230 |
| $R_{APP}$ | N | 2,978 | 5,680 |
| $R_W$ | N | 66,110 | 176,220 |
| $R_B$ | N | 3.3317 | 1.17 |
| $R_{TR}$ | N | 32,461 | 22,250 |
| $R_A$ | N | 76,239 | 156,660 |
| $R_{total}$ | N | 635,700 | 1,185,800 |
| $EHP_{OW}$ | kW | 4,578 | 12,200 |
| $BHP_{mcr}$ | kW | 6,540 | 14,353 |
| FOM main engine per hour | tons/h | 1.0805 | 2.3137 |
| FOM main engine per day | tons/day | 25.93 | 55.53 |
| FOM auxiliary per day | tons/day | 2.59 | 5.55 |
| Total Fuel consumption | tons/day | 28.52 | 61.08 |

As can be seen from Table 4.9, the average daily fuel consumption for both main engine and auxiliary in the open water of Vessel Y is 28.52 tons/day at 14 knots, and that of Vessel X is 61.08 tons/day at 20 knots. The vast difference in Fuel Oil Mass (FOM) of these two vessels can be traced to the vessel size and velocity gap, which causes much higher resistance. There is no effect from the ice resistance, meanwhile other weather conditions and speed are assumed to be unchanged, the fuel consumption is the same at every point.

**Scenario II: Fuel Consumption in Broken Ice**

Basing on the model in Figure 3.1 in Chapter 3, the example in Table 4.10 below illustrates how to calculate the fuel consumption for scenario II, case of vessel Y.

Table 4.10 Example to illustrate the calculation of fuel consumption in Scenario II

| | Units | Broken ice legs | Ice-free legs |
|---|---|---|---|
| Sea region | - | Western Seberian | Chukchi |
| Example at point number | - | 96 | 33 |
| Speed | knots | 7.3 | 12.5 |
| Ice concentration | % | 0.7178 | 0 |
| Ice thickness | m | 0.4769 | 0 |
| Open water resistance ($R_{OW}$) eq. (1) | kN | - | 487.9 |
| Broken ice resistance ($R_{Broken}$) eq. (4) | kN | 871 | - |
| Ship power of main engine eq. (2), (6), (7) | kW | 8,283 | 7,175 |
| Fuel Oil Mass (FOM) | Ton/h | 1.33 | 1.15 |
| Fuel consumption including 10% auxiliary engine | Ton/h | 1.43 | 1.25 |

Figure 4.9 depicts the vessel speed, ship resistance and corresponding power requirement of vessel Y to overcome the resistance in scenario II. Ship power follows the same pattern with ship speed. The faster the ship sails, the higher the power required. However, the pattern has changed for the coordinates from point 91-103 where the ice occurs. Despite the slow speed, the power keeps high due to the increase in the total resistance. The required power reached up to the maximum of power's capacity at around 13,000 kW.

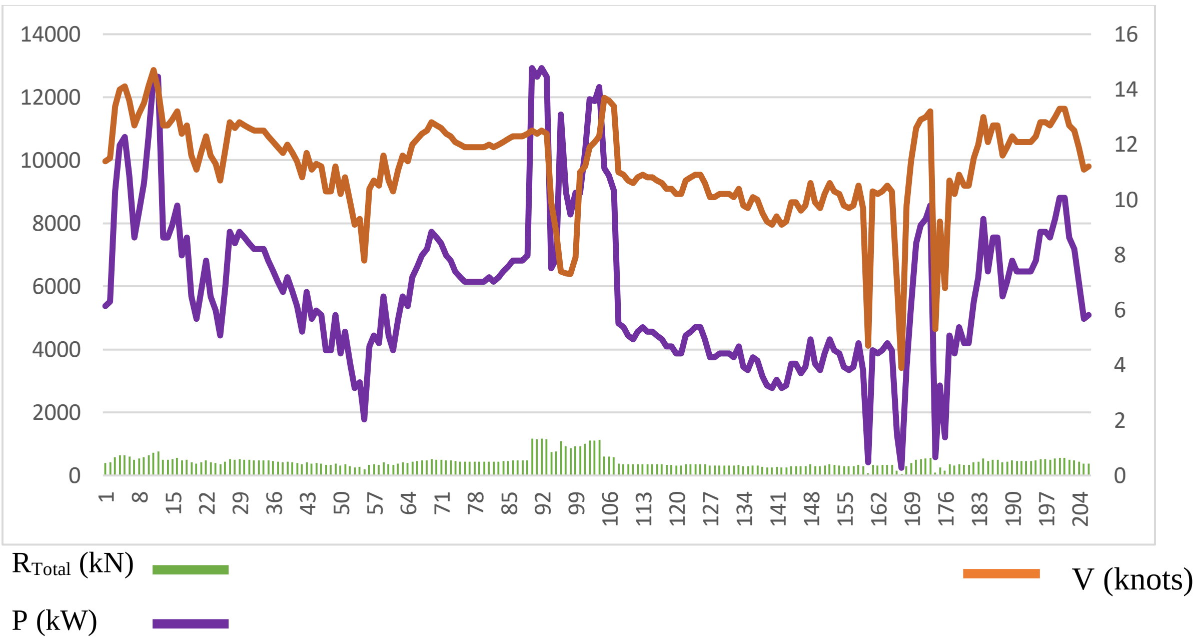


Figure 4.9 Correlation between Speed, Resistance and Power Requirement
in the NSR section of Vessel Y, Scenario II

Accumulating all the studied coordinates in the NSR, Table 4.11 presents the fuel consumptions of studied vessels to accomplish the NSR section (2,580 nm) in broken ice conditions.

Table 4.11 Fuel consumption in Broken Ice in the NSR sections (unit: tons)

| Fuel consumption | Vessel Y | Vessel X |
|---|---|---|
| $C_{OW}$ | 7,500 | 7,746 |
| Main engine | 227.5 | 317.3 |
| Auxiliary engine | 22.7 | 31.7 |
| Total | 250.2 | 349 |

Coefficient $C_{OW}$ in equation (4) is 7,500 for Vessel Y and 7,746 for Vessel X (Li et al., 2019).
In the NSR section, Vessel Y at average speed 11.4 knots consumed 250.2 tons of fuel in 9.4 days meanwhile Vessel X at average speed 18.4 knots need 349 tons in 5.8 days.

**Scenario III: Fuel consumption in Brash Ice**

Basing on the model in Figure 3.1 in Chapter 3, the example in Table 4.12 below illustrates how to calculate the fuel consumption for scenario III, case of vessel Y.

Table 4.12 Example to illustrate the calculation of fuel consumption in Scenario III

| | Units | Brash ice legs | Ice-free legs |
|---|---|---|---|
| Sea region | - | Western Seberian | Chukchi |
| Example at point number | - | 96 | 33 |
| Speed | knots | 7.5 | 12.5 |
| Ice concentration | % | 0.9413 | 0 |
| Ice thickness | m | 0.6859 | 0 |
| Open water resistance ($R_{OW}$) eq. (1) | kN | - | 487.9 |
| Brash ice resistance ($R_{Brash}$) eq. (5) | kN | 927.72 | - |
| Ship power of main engine eq. (2), (6), (7) | kW | 9,105 | 7,175 |
| Fuel Oil Mass (FOM) | Ton/h | 1.47 | 1.15 |
| Fuel consumption including 10% auxiliary engine | Ton/h | 1.57 | 1.25 |

Figure 4.10 depicts the vessel speed, ship resistance and corresponding power requirement of vessel Y to overcome the resistance in Scenario III.

As can be seen from the graph, ship power follows the same pattern with ship speed in open water legs. However, the power increases when ice occurs even though the speed is kept constantly, which is assumed at 7.5 knots. At some points during the voyage (point 176 to 183), the vessel had to stop to wait for ice breaker, the speed is 0 but there is still power used due to auxiliary engine.

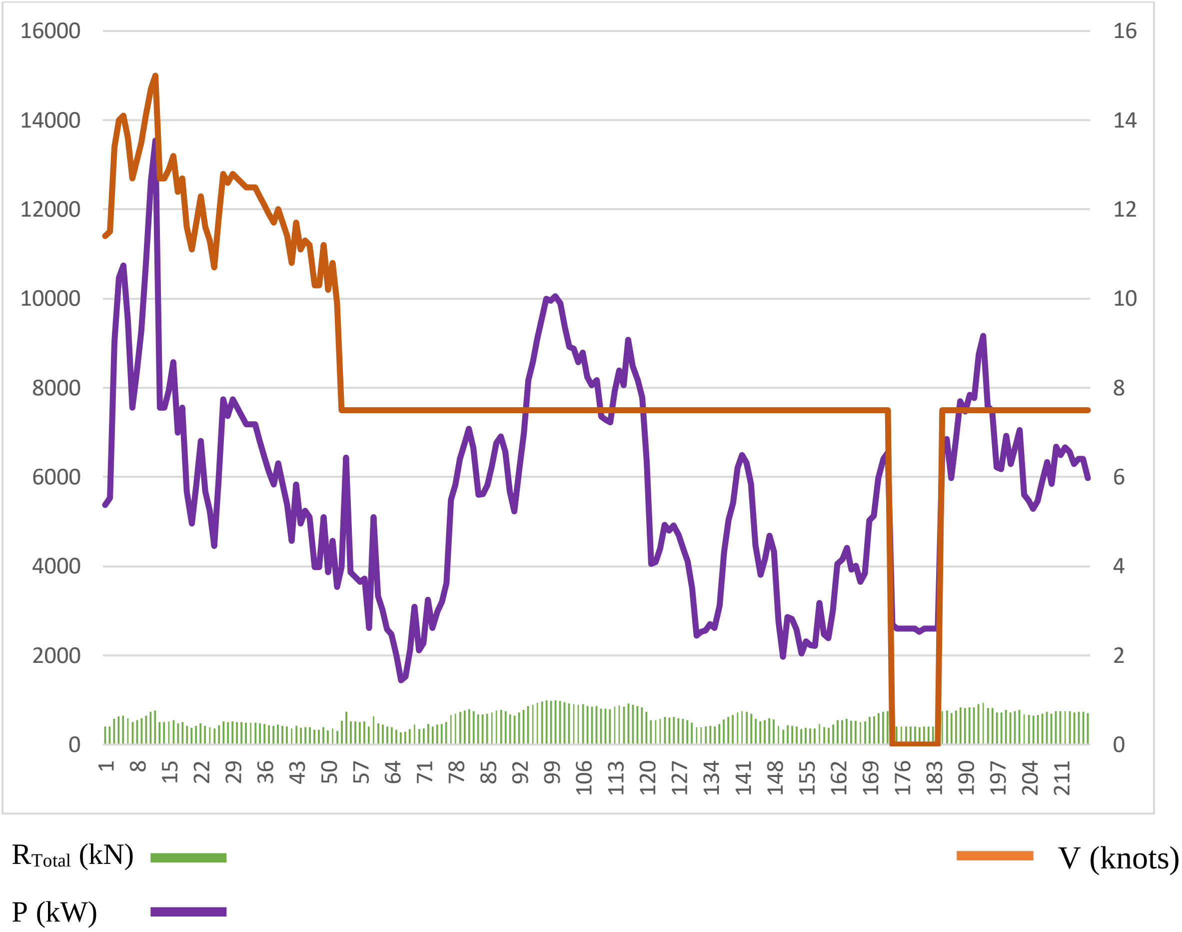


Figure 4.10 Correlation between Speed, Resistance and Power Requirement in the NSR section of Vessel Y, Scenario III

Accumulating all the studied coordinates in the NSR, Table 4.13 shows the summarized fuel consumption result of studied vessels to accomplish the NSR section (2,580 nm) in Brash ice - Scenario III.

Table 4.13 Fuel consumption in Brash Ice in the NSR sections (units: tons)

| Fuel consumption | Vessel Y | Vessel X |
|---|---|---|
| Main engine | 275.7 | 416.3 |
| Auxiliary engine | 27.6 | 41.6 |
| Total | 303.3 | 457.9 |

In brash ice conditions, Vessel Y with an average speed of 8.7 knots consumed 303.3 tons of fuel in 12.4 days whereas Vessel X burned 457.9 tons at average speed 12.5 knots in 8.6 days. In general, both ice thickness and ice concentration are severer compared to Scenario II. However, the average ship power in Scenario III does not surpass that in Scenario II due to considerable slow steaming and the assistance of ice breakers. The increased sailing days of Scenario II led to greater fuel consumption.

**Total fuel consumption**

Table 4.14 and Table 4.15 show the total fuel consumption and fuel cost for the entire voyage of both vessels. Total fuel consumption is calculated by the sum of fuel consumption in open water sections, in the NSR ice waters if any, and waiting time for either canal or ice breaker. Vessels use both the main engine and auxiliary engine when sailing in open waters and icy waters, but the only auxiliary engine is needed when the ship is at berth.

Table 4.14 Total fuel consumption (tons) and total fuel cost (USD) in SCR

| | Engine use | Vessel Y | | Vessel X | |
|---|---|---|---|---|---|
| | | Days | Fuel consumption | Days | Fuel consumption |
| Open water sailing | Both | 33.4 | 953.47 | 23.4 | 1429.4 |
| Port and canal | Auxiliary | 2.4 | 6.16 | 5.4 | 29.85 |
| Total fuel (tons) | | 35.8 | 959.63 | 28.8 | 1459.25 |
| Cost (USD) | | | 422,715 | | 642,798 |

Vessel Y needs 959.63 tons of fuel and 35.8 days to complete one voyage from Shanghai to Gothenburg via SCR, the numbers for Vessel X are 1459.25 tons and 28.8 days.

Table 4.15 Total fuel consumption (tons) and total fuel cost (USD) in NSR

| | Engine | Tian Hui | | | | | | Vessel X | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sept | | Oct | | Nov | | Sept | | Oct | | Nov | |
| | | Days | Fuel | Days | Fuel | Days | Fuel | Days | Fuel | Days | Fuel | Days | Fuel |
| Open water | Both | 15.1 | 430.86 | 15.1 | 430.86 | 15.1 | 430.86 | 10.6 | 645.92 | 10.6 | 645.92 | 10.6 | 645.92 |
| NSR | Both | 7.7 | 218.99 | 9.4 | 250.22 | 12.4 | 300.35 | 5.4 | 328.31 | 5.8 | 349.06 | 8.6 | 457.90 |
| Port time | Auxiliary | 1.0 | 2.59 | 1.0 | 2.59 | 1.0 | 2.59 | 4 | 22 | 4 | 22 | 4 | 22 |
| Total | | 23.8 | 652.4 | 25.5 | 683.67 | 28.5 | 733.79 | 20 | 996.43 | 20.4 | 1017.18 | 23.2 | 1126.02 |
| Fuel cost | | | 287,399 | | 301,156 | | 323,235 | | 438,926 | | 448,069 | | 496,012 |
| Saving % | | | 32 | | 29 | | 24 | | 32 | | 30 | | 23 |

*Price of IFO380 is $440.5/ton (shipandbunker.com)*

Table 4.15 describes the total fuel consumption and total fuel cost. All the NSR scenarios show less amount of fuel consumption compared to the SCR. The ice-free scenario of the NSR can save up to a third of fuel cost. Scenario II leads to greater fuel-savings than Scenario III.

In short, NSR is obviously beneficial for shipowners in terms of fuel cost as the vessels consume less oil from 22.8% to 32% compared to the SCR. The study result shows that regardless of the ice condition, the shorter voyage time save more fuel cost.

**Suez Canal toll**

Table 4.16 shows the Suez Canal fee which is calculated by toll calculator (Suez Canal Authority, 2019b)

Table 4.16 The Suez Canal toll per transit

| | Vessel Y | **Vessel X** |
|---|---|---|
| Suez Canal toll (USD) | 105,361 | 138,392 |

*Special Drawing Rights (SDR) rate with USD is 1.39 (IMF, 2019)*

The Suez Canal toll for Vessel Y and Vessel X is $105,361 and $138,392 respectively for a single transit.

**The Northern Sea Route fee**

Generally, the tariff in summer-autumn period (1 July – 30 November) is lower than in winter-spring period (1 December – 30 June). All three scenarios in the study fall in the summer-autumn period, so the tariff level was computed from the price of FSUE Atomflot (Ministry of Justice of Russia, 2014) as shown in Table 4.17.

Table 4.17 Tariffs during the summer-autumn period of navigation (1 July – 30 November) for ships of gross tonnage from 20,001 to 40,000 (unit: USD)

| | Number of escorting zones | |
|---|---|---|
| | 1 | 4 |
| Vessel Y | 114,910 | 183,853 |
| Vessel X | 166,361 | 266,183 |

*Exchange rate: 1 RUB = 0.016 USD (IMF, 12 Apr 2019)*

According to Juva and Riska (2012), the ice class vessel IA and IA Super can overcome maximum ice thickness of 1 m and 1.2 m respectively and theoretically two vessels in the case study can navigate independently during summer period along the NSR. However, the NSR Administration would require vessels navigating under the escort of ice breaker with the number of zones being decided on specific ice conditions. Basing on the ice data extracted from the simulation, the two vessels can navigate independently in September scenario; however, both of them would require ice breaker escort in 1 zone (Western Siberian Sea) for Scenario II and 4 zones (entire Siberian Sea and the Laptev Sea) for Scenario III. According to interviewee from the shipping company, the tariff published by NSRA is fixed. However, they may negotiate the number of zones using ice breaker. In some cases, the shipping companies request ice breaking escort for safety reasons.

## 4.4 Total cost

After computing capital, operational and capital costs, the total costs for Vessel Y and Vessel X are presented in Table 4.18. As can be seen from the bar charts depicting the percentage of cost components compared to the accumulated costs, fuel cost accounts for around a half of total cost, followed by either ice breaker fee or Suez canal fee. In severe ice condition in November, the NSR fee reaches up to 20 per cent and 25 per cent of the total cost for Vessel Y and Vessel X respectively.

In general, the total cost of both vessels in all three NSR scenarios is less than the cost in the SCR. All the yearly cost components in the NSR relating to repair and maintenance, insurance and crew cost are more expensive than those in the conventional route. However, the NSR voyages gain advantages due to the shortening time by 7 to 12 days, compensating all the increased costs and even becoming more competitive in the end. Apparently, Scenario I is the most advantageous due to the considerable reduction in all cost components and significant shorter time, especially avoiding both ice breaker fee in the NSR and Suez Canal toll.

Turning to the total cost of Vessel X, the NSR also shows more benefits for this container ship. In this case, Scenario III does not save considerable cost because of ice breaker fee and additional fuel cost. Meanwhile, the ice-free scenario clearly highlights the most advantageous option by saving up to $418,645/voyage.

Table 4.18 Total cost for a single voyage of Vessel Y and Vessel X

| | Cost components | Tian Hui | | | | Vessel X | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SCR | NSR | | | SCR | NSR | | |
| | | | Sept | Oct | Nov | | Sept | Oct | Nov |
| Time (days) | | 35.8 | 23.8 | 25.5 | 28.5 | 28.8 | 20.0 | 20.4 | 23.2 |
| Capital cost | Capital cost | 100,732 | 66,909 | 71,835 | 80,068 | 138,546 | 96,039 | 98,289 | 111,564 |
| Operational cost | Repair & maintenance | 33,625 | 22,335 | 28,775 | 32,073 | 45,012 | 31,202 | 38,319 | 43,495 |
| | Insurance | 20,462 | 18,009 | 19,335 | 21,551 | 17,268 | 16,530 | 16,917 | 19,202 |
| | Crew | 111,606 | 81,545 | 87,549 | 97,582 | 100,250 | 76,442 | 78,233 | 88,799 |
| | Ice training | - | 3,410 | 3,410 | 3,410 | - | 3,782 | 3,782 | 3,782 |
| | Administration | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 |
| | Other expenses | - | 700 | 700 | 700 | - | 700 | 700 | 700 |
| Voyage cost | Fuel cost | 422,715 | 287,399 | 301,156 | 323,235 | 642,798 | 438,926 | 448,069 | 496,012 |
| | Suez Canal toll | 105,361 | - | - | - | 138,392 | - | - | - |
| | Ice breaker fee | - | - | 114,910 | 183,853 | - | - | 166,361 | 266,183 |
| TOTAL COST | | 814,501 | 500,308 | 647,671 | 762,471 | 1,102,266 | 683,621 | 870,671 | 1,049,738 |

## 4.5 Summarized results of case study

Handysize bulk carrier Vessel Y and Sub-Panamax container Vessel X were used in the case study to compare the cost between SCR route and three scenarios of the NSR: Scenario I with completely ice-free water, Scenario II when part of the route is covered by broken ice, Scenario III in November when brash ice occurs. The NSR shorten the distance by 32.5% for the voyage from Shanghai to Gothenburg. The time and cost comparison is shown in Figure 4.11.

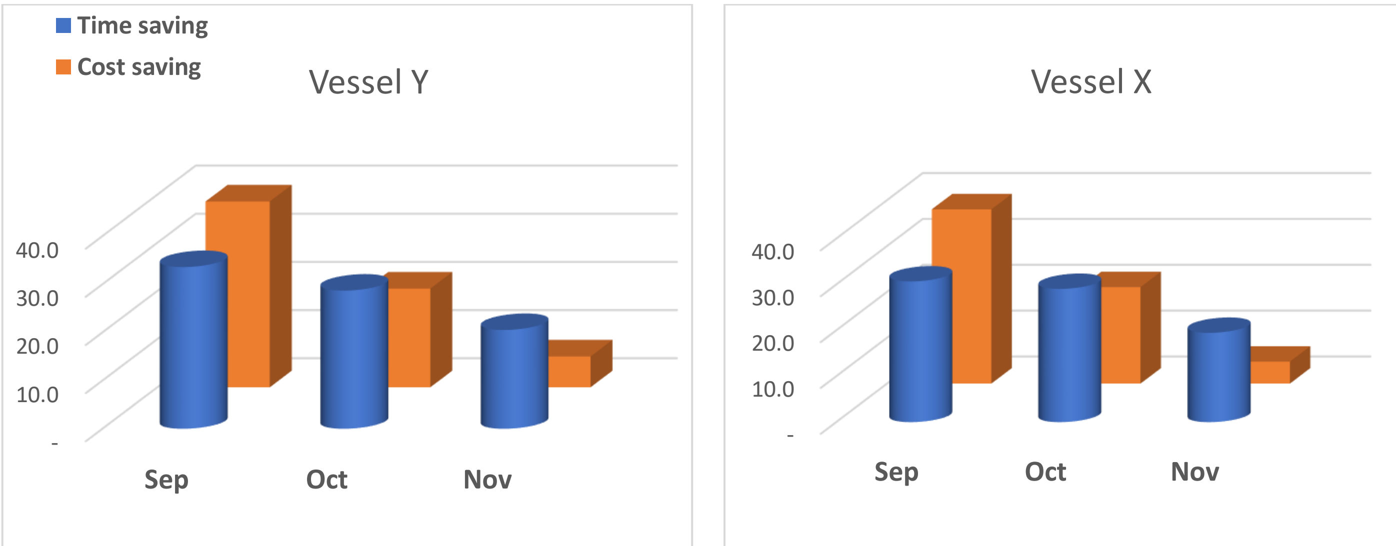


Figure 4.11 Comparison time and cost saving between the SCR and the NSR (Unit: %)

In short, the NSR saves from 19 per cent to 34 per cent of voyage time compared to the SCR. Regarding the cost, for both Vessel Y and Vessel X, the navigation in ice-free period can bring enormous benefits as the cost is cut down by nearly 40 per cent. The percentage of cost-saving decreases when the ice presence and sailing time increases. The ice scenarios lose competitiveness due to longer time in icy regions and extra ice breaker expenses. In Scenario III, the cost does not show much difference with the conventional route.

## 4.6 Sensitivity analysis

Some cost components are particularly sensitive to the market situation, such as the NSR fee. Ice breaker fee is fixed in RUB which means that the cost converted in USD varies by the exchange rate. Figure 4.12 depicts the fluctuation of RUB-USD from 2010 to 2019.

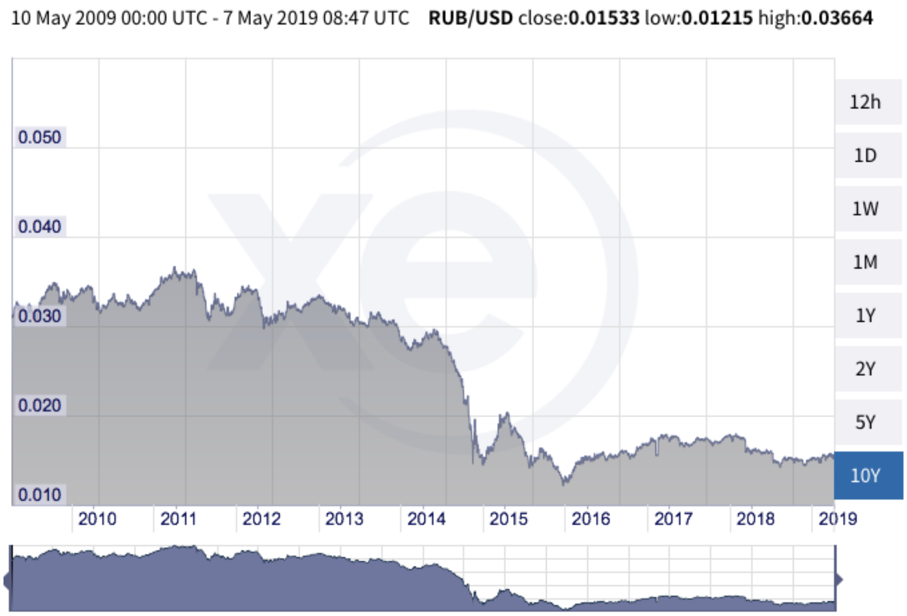


Figure 4.12 The fluctuation of RUB-USD exchange rate from 2010 to 2019
(XE Corporation, 2019)

As can be seen from the graph, the exchange rate of RUB-USD has been volatile significantly during the last decade. The RUB-USD rate in 2011 was 2.25 times higher than in 2019. Devaluation of RUB to USD recently made the NSR fee cheaper than in previous periods and by that increases the competitiveness of the NSR.

Figure 4.13 depicts the sensitivity of the cost of changes in the RUB-USD exchange rate. Saving percentage of four different cases are compared with the SCR: case (1) no ice breaker used when the ship sail independently in the NSR, the RUB-USD exchange rate in case (2) is 0.016 in the year 2019, case (3) is 0.025 in the year 2014, and case (4) is 0.0366 in the year 2011.

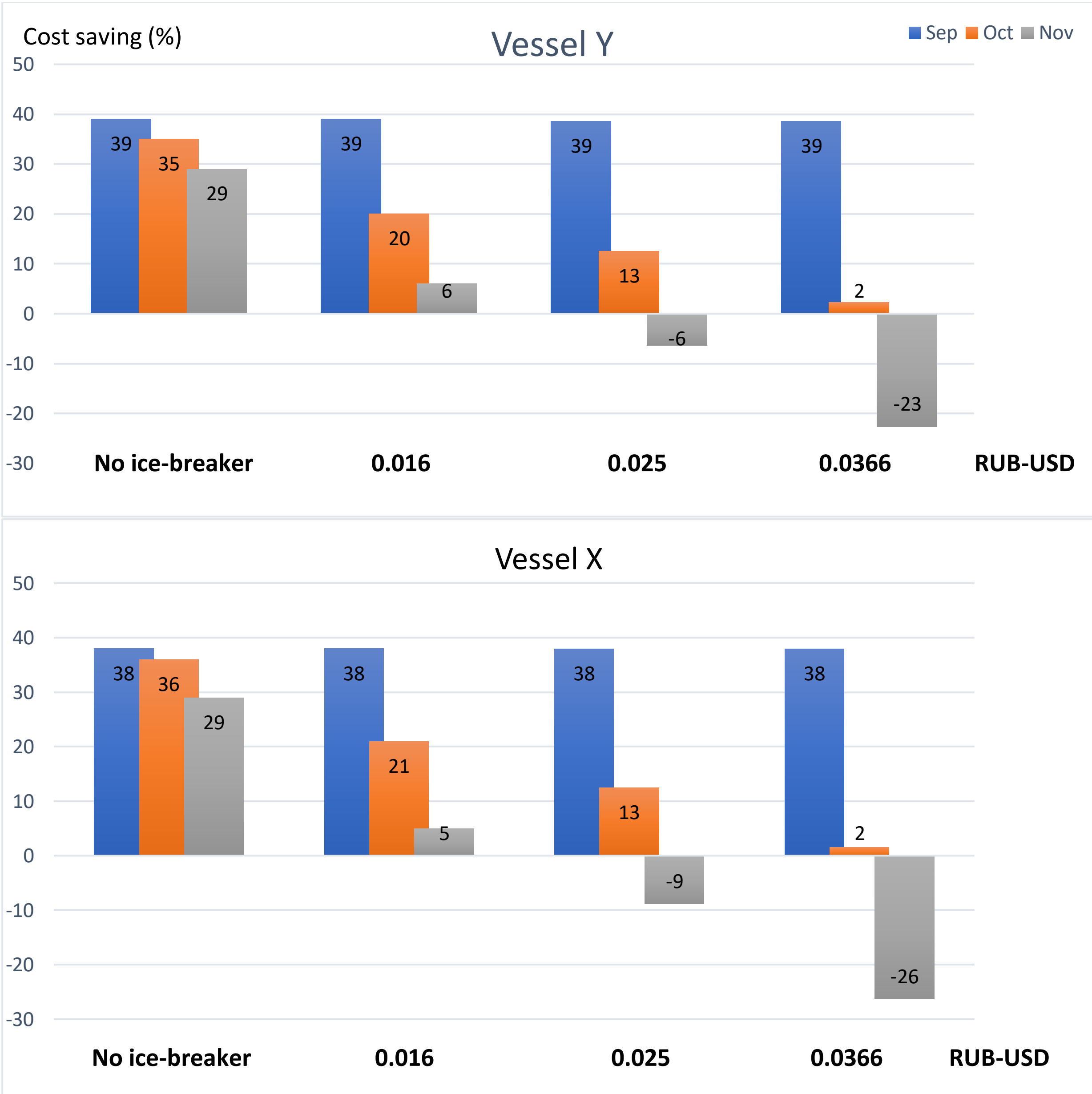


Figure 4.13 Sensitivity of the cost towards changes of RUB-USD exchange rate

Figure 4.13 shows the same pattern of two ships on how RUB-USD exchange rate affects the cost. The figures for Scenario I remain the same in all situations since the ice-free scenario is not dependent on ice breaker escort. If the ships navigate without ice breaker assistance, all three NSR scenarios bring enormous cost savings ranging from 29% to 39% compared with the SCR. Interestingly, in stark contrast, if the RUB-USD rate increases to 0.0366, Scenario III even become 23-26% more expensive than the SCR. Therefore, the currency exchange rate has considerable influence on the loss-benefit analysis.

## 4.7 Interviews and Survey Results

It is important to note that the companies involved in this study are based in Northern Europe. By comparing the results between the three interviewed organizations, many commonalities but differences have been identified. The results have been summarised in Table 4.19.

Table 4.19 Interviewees' perspectives on the NSR

| Subject | Port Authority | Insurance Organization | Shipping Company |
|---|---|---|---|
| Main interests in NSR | Containers, Timber | Selling Premium only by low Risk Likelihood | Regional Commercial Transportation |
| Interest in NSR | Neutral | Occasional Gains | Only Regional Activities |
| Activities in the NSR | Based on Strategic Position | Upon Members Agreement | Establishing Good Regional Business |
| Affects the NSR | Neutral | Strong, require elimination of Risks | Strong as main transporting intermediate |
| Future in the NSR | Optimistic-Long Term | Optimistic-Long Term | Optimistic-Always |
| | | | |
| Prospect Cargos | Bulk, Oil, Gas | Tankers | Project Cargo |
| | | | |
| Environmental Concerns | Quite Uncertain due to PM and oil spillage hard treatment | High risks, difficulty in remoteness | Proper maintenance of the Vessels to avoid hazards |

For further understanding of Table 4.19, the different fields of activities and cargo interests can be easily identified. Port Authorities want to be involved in the futuristic concept of the NSR since it can provide a strategic position to them. The interviewee states that success for a port comes from the location, capabilities and an effective distributing system. This can increase the received amount of cargo and act as a hub to distribute cargo with smaller ships within the Baltic Region and other European Countries. It is important to frequently get informed about any updates regarding the NSR and its prospects as an alternative to the SCR, especially in case of political conflicts in the area. However, they state that the only factor affecting the future of the NSR is going to be the shipping companies.

Moreover, the interviewee from the port authority stated that potential cargos would be dry and wet bulk, oil and gas, unlike liner shipping and car carriers. This is supported due to the accuracy on time of delivery for container ships, which will be a challenge through the NSR since always there is a chance of delays due to extreme weather conditions, waiting time for ice breakers for pilotage, or even stuck in the ice. Additionally, liner shipping is based on a series of port calls that is inevitable in the NSR due to the inadequate port facilities across the full transit. RoRo vessels, on the other side, focus more on reliability than lead time. However, this implies that to be profitable, they must direct routes with fully loaded smaller vessels, an occasion that rarely happens. Finally, the Port Authorities are concerned about the PM from the exhaust gas emissions that tend to sit on ice and increase the rate of melting. Also, environmental diversity in the Arctic will be affected by the increasing traffic of vessels in the area.

Insurance companies invest in a trust-based relationship with their customers, whom they prefer to call members. At first, they are interested in selling a Premium to their members since it provides more incomes varying from 10% up to 300% applying on the H&M since P&I applies worldwide. They are neutrally interested in the NSR because, on the one hand, they want to charge a premium (which is a small amount compared to what it can be the damage in case of an accident). On the other hand, there are various risks to consider and a high likelihood of a ship to stack up there and sometimes a case of the total loss. The premium is usually based on vessels' ice class (prerequisite for NSR), the time of the year that the vessel intends to conduct the voyage (mainly considering ice thickness and risks) the remoteness so in case of an incident what the proximity to the nearest port and ice breakers would be and the if they employ experienced crew on board to carry out the voyage. The interviewee claims that potential cargos can be oil, project cargo, coal, bulkers and with hesitance containers and RoRo. Like Port authorities, they prefer to stay updated for the upcoming changes; however, they believe that NSR is a distant concept and not comparable to the Suez and Panama Canal. Lastly, the most influencing factor is wherever economic benefits appear, especially for shipowners. For NSR, cold climate needs better environmental precautions and treatment thus new IMO requirements which appear as a barrier.

The Shipping Company interviewed, has mainly focused trading project cargo on regional activities than the full transit, because of the extra earnings. Cost is the biggest challenge for the shipping company, mainly because of the ice breaking fee. The tariff is fixed, but shipping companies can negotiate with Russian authority on how to use the ice breaker service like the number of zones that need the ice breaker escort. By building good trust with their insurance company, they can avoid insurance premium. Furthermore, costs related to the extra waiting time for ice breaker which happened to them for ten days of waiting in a remote area. Also, it is essential to consider the extra cost for those waiting days like fuel cost of auxiliary engines, crew cost and crew psychology. Harsh working conditions affect the crew. Usually, shipping companies pay extra for crew depending on how the Union works. However, the crew cost only counts for a minor percentage (around

1% of the total cost). If the crew is not experienced in ice water, shipping companies need to pay the pilot fee. Shipping companies still use normal heavy fuel oil in the NSR even though some companies started converting to greener fuel like LNG-driven to cut down CO2 emission in this sensitive area. The initial investment for ice class vessels is not a big obstacle for companies that already navigated in the Baltic sea (1A or 1A super) as all the vessels need that for all-year-round service, however, it would be a huge challenge for new players.  They concern about safety issues due to the rescue ability in remoteness and darkness. Finally, Shipping companies still hesitate to expand their business for the full transit in the near future but quite optimistic for longer terms (several decades from now). Usually, the ones trying the full transit have commercial initiatives.

Since shipping companies are the main factor that can affect the viability of the NSR, a survey was sent to them, collecting a sample of 9 correspondents (see Appendix for the full survey). Among them, 55% have experience within the NSR market, and 33% remains business related, as it is shown in Figure 4.14.

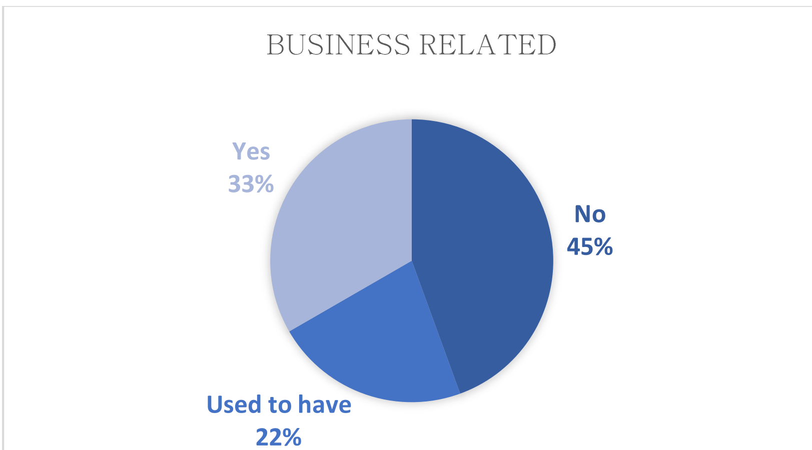


Figure 4.14 Companies business relation to the NSR

As can be seen from Figure 4.15, 77,8% of the surveyed companies are updated about the NSR's potentials. Among them, 33% are actively involved already in the NEP market either by doing business in certain limited areas or having plenty of ice-classed vessels.

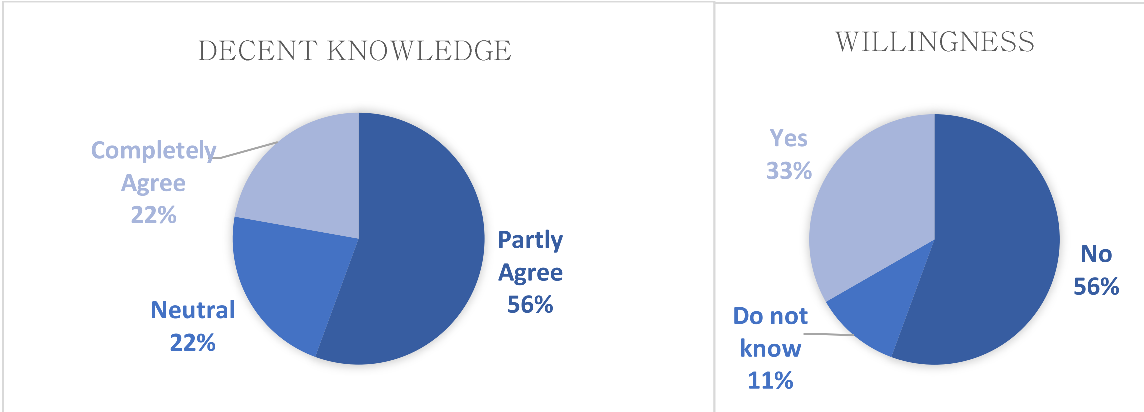


Figure 4.15 Decent knowledge of the NSR and willingness to be involved

Interesting seems the high likelihood of the sample companies to get involved in the near future accounting 78% in Figure 4.16, but they are not stating a solid answer regarding exaggeration of feasibility for the NSR concept compared to the SCR, with vast majority of 44% to remain a neutral and 33% to agree that NSR is not a sufficient alternative to the SCR.

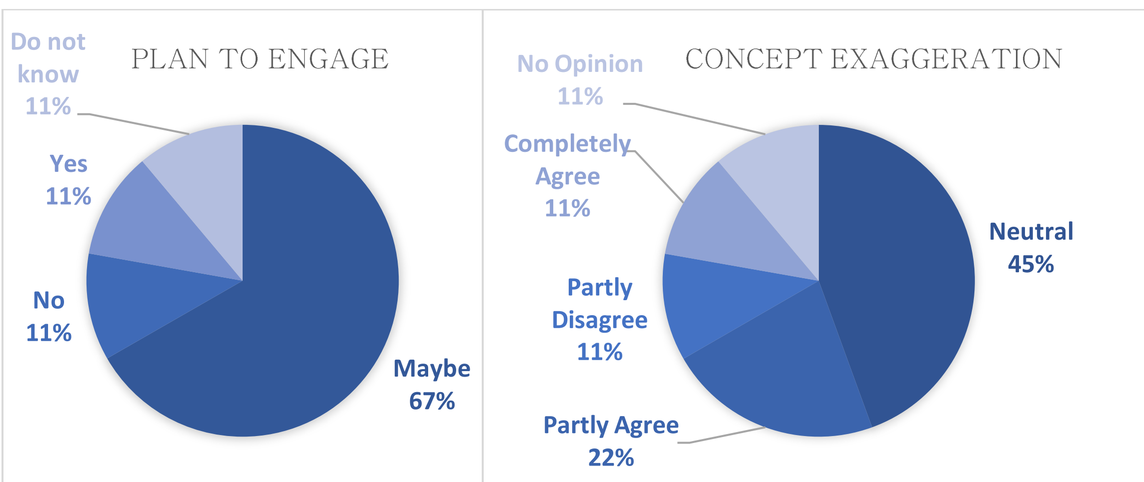


Figure 4.16 Plan to engage in the NSR market (left), concept exaggeration (right)

Furthermore, as it is illustrated in Figure 4.17, 55.6% of the respondents believe that Russia is the most influencing factor, while the remaining two-quarters of 22.2% believe that it depends on the IMO's regulating system and Shipping companies' initiatives.

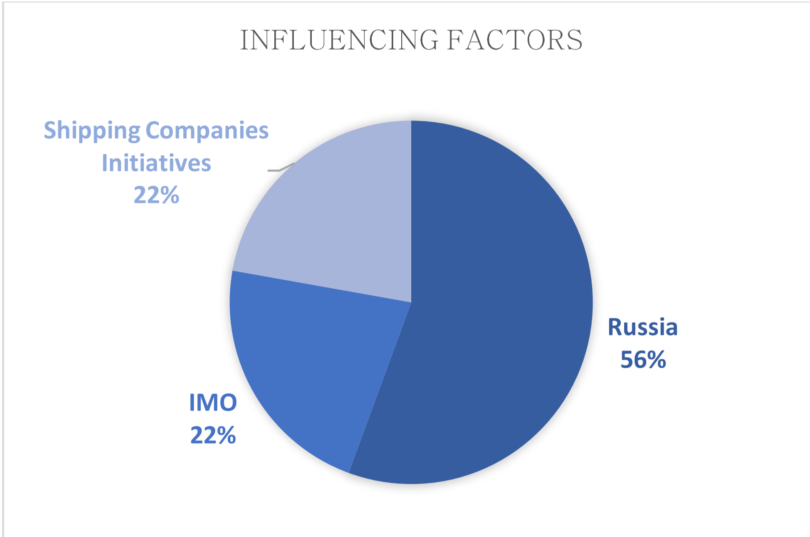


Figure 4.17 Influencing factors of the NSR

Moreover, their potential benefits from the niche market of the NEP from Figure 4.18, are mainly time and distance savings (55.6%) while 33.3% believe that is the extra earnings cost savings and market share, making clear that the minority is interested in research purposes or do not find any benefits at all.

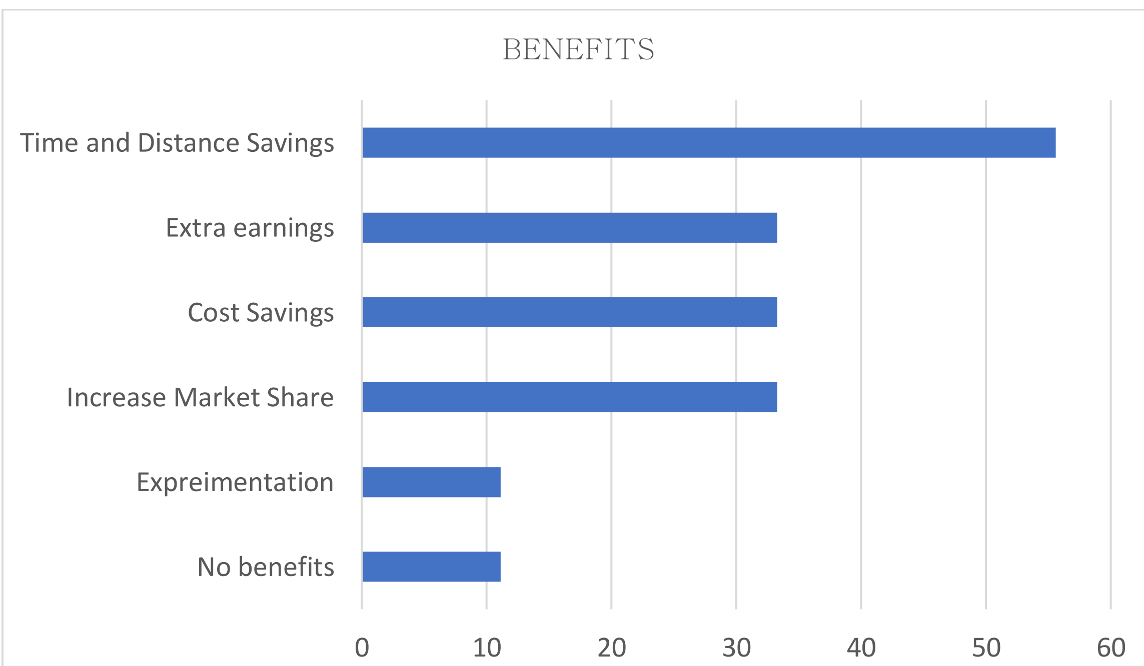


Figure 4.18 Potential benefits of the NSR

Moreover, the respondents could choose the two main challenges of the NSR on the point of view. The facts indicated in Figure 4.19, address the majority's concerns into technological challenges and safety challenges (55.6% for both options). Technological issues come to navigational risks and remoteness of the vessels, limited commercial trade due to inadequate or limited cabotage, and poor infrastructure of ports along the coastline with additional uncertainty of their current conditions and capabilities. Safety issues consider SAR difficult proximity along the Russian coastline and safety uncertainties, especially due to the extreme weather conditions occurring in the Arctic. Cost challenges appear to be influenced according to the respondents, with 44.4%. Cost challenges, likely are capital (initial investments) and voyage costs (fuel cost, ice breaker or pilotage fee, weather forecast services) are the most influential for the shipping companies rather than operational costs (repair, maintenance, insurance, crew, training, additional). A smaller percentage of 22.2% believe that the environment plays a pivotal role for the NSR, considering strict regulations, ice class demands and bunker fuel used. The respondents do not undertake political uncertainties and legal barriers as influencing factors of the NSR feasibility.

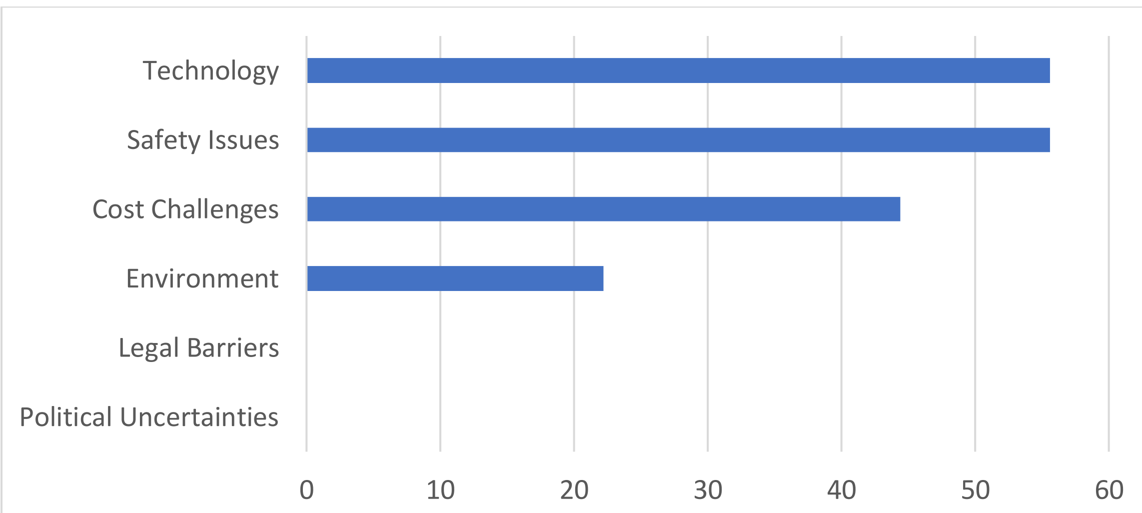


Figure 4.19 Challenges found in the NSR

The general opinion about the potential cargos as shown in Figure 4.20 are gas and oil products (77.8%), then general and bulk cargo (55.6%), an interesting outcome due to the emerging demand on hydrocarbons and natural resources from Asia. However, it seems that the respondents are hesitant about container ships and especially car carriers, as the automotive industry can have enormous prospects for trading between Northern Europe and Asia.

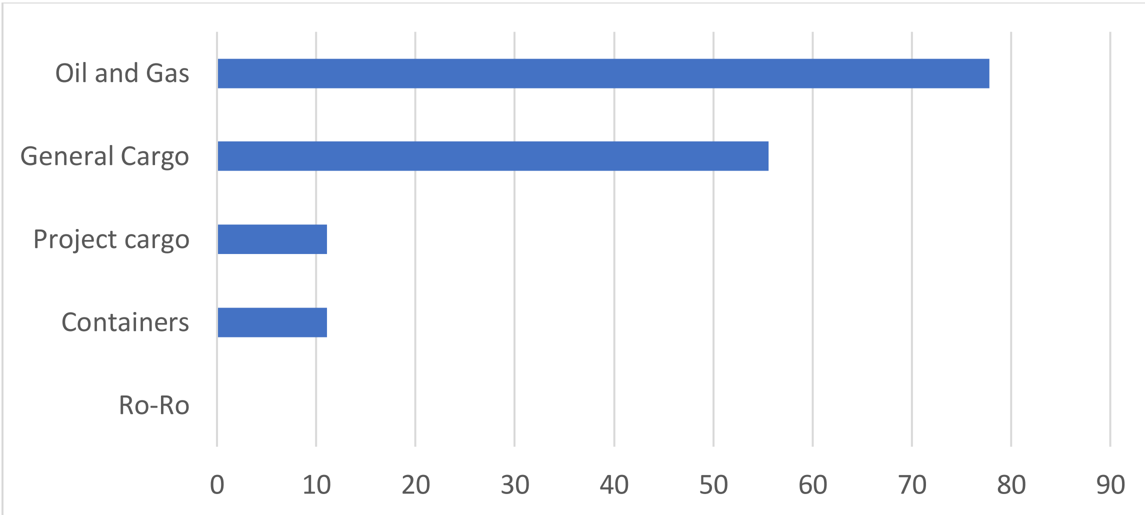


Figure 4.20 Potential Cargo for the NSR

To conclude, despite their lack of experience in the NSR market, shipping companies find trading potentials for the passage, followed by their constant updating and willingness to be involved in the near future. Even though it seems that there are plenty of challenges, costs and risks that need to be considered first, they believe that experience would be a good motive for turning their interest to the NEP. Therefore, big companies conducting the full transit for research and reputation purposes, such as Maersk and COSCO, can lead the way into motivating smaller corporations to seek benefits through the NEP potentials.

# Chapter 5: Discussion

This section broadly discusses the result and analysis presented in Chapter 4, compares with several previous studies on a similar research topic and discusses the interpretation of the cost model. Additionally, the validity and generalization of the research are discussed. The theoretical framework of this study has revealed that the current regulatory scheme for commercial shipping in the NSR is considerably aligned between international level and regional level, except united systems in ice class societies. The regulations have collaborated as can be seen the enforcement of Polar Code in obligatory amendments to SOLAS and MARPOL on January 1, 2017. The study shares the same view with (Grandinetti, 2017) that the additional requirements on ship designs, documentation of Polar Ship Certificates and Polar Water Operational Manual, and ice training for crew increase the cost for Arctic shipping. Consequently, the cost components for capital, manning, repair and maintenance, and insurance are higher than non-ice class vessels.

Several conclusions are drawn from the case study of the two case vessels in three different ice scenarios.

Firstly, the fuel expense is the largest component of the total cost. Fuel consumption rate varies in different scenarios due to discrepancies in velocity, ship resistance, and required engine power to overcome the resistance. In the same time unit, the amount of fuel needed to overcome ice resistance is less than that of open water resistance. It can be explained by the fuel saved by slow-steaming in ice-covered water. Ice breaker fee accounts for the second most prominent part of the total cost for ice scenarios. In the mild ice condition like Scenario II, the cost of Suez Canal toll is roughly the same as the ice breaker fee. However, the more ice breaker escorting zones, the less competitive the NSR becomes. The interviews revealed that the ice breaker fee is negotiable. Furthermore, RUB-USD exchange rate plays a decisive factor as it can reverse from the situation in favour of the NSR to the SCR. In terms of insurance, the findings agreed with Skuld (2013) and Gard (2013) that insurance companies do not charge extra for P&I coverage, but the H&M premium for the NSR shipping might be 2-3 times higher than regular routes.

The calculation result shown that all three NSR scenarios are more time and cost beneficial than the SCR for bulk carrier and container vessel in the study. However, the result cannot be interpreted as profitable because this study purely focuses on a single voyage cost during navigational period instead of year-round operation, which may lead to the shift in cost margin. The interpretation of cost results should be considered together with market factors. On the one hand, the profit is dependent on the earnings potential (Veenstra and Ludema, 2006; Stopford, 2009). According to Lasserre (2014), the average load factor of the NSR is often lower than which of the SCR. For the eastbound, the load factor of the SCR is about 75 per cent meanwhile the NSR can only reach half of the vessels' capacity. The similar pattern can be seen in westbound, the SCR's load factor can be up to 85 per cent whereas that of the NSR is only 70 per cent. The difference in cargo-carried potentials would vastly change the lost-gain analysis in the end. On the other hand, cost efficiency is dependent on how the fleet is organized. In general, ice-class vessels are operated in the NSR during summer time and exploited in the normal SCR in the winter time. For a year-round SCR-NSR combined service, a fleet should have 7-8 vessels (Zhao et al., 2016). The circulation and utilization of the fleet also affect considerably on the cost-benefit performance. Hence, the cost-saving cannot guarantee the profits in the end. Moreover, survey respondents and interviewees expressed a high level of uncertainty for liner container shipping since the service is constrained by schedule and intermediate ports along the route.

## 5.1 Validity of the results

For the cost estimation and fuel consumption calculation, the real-time ice data and vessel' GPS coordinates were extracted. The ice data taken from Copernicus was compared with data in NSDIC. Empirical equations for brash ice kept the variables relating to vessel' speed to increase the accuracy of ship-ice resistance result. As the number of interviews was limited, the result hardly is widely presented for the entire shipping industry. However, selected interviewees are holding a managerial position in their organizations provided a profound and holistic view on the research topic. In addition, the representatives who responded to the survey were all actively working in organizations that have relevant knowledge about commercial shipping in the NSR.

The choice of semi-structured interviews and opened-ended survey reduce the risk of bias when formulating the questions. All in all, triangulation of case study calculation, in-depth interviews with various actors and questionnaire ensures a satisfactory outcome.

## 5.2 Generalization

The findings of this study can be a valid contribution for not only current but also future research since the topic itself is considered being promising in the upcoming decades. Especially hailing of the ice in the Arctic region increases the possibility of year-round navigation in Arctic region.

The suggested cost model can be applied for any further research with various vessel types and sizes, considering the updated ice conditions, market factors, ship particulars, and regulatory framework. The research result can be used as a benchmark for the cost-benefit model and feasibility study about the NSR. The applied process can be replicated by other researchers or shipping companies who desire to estimate the fuel consumption and voyage expenses in the Arctic water. Nevertheless, adjustments may be required to handle influencing factors in practice.

## 5.3 Further research

The authors suggest that further research beyond this thesis various directions can be done. First of all, since this is a cost estimation study, further research on earning potentials can lead to a cost-benefit analysis for the NSR compared to the SCR. Secondly, the application of other types of ships and sizes would be interesting for the cost analysis. Since the emerging oil and LNG market in the Arctic, it would be important to expand the study in these types. Notably, these ship types should be followed by a proper risk and safety management due to the tremendous environmental disasters that an oil leakage can cause.

Thirdly, this research focused on the Northern European point of view. With this in mind, it would be interesting to further the study on the Asian perspectives and initiatives for the NSR since they appear to be more engaged in this trading pattern. Finally, it would be interesting to expand this research into further cost reducing solutions or suggestions on how to operate an ice-classed vessel yearly besides the navigational season.

# Chapter 6: Conclusion

The Northern Sea Route is becoming an emerging shipping lane; an alternative to the conventional Suez Canal Route. Global warming leads to higher hailing of the ice in the Arctic, leading to smoother sea water conditions for the vessels to conduct the full transit. The idea intrigued all actors of the maritime industry and researchers but mostly shipowners. The purpose of this thesis is to present the shipowners' point of view regarding the Northern Sea Route.  Therefore, the research questions have been formed to assess the cost of conducting the full transit by examining all of the possible conditions during the navigational season, the challenges and the possible commercial prospects of this niche market.

- How much is the time and cost for using the NSR compared to the Suez Canal for cargo transportation between Northern Europe and Asia during the navigational season?

The study concluded that the distance and time of the NSR could be minimised up to one third compared to the SCR, including waiting time for icebreaking assistance, if any. Moreover, the ice-free navigational period in September can benefit up to forty per cent of the total cost, due to the absence of ice resistance, the fact that leads to less fuel consumption and not the necessity of ice breaking assistance. It has also been found that fuel cost is the biggest cost component which accounts around half of the total costs. While in ice conditions, resistance is significantly higher; therefore, the reduction of the speed is necessary. Additionally, even though the fuel consumption per hour is lower in ice conditions compared to open water, augmented it is higher fuel consumption due to the longer time of the voyage. In this research, the maximum fuel consumption was calculated so the vessel will be able to traverse the ice. This number exceeds the real speed needed. However maximum load, higher resistance rate, stronger engines thus greater fuel consumption is used, for the reliability of the vessel’s performance in ice conditions. The ice breaker fees account approximately one-fourth of the total costs and the insurance premium up to three times more than the regular price when sailing in the designated waters with extra charging. Also, the feasibility depends on the number of zones that ice breakers will escort the vessel. However, the ice breaker fees and insurance premium can be negotiable. Possible ice breaker fees and insurance premium extenuation are based on trust built out of a long-term collaboration between the parties, a solid voyage and risk management plan and proximity to rescue bases.

In all scenarios in the study, the total cost is less than that of the SCR. However, in brash ice conditions, it is crucial to take into consideration the exchange rate fluctuations between RUB-USD. In case this increases, then it can no longer be beneficial.

- What are the challenges for shipping companies to operate across the NSR?

The most influential challenges, from the shipping companies view, are the technological challenges and the safety challenges. Technological issues come to navigational risks. It is important to note that this can vary between the size of the fleet of each company. For instance, a company possessing a small fleet of three vessels will be susceptible to tremendous loses in case one of the vessels would stack in the ice. On the other hand, companies acquiring large fleet, reliable stakeholders and funding, can more easily conduct the full transit for experimental purposes. The difficulties in the remoteness of the vessels within the extreme weather conditions of the Arctic, raise awareness and concerns. Furthermore, the poor infrastructure of ports along the Russian coastline combined with the uncertainty of their current conditions raises concerns for SAR capabilities since extreme weather conditions disrupt proximity of the rescue teams to the vessel in case of an emergency. Additionally, building an ice-classed vessel might be a financial barrier, especially for new entering shipowners. Notably, the political uncertainties, the legal barriers and the environmental impacts appear to be the least influential factors or last in the challenges list of the shipowners.

- What are the promising cargo types to be transported via the NSR?

From the interviews and the survey of this study, it is evident that the common thought addresses gas and oil products to be the most advantageous cargos to do business within the Arctic. This is motivated by the existing extraction infrastructures for hydrocarbons and the high demand arising in Asia. Furthermore, general and bulk cargo of natural resources seems to be an emerging and efficient cargo to trade. It is interesting to mention that project cargo seems to claim one of the busiest activities lately, due to constructions of Russian Ports and also offshore structures for extraction of hydrocarbons. Finally, despite this thesis approximation of the benefits of a container ship, all of the participants are hesitant about liner shipping and especially for car carriers, a business that could bring enormous trading prospects between Northern Europe and Asia.

## 6.1 Theoretical Contribution

This thesis is aiming on providing a cost estimation model. This model includes the cost estimation factor based on the usage of real time data and economic inputs like additional insurance premium, crew salaries, training costs, fuel costs, extra repair and maintenance costs and ice breaker fees. The model also uses ship parameters and ice resistance calculations to estimate time and costs through ice covered costs. Moreover, it is a feasibility study that does not only consider the cost comparison, but also the influence of each factor in the industry and trends of currencies and ice conditions. This thesis contribution is based on using real time data for more accurate analysis of the fuel consumption rate affected by the ice floes met throughout the voyage. Other feasibility studies seldom take into account current real time data of speed and water resistance; unlike they assume an average speed. Furthermore, this study suggests a cost estimation model for the icy water which comes to reality since actual data of a real case have been used. Also, optimal route planning has been designed taken under consideration bathymetry restrictions, ice conditions and SAR proximity from the closest ports. It is important to note that, optimal size of the ship applicable to the water depths is necessary. Finally, high loading rates have been assumed otherwise the benefit factor is descending exponentially.

## 6.2 Practical Implications

This research provides a cost estimation model for the navigational season; a useful tool for shipowners. Furthermore, all actors of the maritime industry can be aware of the industry directions shifts, each stakeholder's engagement and who are the most influential factors. Besides the costs, further arising considerations and challenges preventing a shipping company from conducting the full transit have been presented thoroughly.

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# Appendix

## Appendix-A: Ice breaker Tariffs on different Navigational times

For ships of gross tonnage from 20 001 to 40 000

| Table 7 – Tariffs during the summer-autumn period of navigation | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ice class of ship | tariff in rubles for a unit of gross tonnage of ship | | | | | | |
| | escorting within 1 zone | escorting within 2 zones | escorting within 3 zones | escorting within 4 zones | escorting within 5 zones | escorting within 6 zones | escorting within 7 zones |
| None | 536,21 | 643,45 | 750,70 | 857,94 | 965,18 | 1072,42 | 1072,42 |
| Ice 1 | 375,35 | 450,42 | 525,49 | 600,56 | 675,63 | 750,70 | 750,70 |
| Ice 2 | 348,54 | 418,24 | 487,95 | 557,66 | 627,37 | 697,07 | 697,07 |
| Ice 3 | 321,73 | 386,07 | 450,42 | 514,76 | 579,11 | 643,45 | 643,45 |
| Arc 4 | 268,11 | 321,73 | 375,35 | 428,97 | 482,59 | 536,21 | 536,21 |
| Arc 5 | 265,42 | 318,51 | 371,59 | 424,68 | 477,76 | 530,85 | 530,85 |
| Arc 6 - Arc 9 | 262,74 | 315,29 | 367,84 | 420,39 | 472,94 | 525,49 | 525,49 |

| Table 8 – Tariffs during the winter-spring period of navigation | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ice class of ship | tariff in rubles for a unit of gross tonnage of ship | | | | | | |
| | escorting within 1 zone | escorting within 2 zones | escorting within 3 zones | escorting within 4 zones | escorting within 5 zones | escorting within 6 zones | escorting within 7 zones |
| Arc 4 | 670,26 | 804,32 | 938,37 | 1072,42 | 1206,47 | 1340,53 | 1340,53 |
| Arc 5 | 663,56 | 796,27 | 928,99 | 1061,70 | 1194,41 | 1327,12 | 1327,12 |
| Arc 6 - Arc 9 | 656,86 | 788,23 | 919,60 | 1050,97 | 1182,35 | 1313,72 | 1313,72 |
| Icebreaker 6 - Icebreaker 8 | 650,16 | 780,19 | 910,22 | 1040,25 | 1170,28 | 1300,31 | 1300,31 |

## Appendix-B: Ship Particulars

| Factors | Units | Vessel Y | Vessel X |
|---|---|---|---|
| | | | |
| Vessel type | - | General-Cargo Bulk-Carrier Handymax | Container-ship Sub-Panamax |
| TEU | - | - | 2808 |
| Build year | - | 2017 | 2017 |
| Ice class | - | IA | IA Super |
| DWT | tons | 37,130 | 40,882 |
| Gross tonnage | tons | 26,787 | 39,174 |
| Net tonnage | tons | 11,415 | 17,884 |
| Light ship | tons | 12,082 | 17,669 |
| Length Overall (LOA) | m | 190 | 232 |
| Length between Perpendiculars (Lpp) | m | 186.4 | 230 |
| Breadth (B) | m | 28.5 | 32.2 |
| Draft (T) | m | 10.7 | 10.8 |
| Displacement volume ($\nabla$) | $m^3$ | 49,159 | 52,030 |
| Design speed | knots | 14.8 | 24 |
| Main engine power | kW | 10,470 | 25,426 |
| Propeller parameter (DP) | m | 6.3 | 6.5 |
| Propeller arrangement | - | 1 | 1 |
| Number of blades | - | 4 | 4 |
| SFOC (high load 85-100%) | g/kWh | 161.2 | 161.2 |
| $C_{OW}$ | | 7,500 | 7,746 |

## Appendix-C: Main engine SFOC

# RT-flex50-E

**IMO Tier II & Tier III (SCR)**

| | |
|---|---|
| **Cylinder bore** | 500 mm |
| **Piston stroke** | 2050 mm |
| **Speed** | 99–124 rpm |
| **Mean effective pressure at R1** | 21.0 bar |
| **Stroke / bore** | 4.10 |

RATED POWER, PRINCIPAL DIMENSIONS AND WEIGHTS

| Cyl. | Output in kW at | | | | Length A mm | Length A* mm | Weight tonnes |
|---|---|---|---|---|---|---|---|
| | 124 rpm | 99 rpm | | | | | |
| | R1 | R2 | R3 | R4 | | | |
| 5 | 8 725 | 6 650 | 6 980 | 5 320 | 5 576 | 6 793 | 200 |
| 6 | 10 470 | 7 980 | 8 375 | 6 385 | 6 456 | 7 670 | 225 |
| 7 | 12 215 | 9 310 | 9 770 | 7 450 | 7 336 | | 255 |
| 8 | 13 960 | 10 640 | 11 165 | 8 510 | 8 216 | | 280 |

| Dimensions (mm) | B | C | D | |
|---|---|---|---|---|
| | 3 150 | 1 088 | 7 646 | |
| | F1 | F2 | F3 | G |
| | 9 270 | 9 270 | 8 800 | 1 636 |

BRAKE SPECIFIC FUEL CONSUMPTION (BSFC) IN g/kWh

**Full load**

| Rating point | | R1 | R2 | R3 | R4 |
|---|---|---|---|---|---|
| BMEP, bar | | 21.0 | 16.0 | 21.0 | 16.0 |
| BSFC | Standard Tuning | 164.8 | 158.8 | 164.8 | 158.8 |

| **Part load, % of R1** | **85** | **70** | **85** | **70** | **65** |
|---|---|---|---|---|---|
| Tuning variant | Standard | Standard | Delta | Delta | Low-Load |
| BSFC | 161.2 | 159.5 | 160.5 | 158.0 | 154.9 |

For definitions see page 42,

# X72

IMO Tier II & Tier III (SCR)

| | |
|---|---|
| **Cylinder bore** | 720 mm |
| **Piston stroke** | 3086 mm |
| **Speed** | 66–89 rpm |
| **Mean effective pressure at R1** | 20.5/19.4 bar |
| **Stroke / bore** | 4.29 |

## RATED POWER, PRINCIPAL DIMENSIONS AND WEIGHTS

| **Cyl.** | **Output in kW at** 84/89 rpm | 66 rpm | | | **Length A mm** | **Weight tonnes** |
|---|---|---|---|---|---|---|
| | **R1/R1+** | **R2/R2+** | **R3** | **R4** | | |
| 5 | 18 050 | 13 500 | 14 200 | 10 600 | 8 085 | 481 |
| 6 | 21 660 | 16 200 | 17 040 | 12 720 | 9 375 | 561 |
| 7 | 25 270 | 18 900 | 19 880 | 14 840 | 10 665 | 642 |
| 8 | 28 880 | 21 600 | 22 720 | 16 960 | 11 960 | 716 |

| **Dimensions (mm)** | | | | |
|---|---|---|---|---|
| | **B** | **C** | **D** | |
| | 4 780 | 1 575 | 10 790 | |
| | **F1** | **F2** | **F3** | **G** |
| | 13 560 | 13 560 | 12 580 | 2 455 |

## BRAKE SPECIFIC FUEL CONSUMPTION (BSFC) IN g/kWh

**Full load**

| Rating point | | **R1/R1+** | **R2/R2+** | **R3** | **R4** |
|---|---|---|---|---|---|
| BMEP, bar | | 20.5/19.4 | 15.4/14.5 | 20.5 | 15.4 |
| BSFC | Standard Tuning | 167/166 | 160 | 167 | 160 |

| **Part load**, % of R1 | **85** | **70** | **85** | **70** | **65** |
|---|---|---|---|---|---|
| Tuning variant | Standard | Standard | Delta | Delta | Low-Load |
| BSFC | 163.2/162.2 | 162.8/161.8 | 162.5/161.5 | 161.3/160.3 | 158.0/157.2 |

For definitions see page 42.

**Appendix-D: Calculations for Fuel Consumption.**

**Fuel Consumption for Scenario I**

Below is presented the resistance, power requirements and fuel consumption for Vessel X in open waters. Further on the ship particulars change at the beginning of the code to calculate for Vessel Y.

For ice free waters, in Scenario I and II of Vessel Y:

```
clear all; close all; clc
% Extract Vs from excel file
T = readtable('Speed.xlsx');
Vs_list = str2double(T.Speed);
total_row = size(Vs_list,1);
R_total_list = zeros(1,total_row);
%% Run the loop for each Vs value
for Vs_index = 1:total_row
%% Big Brother based on Holtrop & Mennen
%%
% = INPUT ===========================================================
% Length of Ship. [m]
L = 190;
% Width of Ship. [m]
B = 28.5;
% Draft of Ship. [m]
T = 10.7;
% Displacement. [m^3]
Disp = 49159;
% Trim by stern = +. [m]
trim = 0;
% Lonitudinal Center of Bouyancy forward of 0.5*L. [m]
lcb = -4;
% Speed. [kts]
Vs = Vs_list(Vs_index);
% Stern Coeff. [-]
% (SEE TABLE ON PAGE 1)
C_stern = 10;
% Wetted transom area at rest. [m^2]
A_T = 15; % Proportional to emperical data
% Water plane area coefficient. [-]
C_WP = 0.75;
% Transverse area of bulb at forward perpendicular. [m^2]
A_BT = 18.5;
% Vertical center of A_BT (max=0.6*T_F). [m]
h_B = 4.3;
% Appendages data. [[-] [m^2]]
% (SEE TABLE ON PAGE 2)
% [1+k2 values]
apps = [1.75, 0; % rudder behind skeg
1.40, 0; % rudder behind stern
2.80, 0; % twin screw balance rudder
3.00, 0; % shaft brackets
1.75, 0; % skeg
3.00, 0; % strut bossings
```

```
2.00, 0; % hull bossings
3.00, 0; % shafts
2.80, 0; % stabilizer fins
2.70, 0; % dome
1.49, 50];% bilge keels
% Bow thruster tunnel diameter. [m]
% Insert 0 if no bow thruster is used.
d = 0;
%% =CONSTANTS===========================================================
% Water density @ 15 degrees Celsius. [kg/m^3]
rho = 1025; %999.1;
% Water kinematic viscosity. [s/m]
nu = 1.187e-6;
% Gravitational Acceleration. [m^2/s]
g = 9.81;
t=1; %hours of operating
SFOC=161.2; %g/kwh
%%
%% Frictional Resistance ------------------------------------------------
% Speed: V
V = Vs * (1852/3600);
% Block Coeff.: C_B
C_B = Disp/(L*B*T);
% Midships Section Coeff.: C_M
%C_M = 0.977+0.085*(C_B-0.6);
C_M=0.98;
% Prismatic Coeff.: C_P
C_P = C_B/C_M;
% Length of Run: L_R
L_R = L*(1 - C_P + 0.06*C_P*lcb/(4*C_P-1));
% Coeff. 12: c12
if T/L < 0.02
c12 = 0.479948;
elseif T/L < 0.05
c12 = 48.20*((T/L - 0.02)^2.078) + 0.479948;
else
c12 =(T/L)^0.2228446;
end
%Coeff. 13: c13
c13 = 1 + 0.003*C_stern;
c14 = 1 + 0.011*C_stern;
% Water Plane Area Coeff.: C_WP
if C_WP == 0
C_WP = C_B/(0.471+0.551*C_B);
end
% Wetted surface area: S
S = L*(2*T+B)*sqrt(C_M)*(0.453 + 0.4425*C_B - 0.2862*C_M - ...
(0.003467*B)/T + 0.3696*C_WP) + (2.38*A_BT)/C_B;
% Formfactor: k1
k1_1982 = -1 + c13 * (0.93 + c12*(B/L_R)^0.92497)*...
((0.95-C_P)^-0.521448) * ((1 - C_P + 0.0225*lcb)^0.6906);
k1 = -1 +0.93 + ( 0.487118 * c14 * ((B/L)^1.06806) * ((T/L)^0.46106) *...
((L/L_R)^0.121563) * ((L^3/Disp)^0.36486) *...
((1-C_P)^-0.604247) );
% Frictional Resistance ITTC-57
C_F = 0.075/(log10(V*L/nu)-2)^2;
```

```
R_F = C_F*0.5*rho*(V^2)*S;
%% Appendage Resistance -------------------------------------------------
% Total appendage area: S_APP
S_APP = sum(apps(:,2));
if S_APP == 0
R_APP = 0;
else
% Equivalent appendage form factor: k2_eq
k2_eq = -1 + sum(apps(:,1).*apps(:,2))/S_APP;
% Bow thruster resistance: R_BT
R_BT = rho*(V^2)*pi*(d^2)*0.0075;
% Appendage Resistance: R_APP
R_APP = 0.5*rho*(V^2)*S_APP*(1+k2_eq)*C_F + R_BT;
end
%% Wave Resistance -----------------------------------------------------
% Froude Number, Fr: [-]
Fr = V/sqrt(g*L);
% Draft aft: T_A
T_A = T + trim;
% Draft forward: T_F
T_F = T - trim;
% Coeff. 7: c7
if B/L < 0.11
c7 = 0.229577*((B/L)^0.33333);
elseif B/L < 0.25
c7 = B/L;
else
c7 = 0.5 - 0.0625*(L/B);
end
% Coeff. 3: c3
c3 = 0.56*(A_BT^1.5) / (B*T*(0.31*sqrt(A_BT) + T_F - h_B));
% Half angle of entrence: i_E
i_E = 1+89*exp( (-1*(L/B)^0.80856) * ((1-C_WP)^0.30484) *...
((1-C_P-0.0225*lcb)^0.6367) * ((L_R/B)^0.34574) * ...
((100*Disp/(L^3))^0.16302) );
% Coeff. 1: c1
c1 = 2223105*(c7^3.78613)*((T/B)^1.07961)*((90 - i_E)^-1.37565);
% Coeff. of reducing wave resistance due to bulbous bow: c2
c2 = exp(-1.89*sqrt(c3));
% Coeff. of reducing resistance due to a transom stern : c5
c5 = 1 - 0.8*A_T/(B*T*C_M);
% Coeff. Lambda: lambda
if L/B <12
lambda = 1.446*C_P - 0.03*(L/B);
else
lambda = 1.446*C_P - 0.36;
end
% Coeff. 16: c16
if C_P < 0.80
c16 = 8.07981*C_P - 13.8673*(C_P^2) + 6.984388*(C_P^3);
else
c16 = 1.73014 - 0.7067*C_P;
end
% Coeff. 15: c15
if (L^3)/Disp < 512
c15 = -1.69385;
```

```
elseif (L^3)/Disp < 1727
c15 = -1.69385 + (L/(Disp^(1/3)) - 8.0)/2.36;
else
c15 = 0;
end
% Coeff. m2: m2
m2 = c15*(C_P^2)*exp(-0.1*(Fr^-2));
% Coeff. m1: m1
m1 = 0.0140407*(L/T) - 1.75254*(Disp^(1/3))/L - 4.79323*(B/L) - c16;
% Wave Resistance: R_W
R_W = c1*c2*c5*Disp*rho*g * exp( m1*(Fr^-0.9) + m2*cos(lambda*(Fr^-2)) );
%% Bolbous-bow-near-the-water wave resistance component -----------------
% Measure of Emergence: P_B
P_B = 0.56*sqrt(A_BT)/(T_F - 1.5*h_B);
% Froude number based on immersion: Fri
Fri = V / sqrt( g*(T_F - h_B - 0.25*sqrt(A_BT)) + 0.15*(V^2) );
% Bolbous wave resistance:. R_B
R_B = 0.11*exp(-3*(P_B^-2)) * (Fri^3)*(A_BT^1.5)*rho*g / (1 + (Fri^2));
%% Immersed transom pressure resistance --------------------------------
% Froude number based on transom emergence: FrT
FrT = V / sqrt( 2*g*A_T/(B + B*C_WP) );
% Coeff. 6: c6
if FrT >= 5
c6 = 0;
else
c6 = 0.2*(1 - 0.2*FrT);
end
% Transom resistance: R_TR
R_TR = 0.5*rho*(V^2)*A_T*c6;
%% Model Ship Correlation resistance Component --------------------------
% Coeff. 4: c4
if T_F/L <= 0.04
c4 = T_F/L;
else
c4 = 0.04;
end
% Corelation allowance coeff.: C_A
C_A = 0.006*((L+100)^-0.16) - 0.00205 + ...
0.003*sqrt(L/7.5)*(C_B^4)*c2*(0.04 - c4);
% Model Ship Correlation resistance Component
R_A = C_A*0.5*rho*(V^2)*S;
%% Total Resistance: R_total -------------------------------------------
R_total = R_F*(1+k1) + R_APP + R_W + R_B + R_TR + R_A;
R_total_list(Vs_index) = R_total;
% Required Power: P_E
P_E = R_total*V/1000;
%EHP=2.03*Rice^1.5/Dp
%Rice is the ice resistance (kN) computed either by formula (1) or (3)
%Kp is a coefficient differing with the number of propellers and propeller type or machinery
in Ice Class Rules. For controllable pitch propellers or electric or hydraulic propulsion
machinery, Kp = 2.03 for 1 propeller, 1.44 for 2 propellers, and 1.18 for 3 propellers; for
fixed pitch propellers, Kp = 2.26 for 1 propeller, 1.6 for 2 propellers, and 1.31 for 3
propellers.
%Required Effective Horse Power in open water is calculated as
EHPow = R_total*V/1000;
%Calculating Fuel Consumption
```

```
%For the shake of simplification, the Effective Horse Power is estimated as 70% of the
Breaking Horse Power Service Continuous Rating BHPmcr
BHPmcr=EHPow/0.7;
FOM=BHPmcr*SFOC*t*10^(-6);%*Ce
%BHPmcr is Breaking Horse Power Service Continuous Rating (kW)
%SFOC is Specific Fuel Oil Consumption (g/kWh)
%t is the time (hours)
%Ce is the coefficient of ship fuel consumption
FOMdaily=FOM*24;
end
%% Print the result
clc
% % Print both Vs and R_total
% fprintf('Speed\tR_total\n')
% for Vs_index = 1:total_row
% fprintf('%0.5f\t%0.5f\n',Vs_list(Vs_index),R_total_list(Vs_index));
% end
% Print only R_total
fprintf('R_total\n')
for Vs_index = 1:total_row
fprintf('%d\n',R_total_list(Vs_index));
end
```

Fuel consumption for Scenario II

| Latitude | Longitude | Ice concentration (%) | Ice thickness (m) | Speed (knots) | Vessel Y Open water resistance (kN) | Broken ice resistance (kN) | Ship power (kW) | FOM (ton/h) |
|---|---|---|---|---|---|---|---|---|
| 64.85333 | -176.598 | 0 | 0 | 11.4 | 400.96 | | 5377.60 | 0.867 |
| 64.85667 | -176.518 | 0 | 0 | 11.5 | 408.19 | | 5522.61 | 0.890 |
| 64.755 | -176.152 | 0 | 0 | 13.4 | 573.47 | | 9040.59 | 1.457 |
| 64.62833 | -175.715 | 0 | 0 | 14 | 635.70 | | 10470.42 | 1.688 |
| 64.495 | -175.263 | 0 | 0 | 14.1 | 647.42 | | 10739.61 | 1.731 |
| 64.36167 | -174.843 | 0 | 0 | 13.6 | 594.44 | | 9511.07 | 1.533 |
| 64.23833 | -174.443 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.217 |
| 64.11833 | -174.017 | 0 | 0 | 13.1 | 541.92 | | 8351.90 | 1.346 |
| 64.04667 | -173.738 | 0 | 0 | 13.5 | 584.09 | | 9276.75 | 1.495 |
| 64.07667 | -173.568 | 0 | 0 | 14.1 | 647.42 | | 10739.61 | 1.731 |
| 64.16167 | -173.06 | 0 | 0 | 14.7 | 730.93 | | 12640.86 | 2.038 |
| 64.26333 | -172.52 | 0 | 0 | 14 | 767.50 | | 12641.14 | 2.038 |
| 64.35167 | -172.04 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.217 |
| 64.52333 | -171.767 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.217 |
| 64.69833 | -171.485 | 0 | 0 | 12.9 | 522.95 | | 7936.48 | 1.279 |
| 64.88167 | -171.195 | 0 | 0 | 13.2 | 552.14 | | 8574.44 | 1.382 |
| 65.065 | -170.903 | 0 | 0 | 12.4 | 479.15 | | 6990.00 | 1.127 |
| 65.295 | -170.642 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.217 |
| 65.39333 | -170.368 | 0 | 0 | 11.6 | 415.60 | | 5671.66 | 0.914 |
| 65.56167 | -170.093 | 0 | 0 | 11.1 | 379.97 | | 4961.93 | 0.800 |
| 65.71167 | -169.848 | 0 | 0 | 11.7 | 423.14 | | 5824.45 | 0.939 |
| 65.88 | -169.583 | 0 | 0 | 12.3 | 470.53 | | 6808.84 | 1.098 |
| 66 | -169.385 | 0 | 0 | 11.6 | 415.60 | | 5671.66 | 0.914 |
| 66.05667 | -169.385 | 0 | 0 | 11.3 | 393.88 | | 5236.24 | 0.844 |
| 66.16833 | -169.395 | 0 | 0 | 10.7 | 353.24 | | 4446.64 | 0.717 |
| 66.225 | -169.48 | 0 | 0 | 11.8 | 430.77 | | 5980.16 | 0.964 |
| 66.39333 | -169.785 | 0 | 0 | 12.8 | 514.06 | | 7741.16 | 1.248 |
| 66.56333 | -170.065 | 0 | 0 | 12.6 | 496.65 | | 7362.12 | 1.187 |
| 66.74333 | -170.362 | 0 | 0 | 12.8 | 514.06 | | 7741.16 | 1.248 |
| 66.92833 | -170.678 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.217 |
| 67.095 | -170.973 | 0 | 0 | 12.6 | 496.65 | | 7362.12 | 1.187 |
| 67.26667 | -171.27 | 0 | 0 | 12.5 | 487.90 | | 7175.02 | 1.157 |
| 67.61 | -171.883 | 0 | 0 | 12.5 | 487.90 | | 7175.02 | 1.157 |
| 67.78667 | -172.205 | 0 | 0 | 12.5 | 487.90 | | 7175.02 | 1.157 |
| 67.95167 | -172.497 | 0 | 0 | 12.3 | 470.53 | | 6808.84 | 1.098 |
| 68.125 | -172.825 | 0 | 0 | 12.1 | 454.04 | | 6463.40 | 1.042 |
| 68.20833 | -173.302 | 0 | 0 | 11.9 | 438.44 | | 6138.21 | 0.989 |
| 68.28667 | -173.787 | 0 | 0 | 11.7 | 423.14 | | 5824.45 | 0.939 |
| 68.36333 | -174.263 | 0 | 0 | 12 | 446.17 | | 6298.89 | 1.015 |
| 68.44333 | -174.763 | 0 | 0 | 11.7 | 423.14 | | 5824.45 | 0.939 |
| 68.52333 | -175.258 | 0 | 0 | 11.4 | 400.96 | | 5377.60 | 0.867 |
| 68.595 | -175.718 | 0 | 0 | 10.8 | 359.76 | | 4571.05 | 0.737 |
| 68.67 | -176.183 | 0 | 0 | 11.7 | 423.14 | | 5824.45 | 0.939 |
| 68.745 | -176.527 | 0 | 0 | 11.1 | 379.97 | | 4961.93 | 0.800 |
| 68.82167 | -177.138 | 0 | 0 | 11.3 | 393.88 | | 5236.24 | 0.844 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 68.89333 | -177.583 | 0 | 0 | 11.2 | 386.89 | | 5097.83 | 0.822 |
| 68.965 | -178.068 | 0 | 0 | 10.3 | 327.94 | | 3973.80 | 0.641 |
| 68.98167 | -178.197 | 0 | 0 | 10.3 | 327.94 | | 3973.80 | 0.641 |
| 69.04667 | -178.637 | 0 | 0 | 11.2 | 386.89 | | 5097.83 | 0.822 |
| 69.11833 | -179.082 | 0 | 0 | 10.2 | 321.82 | | 3861.83 | 0.623 |
| 69.17667 | -179.458 | 0 | 0 | 10.8 | 359.76 | | 4571.05 | 0.737 |
| 69.27167 | -179.92 | 0 | 0 | 9.9 | 303.90 | | 3539.51 | 0.571 |
| 69.35333 | 179.6767 | 0 | 0 | 9.1 | 259.10 | | 2773.87 | 0.447 |
| 69.45333 | 179.19 | 0 | 0 | 9.3 | 269.92 | | 2953.23 | 0.476 |
| 69.525 | 178.8317 | 0 | 0 | 7.8 | 194.27 | | 1782.71 | 0.287 |
| 69.59833 | 178.4567 | 0 | 0 | 10.4 | 334.13 | | 4088.23 | 0.659 |
| 69.70333 | 177.895 | 0 | 0 | 10.7 | 353.24 | | 4446.64 | 0.717 |
| 69.78333 | 177.4883 | 0 | 0 | 10.5 | 340.42 | | 4205.23 | 0.678 |
| 69.88 | 177.0267 | 0 | 0 | 11.6 | 415.60 | | 5671.66 | 0.914 |
| 69.96667 | 176.5567 | 0 | 0 | 10.7 | 353.24 | | 4446.64 | 0.717 |
| 70.05333 | 176.0467 | 0 | 0 | 10.3 | 327.94 | | 3973.80 | 0.641 |
| 70.11833 | 175.6 | 0 | 0 | 11.1 | 379.97 | | 4961.93 | 0.800 |
| 70.18667 | 175.0983 | 0 | 0 | 11.6 | 415.60 | | 5671.66 | 0.914 |
| 70.26167 | 174.5917 | 0 | 0 | 11.4 | 400.96 | | 5377.60 | 0.867 |
| 70.345 | 174.0333 | 0 | 0 | 12 | 446.17 | | 6298.89 | 1.015 |
| 70.425 | 173.51 | 0 | 0 | 12.2 | 462.14 | | 6633.14 | 1.069 |
| 70.50167 | 172.94 | 0 | 0 | 12.4 | 479.15 | | 6990.00 | 1.127 |
| 70.585 | 172.3817 | 0 | 0 | 12.5 | 487.90 | | 7175.02 | 1.157 |
| 70.66667 | 171.7917 | 0 | 0 | 12.8 | 514.06 | | 7741.16 | 1.248 |
| 70.74667 | 171.1833 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.217 |
| 70.82833 | 170.5983 | 0 | 0 | 12.6 | 496.65 | | 7362.12 | 1.187 |
| 70.915 | 170.02 | 0 | 0 | 12.4 | 479.15 | | 6990.00 | 1.127 |
| 70.995 | 169.435 | 0 | 0 | 12.3 | 470.53 | | 6808.84 | 1.098 |
| 71.075 | 168.8567 | 0 | 0 | 12.1 | 454.04 | | 6463.40 | 1.042 |
| 71.15167 | 168.305 | 0 | 0 | 12 | 446.17 | | 6298.89 | 1.015 |
| 71.225 | 167.7433 | 0 | 0 | 11.9 | 438.44 | | 6138.21 | 0.989 |
| 71.30833 | 167.1683 | 0 | 0 | 11.9 | 438.44 | | 6138.21 | 0.989 |
| 71.38667 | 166.5683 | 0 | 0 | 11.9 | 438.44 | | 6138.21 | 0.989 |
| 71.46333 | 166.0183 | 0 | 0 | 11.9 | 438.44 | | 6138.21 | 0.989 |
| 71.54 | 165.4483 | 0 | 0 | 11.9 | 438.44 | | 6138.21 | 0.989 |
| 71.61833 | 164.8717 | 0 | 0 | 12 | 446.17 | | 6298.89 | 1.015 |
| 71.69667 | 164.295 | 0 | 0 | 11.9 | 438.44 | | 6138.21 | 0.989 |
| 71.775 | 163.7083 | 0 | 0 | 12 | 446.17 | | 6298.89 | 1.015 |
| 71.85167 | 163.12 | 0 | 0 | 12.1 | 454.04 | | 6463.40 | 1.042 |
| 71.935 | 162.4883 | 0 | 0 | 12.2 | 462.14 | | 6633.14 | 1.069 |
| 72.005 | 161.9983 | 0 | 0 | 12.3 | 470.53 | | 6808.84 | 1.098 |
| 72.20167 | 161.5717 | 0 | 0 | 12.3 | 470.53 | | 6808.84 | 1.098 |
| 72.36667 | 161.2167 | 0 | 0 | 12.3 | 470.53 | | 6808.84 | 1.098 |
| 72.55 | 160.8333 | 0 | 0 | 12.4 | 479.15 | | 6990.00 | 1.127 |
| 72.71667 | 160.465 | 0.0008 | 0.0015 | 12.5 | | 1171.88 | 12926.39 | 2.084 |
| 72.895 | 160.0783 | 0.1407 | 0.1198 | 12.4 | | 1155.64 | 12658.72 | 2.041 |
| 73.06333 | 159.7017 | 0.3087 | 0.1190 | 9.9 | | 747.44 | 6584.47 | 1.061 |
| 73.24667 | 159.3167 | 0.5482 | 0.3395 | 8.8 | | 770.28 | 6888.62 | 1.110 |
| 73.42667 | 158.895 | 0.7766 | 0.5287 | 7.4 | | 1080.79 | 11449.05 | 1.846 |
| 73.60333 | 158.485 | 0.6986 | 0.5333 | 7.3 | | 916.73 | 8943.65 | 1.442 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 73.78333 | 158.0767 | 0.7178 | 0.4769 | 7.3 | | 871.04 | 8283.53 | 1.335 |
| 73.96833 | 157.6483 | 0.7494 | 0.4021 | 7.9 | | 918.90 | 8975.43 | 1.447 |
| 74.13167 | 157.255 | 0.2423 | 0.1373 | 11 | | 917.05 | 8948.34 | 1.442 |
| 74.48167 | 156.4117 | 0.4416 | 0.1907 | 11.2 | | 1006.83 | 10294.16 | 1.659 |
| 74.66167 | 155.975 | 0.3457 | 0.2228 | 11.9 | | 1110.99 | 11932.19 | 1.923 |
| 74.84333 | 155.53 | 0.2427 | 0.1282 | 12.1 | | 1107.80 | 11880.78 | 1.915 |
| 75.02667 | 155.0817 | 0.0004 | 0.0008 | 12.3 | | 1134.68 | 12315.80 | 1.985 |
| 75.21167 | 154.6067 | 0 | 0 | 13.6 | 594.44 | | 9511.07 | 1.533 |
| 75.40333 | 154.1233 | 0 | 0 | 13.8 | 614.56 | | 9977.59 | 1.608 |
| 75.6 | 153.63 | 0 | 0 | 13.7 | 604.53 | | 9743.66 | 1.571 |
| 75.78333 | 153.1367 | 0 | 0 | 13.6 | 594.44 | | 9511.07 | 1.533 |
| 75.82833 | 153.0167 | 0 | 0 | 13.4 | 573.47 | | 9040.59 | 1.457 |
| 75.98333 | 151.5517 | 0 | 0 | 11 | 373.12 | | 4828.64 | 0.778 |
| 76.05667 | 150.8617 | 0 | 0 | 10.9 | 366.38 | | 4698.30 | 0.757 |
| 76.12833 | 150.185 | 0 | 0 | 10.7 | 353.24 | | 4446.64 | 0.717 |
| 76.20167 | 149.5167 | 0 | 0 | 10.6 | 346.79 | | 4324.74 | 0.697 |
| 76.27333 | 148.835 | 0 | 0 | 10.8 | 359.76 | | 4571.05 | 0.737 |
| 76.345 | 148.1517 | 0 | 0 | 10.9 | 366.38 | | 4698.30 | 0.757 |
| 76.41833 | 147.4467 | 0 | 0 | 10.8 | 359.76 | | 4571.05 | 0.737 |
| 76.48833 | 146.7567 | 0 | 0 | 10.8 | 359.76 | | 4571.05 | 0.737 |
| 76.56 | 146.035 | 0 | 0 | 10.7 | 353.24 | | 4446.64 | 0.717 |
| 76.63333 | 145.325 | 0 | 0 | 10.6 | 346.79 | | 4324.74 | 0.697 |
| 76.7 | 144.6383 | 0 | 0 | 10.4 | 334.13 | | 4088.23 | 0.659 |
| 76.77 | 143.9217 | 0 | 0 | 10.4 | 334.13 | | 4088.23 | 0.659 |
| 76.83667 | 143.2517 | 0 | 0 | 10.2 | 321.82 | | 3861.83 | 0.623 |
| 76.905 | 142.5667 | 0 | 0 | 10.2 | 321.82 | | 3861.83 | 0.623 |
| 76.90833 | 141.765 | 0 | 0 | 10.7 | 353.24 | | 4446.64 | 0.717 |
| 76.91167 | 140.985 | 0 | 0 | 10.8 | 359.76 | | 4571.05 | 0.737 |
| 76.91167 | 140.185 | 0 | 0 | 10.9 | 366.38 | | 4698.30 | 0.757 |
| 76.91167 | 139.4067 | 0 | 0 | 10.9 | 366.38 | | 4698.30 | 0.757 |
| 76.91167 | 138.6267 | 0 | 0 | 10.6 | 346.79 | | 4324.74 | 0.697 |
| 76.91167 | 137.8667 | 0 | 0 | 10.1 | 315.77 | | 3752.14 | 0.605 |
| 76.90833 | 137.3067 | 0 | 0 | 10.1 | 315.77 | | 3752.14 | 0.605 |
| 76.89167 | 137.1433 | 0 | 0 | 10.2 | 321.82 | | 3861.83 | 0.623 |
| 76.82833 | 136.4533 | 0 | 0 | 10.2 | 321.82 | | 3861.83 | 0.623 |
| 76.765 | 135.77 | 0 | 0 | 10.2 | 321.82 | | 3861.83 | 0.623 |
| 76.69833 | 135.075 | 0 | 0 | 10.1 | 315.77 | | 3752.14 | 0.605 |
| 76.63167 | 134.3883 | 0 | 0 | 10.4 | 334.13 | | 4088.23 | 0.659 |
| 76.56833 | 133.73 | 0 | 0 | 9.8 | 298.07 | | 3436.57 | 0.554 |
| 76.50667 | 133.0883 | 0 | 0 | 9.7 | 292.31 | | 3335.77 | 0.538 |
| 76.37833 | 131.795 | 0 | 0 | 10.1 | 315.77 | | 3752.14 | 0.605 |
| 76.31333 | 131.1317 | 0 | 0 | 10 | 309.80 | | 3644.69 | 0.588 |
| 76.25167 | 130.505 | 0 | 0 | 9.5 | 280.99 | | 3140.42 | 0.506 |
| 76.19333 | 129.9083 | 0 | 0 | 9.2 | 264.48 | | 2862.59 | 0.461 |
| 76.13 | 129.3083 | 0 | 0 | 9.1 | 259.10 | | 2773.87 | 0.447 |
| 76.06667 | 128.72 | 0 | 0 | 9.4 | 275.42 | | 3045.84 | 0.491 |
| 76.00833 | 128.14 | 0 | 0 | 9.1 | 259.10 | | 2773.87 | 0.447 |
| 76.00333 | 127.995 | 0 | 0 | 9.2 | 264.48 | | 2862.59 | 0.461 |
| 76.06 | 127.57 | 0 | 0 | 9.9 | 303.90 | | 3539.51 | 0.571 |
| 76.11667 | 126.6717 | 0 | 0 | 9.9 | 303.90 | | 3539.51 | 0.571 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 76.19 | 126.0617 | 0 | 0 | 9.6 | 286.61 | 3237.06 | 0.522 |
| 76.245 | 125.0567 | 0 | 0 | 9.8 | 298.07 | 3436.57 | 0.554 |
| 76.29667 | 124.765 | 0 | 0 | 10.6 | 346.79 | 4324.74 | 0.697 |
| 76.36167 | 124.0617 | 0 | 0 | 9.9 | 303.90 | 3539.51 | 0.571 |
| 76.44 | 123.2117 | 0 | 0 | 9.7 | 292.31 | 3335.77 | 0.538 |
| 76.50333 | 122.5033 | 0 | 0 | 10.2 | 321.82 | 3861.83 | 0.623 |
| 76.56167 | 121.8567 | 0 | 0 | 10.6 | 346.79 | 4324.74 | 0.697 |
| 76.64667 | 120.915 | 0 | 0 | 10.3 | 327.94 | 3973.80 | 0.641 |
| 76.705 | 120.2117 | 0 | 0 | 10.2 | 321.82 | 3861.83 | 0.623 |
| 76.76 | 119.54 | 0 | 0 | 9.8 | 298.07 | 3436.57 | 0.554 |
| 76.81667 | 118.885 | 0 | 0 | 9.7 | 292.31 | 3335.77 | 0.538 |
| 76.87667 | 118.2233 | 0 | 0 | 9.8 | 298.07 | 3436.57 | 0.554 |
| 76.93833 | 117.5433 | 0 | 0 | 10.5 | 340.42 | 4205.23 | 0.678 |
| 77 | 116.82 | 0 | 0 | 9.7 | 292.31 | 3335.77 | 0.538 |
| 77.03167 | 116.465 | 0 | 0 | 4.7 | 75.48 | 417.36 | 0.067 |
| 77.09333 | 115.965 | 0 | 0 | 10.3 | 327.94 | 3973.80 | 0.641 |
| 77.15333 | 115.1367 | 0 | 0 | 10.2 | 321.82 | 3861.83 | 0.623 |
| 77.18 | 114.8417 | 0 | 0 | 10.3 | 327.94 | 3973.80 | 0.641 |
| 77.255 | 114.5617 | 0 | 0 | 10.5 | 340.42 | 4205.23 | 0.678 |
| 77.39 | 114.0467 | 0 | 0 | 10.3 | 327.94 | 3973.80 | 0.641 |
| 77.52167 | 113.5767 | 0 | 0 | 7 | 158.82 | 1307.89 | 0.211 |
| 77.60167 | 113.3917 | 0 | 0 | 3.9 | 53.21 | 244.15 | 0.039 |
| 77.77333 | 113.4833 | 0 | 0 | 9.8 | 298.07 | 3436.57 | 0.554 |
| 77.87667 | 112.9833 | 0 | 0 | 11.4 | 400.96 | 5377.60 | 0.867 |
| 77.85 | 112.14 | 0 | 0 | 12.6 | 496.65 | 7362.12 | 1.187 |
| 77.77667 | 111.235 | 0 | 0 | 12.9 | 522.95 | 7936.48 | 1.279 |
| 77.69667 | 110.3283 | 0 | 0 | 13 | 532.19 | 8139.36 | 1.312 |
| 77.58333 | 109.46 | 0 | 0 | 13.2 | 552.14 | 8574.44 | 1.382 |
| 77.53 | 109.1167 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.49833 | 108.915 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.465 | 108.695 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.46833 | 108.61 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.47167 | 108.585 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.465 | 108.705 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.455 | 108.6167 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.46333 | 108.6167 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.47 | 108.6483 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.47167 | 108.8017 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.47 | 108.7183 | 0 | 0 | 0 | 0.00 | 0.00 | 0.000 |
| 77.44167 | 108.6567 | 0 | 0 | 5.3 | 94.50 | 589.26 | 0.095 |
| 77.46667 | 108.0483 | 0 | 0 | 9.2 | 264.48 | 2862.59 | 0.461 |
| 77.53667 | 107.4217 | 0 | 0 | 6.8 | 150.47 | 1203.74 | 0.194 |
| 77.615 | 106.1333 | 0 | 0 | 10.7 | 353.24 | 4446.64 | 0.717 |
| 77.70667 | 105.445 | 0 | 0 | 10.2 | 321.82 | 3861.83 | 0.623 |
| 77.75167 | 104.5917 | 0 | 0 | 10.9 | 366.38 | 4698.30 | 0.757 |
| 77.73 | 103.8 | 0 | 0 | 10.5 | 340.42 | 4205.23 | 0.678 |
| 77.645 | 103.0383 | 0 | 0 | 10.5 | 340.42 | 4205.23 | 0.678 |
| 77.51667 | 102.3633 | 0 | 0 | 11.5 | 408.19 | 5522.61 | 0.890 |
| 77.36 | 101.81 | 0 | 0 | 12 | 446.17 | 6298.89 | 1.015 |
| 77.21833 | 101.1633 | 0 | 0 | 13 | 532.19 | 8139.36 | 1.312 |

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|---|---|---|---|---|---|---|---|
| 77.10667 | 100.38 | 0 | 0 | 12.1 | 454.04 | 6463.40 | 1.042 |
| 76.985 | 99.67 | 0 | 0 | 12.7 | 505.35 | 7550.52 | 1.217 |
| 76.83833 | 99.00833 | 0 | 0 | 12.7 | 505.35 | 7550.52 | 1.217 |
| 76.555 | 97.80833 | 0 | 0 | 11.6 | 415.60 | 5671.66 | 0.914 |
| 76.51833 | 97.02 | 0 | 0 | 11.9 | 438.44 | 6138.21 | 0.989 |
| 76.49 | 96.195 | 0 | 0 | 12.3 | 470.53 | 6808.84 | 1.098 |
| 76.375 | 95.40833 | 0 | 0 | 12.1 | 454.04 | 6463.40 | 1.042 |
| 76.27 | 93.91333 | 0 | 0 | 12.1 | 454.04 | 6463.40 | 1.042 |
| 76.23833 | 93.12667 | 0 | 0 | 12.1 | 454.04 | 6463.40 | 1.042 |
| 76.20833 | 92.29833 | 0 | 0 | 12.1 | 454.04 | 6463.40 | 1.042 |
| 76.18833 | 91.46 | 0 | 0 | 12.3 | 470.53 | 6808.84 | 1.098 |
| 76.16333 | 90.58167 | 0 | 0 | 12.8 | 514.06 | 7741.16 | 1.248 |
| 76.16333 | 90.33167 | 0 | 0 | 12.8 | 514.06 | 7741.16 | 1.248 |
| 76.18667 | 89.71333 | 0 | 0 | 12.7 | 505.35 | 7550.52 | 1.217 |
| 76.22833 | 88.85167 | 0 | 0 | 13 | 532.19 | 8139.36 | 1.312 |
| 76.27167 | 87.95667 | 0 | 0 | 13.3 | 562.74 | 8805.18 | 1.419 |
| 76.315 | 87.05167 | 0 | 0 | 13.3 | 562.74 | 8805.18 | 1.419 |
| 76.35667 | 86.15 | 0 | 0 | 12.7 | 505.35 | 7550.52 | 1.217 |
| 76.405 | 85.14833 | 0 | 0 | 12.5 | 487.90 | 7175.02 | 1.157 |
| 76.43667 | 84.265 | 0 | 0 | 11.9 | 438.44 | 6138.21 | 0.989 |
| 76.46833 | 83.41833 | 0 | 0 | 11.1 | 379.97 | 4961.93 | 0.800 |
| 76.49167 | 82.71333 | 0 | 0 | 11.2 | 386.89 | 5097.83 | 0.822 |

| | | Vessel X | | |
|---|---|---|---|---|
| Assumed Speed (knots) | Open water resistance (kN) | Broken ice resistance (kN) | Ship power (kW) | FOM (ton/h) |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |

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| 10 | | 774.6 | 6,947 | 1.12 |
| 10 | | 776.5 | 6,972 | 1.12 |
| 10 | | 787.1 | 7,116 | 1.15 |
| 10 | | 994.7 | 10,109 | 1.63 |
| 10 | | 1728.6 | 23,159 | 3.73 |
| 10 | | 1522.6 | 19,144 | 3.09 |

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| 10 | | 1456.5 | 17,911 | 2.89 |
| 10 | | 1369.1 | 16,322 | 2.63 |
| 10 | | 783.1 | 7,062 | 1.14 |
| 10 | | 832.4 | 7,739 | 1.25 |
| 10 | | 814.5 | 7,490 | 1.21 |
| 10 | | 782.4 | 7,051 | 1.14 |
| 10 | | 774.6 | 6,947 | 1.12 |
| 20 | 1185.8 | | 14,353 | 2.3 |
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| 20 | 1185.8 | 14,353 | 2.3 |

Fuel consumption for Scenario III

| Latitude | Longitude | Ice concentration (%) | Ice thickness (m) | Assumed Speed (knots) | Vessel Y Open water resistance (kN) | Brash ice resistance (kN) | Ship power (kW) | FOM (ton/h) |
|---|---|---|---|---|---|---|---|---|
| 64.85333 | -176.598 | 0 | 0 | 11.4 | 400.96 | | 5377.60 | 0.868 |
| 64.85667 | -176.518 | 0 | 0 | 11.5 | 408.19 | | 5522.61 | 0.892 |
| 64.755 | -176.152 | 0 | 0 | 13.4 | 573.47 | | 9040.59 | 1.460 |
| 64.62833 | -175.715 | 0 | 0 | 14 | 635.70 | | 10470.42 | 1.691 |
| 64.495 | -175.263 | 0 | 0 | 14.1 | 647.42 | | 10739.61 | 1.734 |
| 64.36167 | -174.843 | 0 | 0 | 13.6 | 594.44 | | 9511.07 | 1.536 |
| 64.23833 | -174.443 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.219 |
| 64.11833 | -174.017 | 0 | 0 | 13.1 | 541.92 | | 8351.90 | 1.349 |
| 64.04667 | -173.738 | 0 | 0 | 13.5 | 584.09 | | 9276.75 | 1.498 |
| 64.07667 | -173.568 | 0 | 0 | 14.1 | 647.42 | | 10739.61 | 1.734 |
| 64.16167 | -173.06 | 0 | 0 | 14.7 | 730.93 | | 12640.86 | 2.041 |
| 64.26333 | -172.52 | 0 | 0 | 15 | 767.50 | | 13544.07 | 2.187 |
| 64.35167 | -172.04 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.219 |
| 64.52333 | -171.767 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.219 |
| 64.69833 | -171.485 | 0 | 0 | 12.9 | 522.95 | | 7936.48 | 1.282 |
| 64.88167 | -171.195 | 0 | 0 | 13.2 | 552.14 | | 8574.44 | 1.385 |
| 65.065 | -170.903 | 0 | 0 | 12.4 | 479.15 | | 6990.00 | 1.129 |
| 65.295 | -170.642 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.219 |
| 65.39333 | -170.368 | 0 | 0 | 11.6 | 415.60 | | 5671.66 | 0.916 |
| 65.56167 | -170.093 | 0 | 0 | 11.1 | 379.97 | | 4961.93 | 0.801 |
| 65.71167 | -169.848 | 0 | 0 | 11.7 | 423.14 | | 5824.45 | 0.941 |
| 65.88 | -169.583 | 0 | 0 | 12.3 | 470.53 | | 6808.84 | 1.100 |
| 66 | -169.385 | 0 | 0 | 11.6 | 415.60 | | 5671.66 | 0.916 |
| 66.05667 | -169.385 | 0 | 0 | 11.3 | 393.88 | | 5236.24 | 0.846 |
| 66.16833 | -169.395 | 0 | 0 | 10.7 | 353.24 | | 4446.64 | 0.718 |
| 66.225 | -169.48 | 0 | 0 | 11.8 | 430.77 | | 5980.16 | 0.966 |
| 66.39333 | -169.785 | 0 | 0 | 12.8 | 514.06 | | 7741.16 | 1.250 |
| 66.56333 | -170.065 | 0 | 0 | 12.6 | 496.65 | | 7362.12 | 1.189 |
| 66.74333 | -170.362 | 0 | 0 | 12.8 | 514.06 | | 7741.16 | 1.250 |
| 66.92833 | -170.678 | 0 | 0 | 12.7 | 505.35 | | 7550.52 | 1.219 |
| 67.095 | -170.973 | 0 | 0 | 12.6 | 496.65 | | 7362.12 | 1.189 |
| 67.26667 | -171.27 | 0 | 0 | 12.5 | 487.90 | | 7175.02 | 1.159 |
| 67.61 | -171.883 | 0 | 0 | 12.5 | 487.90 | | 7175.02 | 1.159 |
| 67.78667 | -172.205 | 0 | 0 | 12.5 | 487.90 | | 7175.02 | 1.159 |
| 67.95167 | -172.497 | 0 | 0 | 12.3 | 470.53 | | 6808.84 | 1.100 |
| 68.125 | -172.825 | 0 | 0 | 12.1 | 454.04 | | 6463.40 | 1.044 |
| 68.20833 | -173.302 | 0 | 0 | 11.9 | 438.44 | | 6138.21 | 0.991 |
| 68.28667 | -173.787 | 0 | 0 | 11.7 | 423.14 | | 5824.45 | 0.941 |
| 68.36333 | -174.263 | 0 | 0 | 12 | 446.17 | | 6298.89 | 1.017 |
| 68.44333 | -174.763 | 0 | 0 | 11.7 | 423.14 | | 5824.45 | 0.941 |
| 68.52333 | -175.258 | 0 | 0 | 11.4 | 400.96 | | 5377.60 | 0.868 |
| 68.595 | -175.718 | 0 | 0 | 10.8 | 359.76 | | 4571.05 | 0.738 |
| 68.67 | -176.183 | 0 | 0 | 11.7 | 423.14 | | 5824.45 | 0.941 |
| 68.745 | -176.527 | 0 | 0 | 11.1 | 379.97 | | 4961.93 | 0.801 |
| 68.82167 | -177.138 | 0 | 0 | 11.3 | 393.88 | | 5236.24 | 0.846 |

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| 68.89333 | -177.583 | 0 | 0 | 11.2 | 386.89 | | 5097.83 | 0.823 |
| 68.965 | -178.068 | 0 | 0 | 10.3 | 327.94 | | 3973.80 | 0.642 |
| 68.98167 | -178.197 | 0 | 0 | 10.3 | 327.94 | | 3973.80 | 0.642 |
| 69.04667 | -178.637 | 0 | 0 | 11.2 | 386.89 | | 5097.83 | 0.823 |
| 69.11833 | -179.082 | 0 | 0 | 10.2 | 321.82 | | 3861.83 | 0.624 |
| 69.17667 | -179.458 | 0 | 0 | 10.8 | 359.76 | | 4571.05 | 0.738 |
| 69.27167 | -179.92 | 0 | 0 | 9.9 | 303.90 | | 3539.51 | 0.572 |
| 69.35333 | 179.6767 | 0.5362 | 0.4028 | 7.5 | | 533.94 | 3975.58 | 0.642 |
| 69.45333 | 179.19 | 0.2340 | 0.5501 | 7.5 | | 736.52 | 6440.72 | 1.040 |
| 69.525 | 178.8317 | 0.4873 | 0.3952 | 7.5 | | 523.59 | 3860.47 | 0.623 |
| 69.59833 | 178.4567 | 0.5707 | 0.3876 | 7.5 | | 513.25 | 3746.65 | 0.605 |
| 69.70333 | 177.895 | 0.5818 | 0.3807 | 7.5 | | 503.95 | 3645.32 | 0.589 |
| 69.78333 | 177.4883 | 0.7191 | 0.3861 | 7.5 | | 511.18 | 3724.04 | 0.601 |
| 69.88 | 177.0267 | 0.8138 | 0.3059 | 7.5 | | 403.47 | 2611.42 | 0.422 |
| 69.96667 | 176.5567 | 0.6661 | 0.4730 | 7.5 | | 629.88 | 5093.79 | 0.823 |
| 70.05333 | 176.0467 | 0.7987 | 0.3586 | 7.5 | | 474.07 | 3326.01 | 0.537 |
| 70.11833 | 175.6 | 0.8440 | 0.3365 | 7.5 | | 444.32 | 3017.83 | 0.487 |
| 70.18667 | 175.0983 | 0.8590 | 0.3037 | 7.5 | | 400.42 | 2581.82 | 0.417 |
| 70.26167 | 174.5917 | 0.8924 | 0.2953 | 7.5 | | 389.23 | 2474.39 | 0.400 |
| 70.345 | 174.0333 | 0.9070 | 0.2548 | 7.5 | | 335.58 | 1980.84 | 0.320 |
| 70.425 | 173.51 | 0.9314 | 0.2060 | 7.5 | | 271.34 | 1440.23 | 0.233 |
| 70.50167 | 172.94 | 0.9462 | 0.2136 | 7.5 | | 281.34 | 1520.56 | 0.246 |
| 70.585 | 172.3817 | 0.9486 | 0.2663 | 7.5 | | 350.72 | 2116.42 | 0.342 |
| 70.66667 | 171.7917 | 0.9452 | 0.3418 | 7.5 | | 451.49 | 3091.19 | 0.499 |
| 70.74667 | 171.1833 | 0.9510 | 0.2655 | 7.5 | | 349.71 | 2107.28 | 0.340 |
| 70.82833 | 170.5983 | 0.9569 | 0.2785 | 7.5 | | 366.91 | 2264.63 | 0.366 |
| 70.915 | 170.02 | 0.9618 | 0.3533 | 7.5 | | 466.88 | 3250.59 | 0.525 |
| 70.995 | 169.435 | 0.9788 | 0.3059 | 7.5 | | 403.47 | 2611.42 | 0.422 |
| 71.075 | 168.8567 | 0.9843 | 0.3342 | 7.5 | | 441.25 | 2986.59 | 0.482 |
| 71.15167 | 168.305 | 0.9767 | 0.3494 | 7.5 | | 461.75 | 3197.12 | 0.516 |
| 71.225 | 167.7433 | 0.9717 | 0.3792 | 7.5 | | 501.89 | 3622.95 | 0.585 |
| 71.30833 | 167.1683 | 0.9746 | 0.4959 | 7.5 | | 661.41 | 5481.05 | 0.885 |
| 71.38667 | 166.5683 | 0.9638 | 0.5158 | 7.5 | | 688.84 | 5825.49 | 0.941 |
| 71.46333 | 166.0183 | 0.9528 | 0.5478 | 7.5 | | 733.34 | 6398.96 | 1.033 |
| 71.54 | 165.4483 | 0.9621 | 0.5661 | 7.5 | | 758.87 | 6736.03 | 1.088 |
| 71.61833 | 164.8717 | 0.9712 | 0.5844 | 7.5 | | 784.47 | 7079.83 | 1.143 |
| 71.69667 | 164.295 | 0.9729 | 0.5615 | 7.5 | | 752.48 | 6651.13 | 1.074 |
| 71.775 | 163.7083 | 0.9730 | 0.5028 | 7.5 | | 670.90 | 5599.35 | 0.904 |
| 71.85167 | 163.12 | 0.9712 | 0.5036 | 7.5 | | 671.95 | 5612.56 | 0.906 |
| 71.935 | 162.4883 | 0.9744 | 0.5150 | 7.5 | | 687.78 | 5812.09 | 0.939 |
| 72.005 | 161.9983 | 0.9742 | 0.5394 | 7.5 | | 721.66 | 6246.74 | 1.009 |
| 72.20167 | 161.5717 | 0.9698 | 0.5676 | 7.5 | | 761.00 | 6764.42 | 1.092 |
| 72.36667 | 161.2167 | 0.9567 | 0.5753 | 7.5 | | 771.66 | 6907.09 | 1.115 |
| 72.55 | 160.8333 | 0.9531 | 0.5570 | 7.5 | | 746.09 | 6566.65 | 1.061 |
| 72.71667 | 160.465 | 0.9687 | 0.5074 | 7.5 | | 677.22 | 5678.77 | 0.917 |
| 72.895 | 160.0783 | 0.9669 | 0.4807 | 7.5 | | 640.38 | 5221.65 | 0.843 |
| 73.06333 | 159.7017 | 0.9680 | 0.5364 | 7.5 | | 717.42 | 6191.74 | 1.000 |
| 73.24667 | 159.3167 | 0.9835 | 0.5791 | 7.5 | | 777.00 | 6978.86 | 1.127 |
| 73.42667 | 158.895 | 0.9732 | 0.6401 | 7.5 | | 862.82 | 8166.48 | 1.319 |
| 73.60333 | 158.485 | 0.9599 | 0.6600 | 7.5 | | 890.89 | 8568.21 | 1.384 |

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| 73.78333 | 158.0767 | 0.9414 | 0.6859 | 7.5 | 927.72 | 9105.05 | 1.470 |
| 73.96833 | 157.6483 | 0.9511 | 0.7073 | 7.5 | 958.16 | 9556.87 | 1.543 |
| 74.13167 | 157.255 | 0.9534 | 0.7279 | 7.5 | 987.61 | 10000.82 | 1.615 |
| 74.48167 | 156.4117 | 0.9505 | 0.7256 | 7.5 | 984.34 | 9951.09 | 1.607 |
| 74.66167 | 155.975 | 0.9511 | 0.7302 | 7.5 | 990.89 | 10050.65 | 1.623 |
| 74.84333 | 155.53 | 0.9490 | 0.7233 | 7.5 | 981.06 | 9901.47 | 1.599 |
| 75.02667 | 155.0817 | 0.9458 | 0.6981 | 7.5 | 945.11 | 9362.16 | 1.512 |
| 75.21167 | 154.6067 | 0.9408 | 0.6767 | 7.5 | 914.70 | 8914.09 | 1.440 |
| 75.40333 | 154.1233 | 0.9486 | 0.6752 | 7.5 | 912.54 | 8882.42 | 1.435 |
| 75.6 | 153.63 | 0.9376 | 0.6600 | 7.5 | 890.89 | 8568.21 | 1.384 |
| 75.78333 | 153.1367 | 0.9116 | 0.6706 | 7.5 | 906.04 | 8787.68 | 1.419 |
| 75.82833 | 153.0167 | 0.9445 | 0.6439 | 7.5 | 868.21 | 8243.14 | 1.331 |
| 75.98333 | 151.5517 | 0.9490 | 0.6348 | 7.5 | 855.28 | 8059.64 | 1.302 |
| 76.05667 | 150.8617 | 0.9001 | 0.6401 | 7.5 | 862.82 | 8166.48 | 1.319 |
| 76.12833 | 150.185 | 0.8920 | 0.5989 | 7.5 | 804.80 | 7356.75 | 1.188 |
| 76.20167 | 149.5167 | 0.8931 | 0.5951 | 7.5 | 799.45 | 7283.47 | 1.176 |
| 76.27333 | 148.835 | 0.9179 | 0.5921 | 7.5 | 795.17 | 7225.06 | 1.167 |
| 76.345 | 148.1517 | 0.9908 | 0.6279 | 7.5 | 845.59 | 7923.08 | 1.280 |
| 76.41833 | 147.4467 | 0.9178 | 0.6508 | 7.5 | 877.92 | 8381.84 | 1.354 |
| 76.48833 | 146.7567 | 0.8984 | 0.6348 | 7.5 | 855.28 | 8059.64 | 1.302 |
| 76.56 | 146.035 | 0.8692 | 0.6844 | 7.5 | 925.55 | 9073.11 | 1.465 |
| 76.63333 | 145.325 | 0.8519 | 0.6561 | 7.5 | 885.48 | 8490.36 | 1.371 |
| 76.7 | 144.6383 | 0.8275 | 0.6401 | 7.5 | 862.82 | 8166.48 | 1.319 |
| 76.77 | 143.9217 | 0.8322 | 0.6211 | 7.5 | 835.91 | 7787.46 | 1.258 |
| 76.83667 | 143.2517 | 0.8728 | 0.5448 | 7.5 | 729.09 | 6343.44 | 1.024 |
| 76.905 | 142.5667 | 0.8708 | 0.4074 | 7.5 | 540.17 | 4045.26 | 0.653 |
| 76.90833 | 141.765 | 0.8878 | 0.4105 | 7.5 | 544.32 | 4091.96 | 0.661 |
| 76.91167 | 140.985 | 0.8810 | 0.4295 | 7.5 | 570.30 | 4388.48 | 0.709 |
| 76.91167 | 140.185 | 0.8510 | 0.4631 | 7.5 | 616.25 | 4929.39 | 0.796 |
| 76.91167 | 139.4067 | 0.7539 | 0.4547 | 7.5 | 604.74 | 4791.91 | 0.774 |
| 76.91167 | 138.6267 | 0.7155 | 0.4624 | 7.5 | 615.20 | 4916.83 | 0.794 |
| 76.91167 | 137.8667 | 0.7784 | 0.4486 | 7.5 | 596.38 | 4692.86 | 0.758 |
| 76.90833 | 137.3067 | 0.7659 | 0.4303 | 7.5 | 571.34 | 4400.51 | 0.711 |
| 76.89167 | 137.1433 | 0.7709 | 0.4112 | 7.5 | 545.35 | 4103.67 | 0.663 |
| 76.82833 | 136.4533 | 0.8366 | 0.3716 | 7.5 | 491.57 | 3511.86 | 0.567 |
| 76.765 | 135.77 | 0.8506 | 0.2922 | 7.5 | 385.17 | 2435.74 | 0.393 |
| 76.69833 | 135.075 | 0.8481 | 0.2998 | 7.5 | 395.33 | 2532.78 | 0.409 |
| 76.63167 | 134.3883 | 0.8328 | 0.3014 | 7.5 | 397.37 | 2552.36 | 0.412 |
| 76.56833 | 133.73 | 0.8264 | 0.3128 | 7.5 | 412.64 | 2700.95 | 0.436 |
| 76.50667 | 133.0883 | 0.5535 | 0.3059 | 7.5 | 403.47 | 2611.42 | 0.422 |
| 76.37833 | 131.795 | 0.8701 | 0.3433 | 7.5 | 453.54 | 3112.27 | 0.503 |
| 76.31333 | 131.1317 | 0.8884 | 0.4250 | 7.5 | 564.06 | 4316.60 | 0.697 |
| 76.25167 | 130.505 | 0.9007 | 0.4700 | 7.5 | 625.68 | 5042.98 | 0.814 |
| 76.19333 | 129.9083 | 0.8856 | 0.4921 | 7.5 | 656.15 | 5415.74 | 0.875 |
| 76.13 | 129.3083 | 0.8394 | 0.5371 | 7.5 | 718.48 | 6205.48 | 1.002 |
| 76.06667 | 128.72 | 0.8361 | 0.5531 | 7.5 | 740.77 | 6496.57 | 1.049 |
| 76.00833 | 128.14 | 0.8491 | 0.5432 | 7.5 | 726.96 | 6315.76 | 1.020 |
| 76.00333 | 127.995 | 0.8372 | 0.5165 | 7.5 | 689.90 | 5838.90 | 0.943 |
| 76.06 | 127.57 | 0.7619 | 0.4341 | 7.5 | 576.55 | 4460.82 | 0.720 |
| 76.11667 | 126.6717 | 0.7727 | 0.3914 | 7.5 | 518.42 | 3803.40 | 0.614 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 76.19 | 126.0617 | 0.8202 | 0.4151 | 7.5 | 550.54 | 4162.41 | 0.672 |
| 76.245 | 125.0567 | 0.8525 | 0.4479 | 7.5 | 595.33 | 4680.54 | 0.756 |
| 76.29667 | 124.765 | 0.8671 | 0.4257 | 7.5 | 565.10 | 4328.55 | 0.699 |
| 76.36167 | 124.0617 | 0.8861 | 0.3166 | 7.5 | 417.74 | 2751.17 | 0.444 |
| 76.44 | 123.2117 | 0.9046 | 0.2533 | 7.5 | 333.56 | 1963.02 | 0.317 |
| 76.50333 | 122.5033 | 0.8932 | 0.3250 | 7.5 | 428.97 | 2862.86 | 0.462 |
| 76.56167 | 121.8567 | 0.8810 | 0.3212 | 7.5 | 423.87 | 2811.89 | 0.454 |
| 76.64667 | 120.915 | 0.8621 | 0.3044 | 7.5 | 401.44 | 2591.67 | 0.419 |
| 76.705 | 120.2117 | 0.8755 | 0.2602 | 7.5 | 342.64 | 2043.70 | 0.330 |
| 76.76 | 119.54 | 0.8724 | 0.2823 | 7.5 | 371.98 | 2311.70 | 0.373 |
| 76.81667 | 118.885 | 0.8699 | 0.2754 | 7.5 | 362.86 | 2227.23 | 0.360 |
| 76.87667 | 118.2233 | 0.8652 | 0.2747 | 7.5 | 361.85 | 2217.92 | 0.358 |
| 76.93833 | 117.5433 | 0.8652 | 0.3479 | 7.5 | 459.69 | 3175.83 | 0.513 |
| 77 | 116.82 | 0.9092 | 0.2945 | 7.5 | 388.22 | 2464.71 | 0.398 |
| 77.03167 | 116.465 | 0.9053 | 0.2876 | 7.5 | 379.08 | 2378.20 | 0.384 |
| 77.09333 | 115.965 | 0.8819 | 0.3349 | 7.5 | 442.27 | 2996.99 | 0.484 |
| 77.15333 | 115.1367 | 0.8548 | 0.4082 | 7.5 | 541.20 | 4056.91 | 0.655 |
| 77.18 | 114.8417 | 0.8507 | 0.4143 | 7.5 | 549.51 | 4150.63 | 0.670 |
| 77.255 | 114.5617 | 0.8251 | 0.4311 | 7.5 | 572.39 | 4412.55 | 0.713 |
| 77.39 | 114.0467 | 0.8108 | 0.3990 | 7.5 | 528.76 | 3917.86 | 0.633 |
| 77.52167 | 113.5767 | 0.8357 | 0.4051 | 7.5 | 537.05 | 4010.36 | 0.648 |
| 77.60167 | 113.3917 | 0.8644 | 0.3807 | 7.5 | 503.95 | 3645.32 | 0.589 |
| 77.77333 | 113.4833 | 0.9022 | 0.3937 | 7.5 | 521.52 | 3837.61 | 0.620 |
| 77.87667 | 112.9833 | 0.9443 | 0.4692 | 7.5 | 624.63 | 5030.31 | 0.812 |
| 77.85 | 112.14 | 0.9324 | 0.4753 | 7.5 | 633.03 | 5132.02 | 0.829 |
| 77.77667 | 111.235 | 0.9369 | 0.5242 | 7.5 | 700.47 | 5973.65 | 0.965 |
| 77.69667 | 110.3283 | 0.9296 | 0.5478 | 7.5 | 733.34 | 6398.96 | 1.033 |
| 77.58333 | 109.46 | 0.9072 | 0.5562 | 7.5 | 745.03 | 6552.61 | 1.058 |
| 77.53 | 109.1167 | 0.8785 | 0.5768 | 0 | 411.32 | 2687.99 | 0.434 |
| 77.49833 | 108.915 | 0.8738 | 0.5654 | 0 | 402.52 | 2602.17 | 0.420 |
| 77.465 | 108.695 | 0.8678 | 0.5646 | 0 | 401.93 | 2596.50 | 0.419 |
| 77.46833 | 108.61 | 0.8656 | 0.5654 | 0 | 402.52 | 2602.17 | 0.420 |
| 77.47167 | 108.585 | 0.8656 | 0.5654 | 0 | 402.52 | 2602.17 | 0.420 |
| 77.465 | 108.705 | 0.8678 | 0.5646 | 0 | 401.93 | 2596.50 | 0.419 |
| 77.455 | 108.6167 | 0.8240 | 0.5547 | 0 | 394.33 | 2523.18 | 0.407 |
| 77.46333 | 108.6167 | 0.8656 | 0.5654 | 0 | 402.52 | 2602.17 | 0.420 |
| 77.47 | 108.6483 | 0.8678 | 0.5646 | 0 | 401.93 | 2596.50 | 0.419 |
| 77.47167 | 108.8017 | 0.8704 | 0.5654 | 0 | 402.52 | 2602.17 | 0.420 |
| 77.47 | 108.7183 | 0.8700 | 0.5654 | 0 | 402.52 | 2602.17 | 0.420 |
| 77.44167 | 108.6567 | 0.8269 | 0.5562 | 7.5 | 745.03 | 6552.61 | 1.058 |
| 77.46667 | 108.0483 | 0.8787 | 0.5722 | 7.5 | 767.39 | 6849.88 | 1.106 |
| 77.53667 | 107.4217 | 0.7581 | 0.5242 | 7.5 | 700.47 | 5973.65 | 0.965 |
| 77.615 | 106.1333 | 0.8872 | 0.5692 | 7.5 | 763.13 | 6792.86 | 1.097 |
| 77.70667 | 105.445 | 0.9426 | 0.6165 | 7.5 | 829.47 | 7697.55 | 1.243 |
| 77.75167 | 104.5917 | 0.9452 | 0.6050 | 7.5 | 813.37 | 7474.60 | 1.207 |
| 77.73 | 103.8 | 0.8860 | 0.6241 | 7.5 | 840.21 | 7847.62 | 1.267 |
| 77.645 | 103.0383 | 0.8819 | 0.6203 | 7.5 | 834.84 | 7772.44 | 1.255 |
| 77.51667 | 102.3633 | 0.7942 | 0.6684 | 7.5 | 902.79 | 8740.47 | 1.412 |
| 77.36 | 101.81 | 0.6867 | 0.6890 | 7.5 | 932.06 | 9169.06 | 1.481 |
| 77.21833 | 101.1633 | 0.8576 | 0.6104 | 7.5 | 820.88 | 7578.33 | 1.224 |

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|---|---|---|---|---|---|---|---|
| 77.10667 | 100.38 | 0.8671 | 0.6058 | 7.5 | 814.44 | 7489.39 | 1.210 |
| 76.985 | 99.67 | 0.8966 | 0.5379 | 7.5 | 719.54 | 6219.22 | 1.004 |
| 76.83833 | 99.00833 | 0.8780 | 0.5356 | 7.5 | 716.36 | 6178.02 | 0.998 |
| 76.555 | 97.80833 | 0.8237 | 0.5760 | 7.5 | 772.73 | 6921.42 | 1.118 |
| 76.51833 | 97.02 | 0.7620 | 0.5417 | 7.5 | 724.84 | 6288.11 | 1.016 |
| 76.49 | 96.195 | 0.5609 | 0.5623 | 7.5 | 753.54 | 6665.25 | 1.076 |
| 76.375 | 95.40833 | 0.6636 | 0.5829 | 7.5 | 782.34 | 7050.92 | 1.139 |
| 76.27 | 93.91333 | 0.8488 | 0.5028 | 7.5 | 670.90 | 5599.35 | 0.904 |
| 76.23833 | 93.12667 | 0.8541 | 0.4952 | 7.5 | 660.36 | 5467.96 | 0.883 |
| 76.20833 | 92.29833 | 0.8431 | 0.4845 | 7.5 | 645.63 | 5286.05 | 0.854 |
| 76.18833 | 91.46 | 0.7919 | 0.4944 | 7.5 | 659.31 | 5454.89 | 0.881 |
| 76.16333 | 90.58167 | 0.6998 | 0.5196 | 7.5 | 694.12 | 5892.66 | 0.952 |
| 76.16333 | 90.33167 | 0.6798 | 0.5440 | 7.5 | 728.03 | 6329.59 | 1.022 |
| 76.18667 | 89.71333 | 0.6087 | 0.5165 | 7.5 | 689.90 | 5838.90 | 0.943 |
| 76.22833 | 88.85167 | 0.7134 | 0.5631 | 7.5 | 754.61 | 6679.38 | 1.079 |
| 76.27167 | 87.95667 | 0.7050 | 0.5531 | 7.5 | 740.77 | 6496.57 | 1.049 |
| 76.315 | 87.05167 | 0.7286 | 0.5623 | 7.5 | 753.54 | 6665.25 | 1.076 |
| 76.35667 | 86.15 | 0.7588 | 0.5570 | 7.5 | 746.09 | 6566.65 | 1.061 |
| 76.405 | 85.14833 | 0.7450 | 0.5417 | 7.5 | 724.84 | 6288.11 | 1.016 |
| 76.43667 | 84.265 | 0.8676 | 0.5486 | 7.5 | 734.40 | 6412.87 | 1.036 |
| 76.46833 | 83.41833 | 0.8850 | 0.5478 | 7.5 | 733.34 | 6398.96 | 1.033 |
| 76.49167 | 82.71333 | 0.8941 | 0.5242 | 7.5 | 700.47 | 5973.65 | 0.965 |

Vessel X

| Assumed Speed (knots) | Open water resistance (kN) | Brash ice resistance (kN) | Ship power (kW) | FOM (ton/h) |
|---|---|---|---|---|
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |

| | | | | |
|---|---|---|---|---|
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 20 | 1185.8 | | 14,353 | 2.3 |
| 10 | | 730.84 | 6,366 | 1.47 |
| 10 | | 1005.39 | 10,272 | 2.37 |
| 10 | | 716.76 | 6,183 | 1.42 |
| 10 | | 702.69 | 6,002 | 1.38 |
| 10 | | 690.03 | 5,841 | 1.35 |
| 10 | | 699.87 | 5,966 | 1.37 |
| 10 | | 553.01 | 4,190 | 0.96 |
| 10 | | 861.09 | 8,142 | 1.87 |
| 10 | | 649.34 | 5,332 | 1.23 |
| 10 | | 608.77 | 4,840 | 1.11 |
| 10 | | 548.84 | 4,143 | 0.95 |
| 10 | | 533.55 | 3,971 | 0.91 |
| 10 | | 460.13 | 3,180 | 0.73 |
| 10 | | 372.03 | 2,312 | 0.53 |
| 10 | | 385.76 | 2,441 | 0.56 |
| 10 | | 480.87 | 3,398 | 0.78 |
| 10 | | 618.55 | 4,957 | 1.14 |
| 10 | | 479.49 | 3,383 | 0.78 |
| 10 | | 503.03 | 3,635 | 0.84 |
| 10 | | 639.54 | 5,211 | 1.20 |
| 10 | | 553.01 | 4,190 | 0.96 |
| 10 | | 604.58 | 4,790 | 1.10 |
| 10 | | 632.54 | 5,126 | 1.18 |
| 10 | | 687.22 | 5,805 | 1.34 |
| 10 | | 903.81 | 8,755 | 2.02 |
| 10 | | 940.93 | 9,300 | 2.14 |
| 10 | | 1001.09 | 10,206 | 2.35 |
| 10 | | 1035.57 | 10,738 | 2.47 |
| 10 | | 1070.13 | 11,280 | 2.60 |
| 10 | | 1026.94 | 10,604 | 2.44 |
| 10 | | 916.65 | 8,942 | 2.06 |
| 10 | | 918.07 | 8,963 | 2.06 |
| 10 | | 939.50 | 9,279 | 2.14 |
| 10 | | 985.31 | 9,966 | 2.29 |
| 10 | | 1038.45 | 10,783 | 2.48 |
| 10 | | 1052.84 | 11,008 | 2.53 |
| 10 | | 1018.32 | 10,471 | 2.41 |
| 10 | | 925.21 | 9,068 | 2.09 |
| 10 | | 875.31 | 8,344 | 1.92 |
| 10 | | 979.58 | 9,879 | 2.27 |
| 10 | | 1060.04 | 11,121 | 2.56 |
| 10 | | 1175.69 | 12,990 | 2.99 |
| 10 | | 1213.46 | 13,621 | 3.14 |

| | | | |
|---|---|---|---|
| 10 | 1262.97 | 14,463 | 3.33 |
| 10 | 1303.86 | 15,171 | 3.49 |
| 10 | 1343.37 | 15,865 | 3.65 |
| 10 | 1338.98 | 15,788 | 3.64 |
| 10 | 1347.77 | 15,943 | 3.67 |
| 10 | 1334.58 | 15,710 | 3.62 |
| 10 | 1286.32 | 14,866 | 3.42 |
| 10 | 1245.48 | 14,163 | 3.26 |
| 10 | 1242.57 | 14,114 | 3.25 |
| 10 | 1213.46 | 13,621 | 3.14 |
| 10 | 1233.83 | 13,965 | 3.22 |
| 10 | 1182.95 | 13,110 | 3.02 |
| 10 | 1165.54 | 12,822 | 2.95 |
| 10 | 1175.69 | 12,990 | 2.99 |
| 10 | 1097.54 | 11,716 | 2.70 |
| 10 | 1090.32 | 11,601 | 2.67 |
| 10 | 1084.55 | 11,509 | 2.65 |
| 10 | 1152.50 | 12,607 | 2.90 |
| 10 | 1196.02 | 13,328 | 3.07 |
| 10 | 1165.54 | 12,822 | 2.95 |
| 10 | 1260.06 | 14,413 | 3.32 |
| 10 | 1206.19 | 13,498 | 3.11 |
| 10 | 1175.69 | 12,990 | 2.99 |
| 10 | 1139.46 | 12,394 | 2.85 |
| 10 | 995.35 | 10,119 | 2.33 |
| 10 | 739.30 | 6,477 | 1.49 |
| 10 | 744.94 | 6,552 | 1.51 |
| 10 | 780.25 | 7,023 | 1.62 |
| 10 | 842.61 | 7,881 | 1.81 |
| 10 | 827.00 | 7,663 | 1.76 |
| 10 | 841.19 | 7,861 | 1.81 |
| 10 | 815.65 | 7,506 | 1.73 |
| 10 | 781.67 | 7,042 | 1.62 |
| 10 | 746.35 | 6,570 | 1.51 |
| 10 | 673.18 | 5,628 | 1.30 |
| 10 | 527.99 | 3,909 | 0.90 |
| 10 | 541.89 | 4,065 | 0.94 |
| 10 | 544.67 | 4,096 | 0.94 |
| 10 | 565.54 | 4,334 | 1.00 |
| 10 | 553.01 | 4,190 | 0.96 |
| 10 | 621.35 | 4,991 | 1.15 |
| 10 | 771.77 | 6,909 | 1.59 |
| 10 | 855.40 | 8,061 | 1.86 |
| 10 | 896.68 | 8,652 | 1.99 |
| 10 | 981.01 | 9,901 | 2.28 |
| 10 | 1011.14 | 10,360 | 2.39 |
| 10 | 992.48 | 10,075 | 2.32 |
| 10 | 942.36 | 9,321 | 2.15 |
| 10 | 788.74 | 7,138 | 1.64 |
| 10 | 709.72 | 6,092 | 1.40 |

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|---|---|---|---|
| 10 | 753.41 | 6,664 | 1.53 |
| 10 | 814.23 | 7,487 | 1.72 |
| 10 | 773.19 | 6,928 | 1.60 |
| 10 | 572.50 | 4,414 | 1.02 |
| 10 | 457.37 | 3,152 | 0.73 |
| 10 | 587.83 | 4,592 | 1.06 |
| 10 | 580.86 | 4,511 | 1.04 |
| 10 | 550.23 | 4,159 | 0.96 |
| 10 | 469.81 | 3,281 | 0.76 |
| 10 | 509.96 | 3,711 | 0.85 |
| 10 | 497.48 | 3,575 | 0.82 |
| 10 | 496.10 | 3,560 | 0.82 |
| 10 | 629.74 | 5,092 | 1.17 |
| 10 | 532.16 | 3,956 | 0.91 |
| 10 | 519.67 | 3,817 | 0.88 |
| 10 | 605.98 | 4,807 | 1.11 |
| 10 | 740.71 | 6,496 | 1.50 |
| 10 | 752.00 | 6,645 | 1.53 |
| 10 | 783.08 | 7,061 | 1.63 |
| 10 | 723.80 | 6,275 | 1.44 |
| 10 | 735.07 | 6,422 | 1.48 |
| 10 | 690.03 | 5,841 | 1.35 |
| 10 | 713.94 | 6,147 | 1.42 |
| 10 | 853.98 | 8,041 | 1.85 |
| 10 | 865.35 | 8,202 | 1.89 |
| 10 | 956.66 | 9,534 | 2.20 |
| 10 | 1001.09 | 10,206 | 2.35 |
| 10 | 1016.88 | 10,449 | 2.41 |
| 0 | 411.32 | 2,688 | 0.62 |
| 0 | 402.52 | 2,602 | 0.60 |
| 0 | 401.93 | 2,596 | 0.60 |
| 0 | 402.52 | 2,602 | 0.60 |
| 0 | 402.52 | 2,602 | 0.60 |
| 0 | 401.93 | 2,596 | 0.60 |
| 0 | 394.33 | 2,523 | 0.58 |
| 0 | 402.52 | 2,602 | 0.60 |
| 0 | 401.93 | 2,596 | 0.60 |
| 0 | 402.52 | 2,602 | 0.60 |
| 0 | 402.52 | 2,602 | 0.60 |
| 10 | 1016.88 | 10,449 | 2.41 |
| 10 | 1047.08 | 10,918 | 2.51 |
| 10 | 956.66 | 9,534 | 2.20 |
| 10 | 1041.32 | 10,828 | 2.49 |
| 10 | 1130.78 | 12,252 | 2.82 |
| 10 | 1109.09 | 11,902 | 2.74 |
| 10 | 1145.26 | 12,488 | 2.88 |
| 10 | 1138.02 | 12,370 | 2.85 |
| 10 | 1229.46 | 13,891 | 3.20 |
| 10 | 1268.81 | 14,563 | 3.35 |
| 10 | 1119.21 | 12,065 | 2.78 |

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|---|---|---|---|
| 10 | 1110.54 | 11,925 | 2.75 |
| 10 | 982.44 | 9,922 | 2.28 |
| 10 | 978.14 | 9,857 | 2.27 |
| 10 | 1054.28 | 11,030 | 2.54 |
| 10 | 989.61 | 10,031 | 2.31 |
| 10 | 1028.38 | 10,626 | 2.45 |
| 10 | 1067.24 | 11,234 | 2.59 |
| 10 | 916.65 | 8,942 | 2.06 |
| 10 | 902.38 | 8,735 | 2.01 |
| 10 | 882.43 | 8,446 | 1.95 |
| 10 | 900.96 | 8,714 | 2.01 |
| 10 | 948.08 | 9,406 | 2.17 |
| 10 | 993.91 | 10,097 | 2.33 |
| 10 | 942.36 | 9,321 | 2.15 |
| 10 | 1029.82 | 10,649 | 2.45 |
| 10 | 1011.14 | 10,360 | 2.39 |
| 10 | 1028.38 | 10,626 | 2.45 |
| 10 | 1018.32 | 10,471 | 2.41 |
| 10 | 989.61 | 10,031 | 2.31 |
| 10 | 1002.52 | 10,228 | 2.36 |
| 10 | 1001.09 | 10,206 | 2.35 |
| 10 | 956.66 | 9,534 | 2.20 |

**Appendix-E: Interview Questions - Survey**

**Introduction**
We are Van and Miltiadis from Chalmers University. Thank you again for participating in this interview. The aim of this interview is to gather your view on feasibility of commercial shipping in the Northern Sea Route (NSR) as we had already discussed previously via email. The interview will take about 30 minutes and covers six opened-ended questions. We are solely interested in your views and you can answer the questions from any angle of your preference. For the purpose of analysing this interview we would like to have your permission to audio record this interview. Is it ok for you? Everything you share with us will be treated confidentially and te transcript of this interview will be anonymized.

**Interview 1: Representative from Insurance company**

1. In your opinion, how much are insurance companies interested in the niche market of the NSR shipping if you have to range from 1 as the least interest to 5 as the most interest?
2. In the survey question number 8 about "The biggest challenges for the shipping companies to use the NSR", you answered [XXXX], can you elaborate why do you think [XXXX] are the considerable challenges? Besides these challenges, do you see any others?
3. What are the criteria for estimating insurance premium (P&I, H&M) for the vessels navigating in the Arctic water? In other words, how do insurance company assess the risks in this case?
4. What are the differences between the Arctic insurance costs than that of conventional ones?
5. Have your company or other companies you know that encountered accidents in Arctic waters? In case of accidents, is there any specific SAR plan?
6. Would you propose any possible ways to reduce insurance costs for vessels sailing along the NSR?

**Interview 2: Representative from Port Authority**

1. In your opinion, how much are your organization and ports in the northern hemisphere in general interested in the niche market of the NSR shipping?
2. What do you see about the benefits of your organization in taking part in the network of Arctic shipping?
3. In the survey question number 8 about "The biggest challenges for the shipping companies to use the NSR", you answered [XXXX], can you elaborate more? Besides these challenges, do you see any others? Maybe, are you willing to propose compelling suggestions to make your organization more attractive to shipping companies?
4. In survey question 10, you answered that [XXXX types of cargo/ vessels] would be potential for the NSR trading, why do you think so?
5. What factors can make the NSR more competitive? Does your organization have any expectation about the development of the NSR as an alternative compared to the SCR?
6. Is there any obstacle for your organization to further engage in the NSR business activities? (e.x infrastructure for ice-class vessels, extra investment, etc). What would be useful strategic collaboration to increase the port income thanks to the NSR?

**Interview 3: Representative from Shipping Companies**

1. In your opinion, how much are your company and other shipping companies in general interested in the NSR shipping?
2. Based on the answer on survey question 7 "What is (are) the benefit(s) of the NSR for the shipping companies", can you elaborate more on how does the NSR benefit your shipping company?
3. Why do you think [XXX cargo/vessel type – answered in question 10] would be the most economically feasible to trade through the NSR?
4. In the survey question number 8 about "The biggest challenges for the shipping companies to use the NSR", you answered [XXXX], can you elaborate more? Besides these challenges, do you see any others (environmental risk, SAR)?
5. You answered that [XXXX-name of the cost] is influent the most for the shipping companies when using the NSR, can you explain why? Have you considered alternatives to reduce costs when navigating on the NSR?

Follow-up question: Is the initial investment for ice-class vessels constraint the shipping companies join the market? How much different of capital cost between ice class vessels and non-ice class ones in the same category?

6. What do you think about the future development of the NSR? Can you share your company's perspective about the future initiative if any?

**Closing the interview**

Thank you very much for participating in this interview. After the analyzing procedure, we would send you a copy of the "Interview Output" to ensure that we interpret your answers correctly. When we have finalized our thesis, and if you would like to receive a copy, we are happy to send you via email. Your contribution is greatly important to our work. We really appreciate that. Thank you!

# The Northern Sea Route

Dear respondents,

We are Van and Miltiadis, students from Mechanics and Maritime Sciences Department of Chalmers University in Gothenburg, Sweden.

We are conducting the Master's thesis with the topic "Feasibility study on commercial shipping in the Northern Sea Route".

*Required

1. **Email address** *

## About the research

During the last decades, global warming has led to the melting of the ice in the Arctic region. Therefore, the Northern Sea Route (NSR) has emerged as a compelling alternative due to its reduced distance; approximately 40% compared to the Suez Canal Route (SCR).

However, besides the possible benefits, there are a number of challenges affecting the viability of the Arctic shipping. The aim of this questionnaire is to gather your view, based on your experience and expertise, on the feasibility of using the NSR for commercial vessels.

There are 11 questions which will take you approximately 5-7 minutes.

2. **Name of your Organization** *
   (information treated anonymously)

3. **Question 1: Has your company had business relating to the NSR shipping?** *
*Mark only one oval.*

- ◯ Yes
- ◯ No
- ◯ Used to have but not anymore
- ◯ I do not know

4. **Question 2: Your organization has decent knowledge about the NSR** *
*Mark only one oval.*

- ◯ Completely Agree
- ◯ Partly Agree
- ◯ Neutral
- ◯ Partly Disagree
- ◯ Strongly Disagree
- ◯ I do not have an opinion

5. **Question 3: Does your organization has competitive advantage on sailing along the NSR or having business regarding to it?** *
*Mark only one oval.*

- ◯ Yes
- ◯ No
- ◯ I do not know

6. **Can you briefly describe how? (e.x the know-how, incentives from government, a lot of experience)** *

_______________________
_______________________
_______________________
_______________________
_______________________

7. **Question 4: The NSR has or will have commercial potential for your company?** *
*Mark only one oval.*

- ◯ Yes
- ◯ No
- ◯ Maybe
- ◯ I do not know

8. **Comments**

_______________________
_______________________
_______________________
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_______________________

9. **Question 5: “The industry discussion on the potential and the emerge of NSR as the compelling alternative of the SCR is exaggerated”. In what extend do you agree or disagree with this statement? ***

*Mark only one oval.*

- Completely Agree
- Partly Agree
- Neutral
- Partly Disagree
- Strongly Disagree
- I dont have an opinion

10. **Question 6: From your perspective, which of the following bodies strongly influences the development of the NSR? ***

*Mark only one oval.*

- The Interational Maritime Organization (IMO)
- The Arctic Council
- Russia
- Your Country
- The drive of shipping companies themselves
- Other: ______________________

11. **Question 7: What is (are) the benefit(s) of the NSR for the shipping companies? ***

You can choose up to 2 answers

*Tick all that apply.*

- Extra Earnings
- Cost Saving
- Time and distance saving
- Increase in market share as pioneer in the new route
- Research and experiment voyage
- No benefits at all

12. **Comments**

13. **Question 8: Which is (are) the biggest challenge(s) for the shipping companies to use the NSR?** *

You can choose up to 2 answers
*Tick all that apply.*

- [ ] Political Uncertainties
- [ ] Cost Challenges
- [ ] Technological challenges (ex. the ships or ports' infrastructure can not meet the requirements fot the Arctic Shipping)
- [ ] Environmental Challenges
- [ ] Legal Barriers
- [ ] Safety issues

14. **Comments** *

_______________
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_______________

15. **Question 9: In terms of cost, which cost component is the most influent for the shipping companies in using the NSR?** *

*Mark only one oval.*

- ( ) Capital Cost (e.initial investment for ice class ships)
- ( ) Operational cost (including repair and maintenance, insurance, crew training, additional equipment)
- ( ) Voyage cost ( including fuel cost, ice breaker fee, ice pilotage fee, weather forecast services)
- ( ) Other: _______________

16. **Comments** *

_______________
_______________
_______________
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_______________

17. **Question 10: What kind of cargo/ vessels is potential if the ship owner or your organization involves in the NSR?** *

You can choose more than one answer
*Tick all that apply.*

- [ ] Containers
- [ ] General Cargo, bulk cargo
- [ ] Tanker, LNG
- [ ] Ro-Ro
- [ ] Other: _______________

18. **Can you further specify the type of cargo?** *
(ex. crude oil, timbers, cars, paper pulps)

19. **Question 11: Does your organization have plan to engage more in business relating to the NSR?** *
*Mark only one oval.*

- Yes
- No
- Maybe
- I do not know

20. **Comments**

## We are done!

You've just completed all the questions in the survey. Thank you very much for your participation. Your contribution is greatly important for our thesis.

Best regards,
Van and Miltiadis