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Analysis of the economic feasibility of the future NSR transport solution

by

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Acknowledgements

It was full of twists and turns, but I have finally finished writing my Master's thesis. I am now feeling some mixed emotions of relief, joy and some panic. Thanks to the acknowledgements section, I can write a few words of my own in these serious tens of thousands of words.

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Abstract

Global warming has led to a gradual melting of the Arctic ice floes, improved navigation conditions and increased navigable time in the Arctic. At the same time, the Russian authorities are increasing their efforts to build infrastructure along the NSR and ports at both ends of the NSR. Consequently, shipping activities using the NSR have begun to increase in frequency, and the volume of NSR cargo has been increasing year on year. Although the current volume of NSR cargo is still insignificant compared to that of the SCR, the short voyage and fast sailing time of the NSR are also attractive. In recent years there has been an increase in research into the use of NSR for transport and a growing debate about whether NSR can compete with SCR. In various studies on the economic feasibility of NSR, the transport transport solutions designed and the elements selected in the cost models vary, and the conclusions obtained are therefore very different. This paper focuses on the economic feasibility of a particular NSR transport solution. It starts with a possible future operation type of the NSR and designs a transport solution using the ports of Murmansk and Petropavlovsk-Kamchatsky at both ends of the NSR as hub ports and using ice-class vessels for transshipment, offering a new possibility for future shipping between Asia and Europe. Subsequently, the cost components of the transport process were identified in three main categories, namely shipping cost, handling cost and inventory cost. The elements of each cost component are taken together and calculated to create a cost model. Costs are calculated for both NSR and SCR transport solution, and the results are analysed to measure the economic feasibility of the NSR transport solution. Finally, sensitivity analyses and scenario-specific constraints are used to identify the key factors affecting the economic feasibility of the NSR transport solution, and scenario simulations are used to provide a viable reference for the subsequent development of NSR. Overall, the key factors that have the most significant impact on the economic feasibility of this new transport solution, NSR, are fuel cost, Handling cost and load factor. When fuel prices and load factors are higher for NSR, the NSR is less costly and more economically feasible than SCR. The handling cost of loading and unloading at the two hub ports also has a critical impact on the cost structure of the NSR transport solution, and a reduction in handling cost will significantly reduce the cost of the NSR transport solution. In the scenario analysis, we focus on the study's practical implications and set up two lower sulphur modes under the IMO's sulphur limit for marine fuels, which is more suitable for the future use of NSR and gives a cost reference for the future transportation solution of NSR.

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List of Abbreviations

NSR	Northern Sea Route
SCR	Suez Canal Route
NEP	Northeast Passage
NWP	Northwest Passage
TPP	Trans Polar Passages
EEZ	Exclusive Economic Zone
INSROP	International Northern Sea Route Research Programme
ARCDEV	Arctic Demonstration and Exploratory Voyage
CHNL	Centre for High North Logistics
NSRA	Northern Sea Route Administration
IMO	International Maritime Organization
WSC	World Shipping Council
OPEC	Organization of the Petroleum Exporting Countries
P&I	Protection and Indemnity insurance
H&M	Hull & Machinery insurance
GT	Gross tonnage
LDT	Net tonnage
IFO	Intermediate Fuel Oil
VLSFO	Very Low Sulfur Fuel Oil
MGO	Marine Gas Oil

1. Introduction

The NSR is the shortest sea route between Asia and Europe. For example, the route from Northwest Europe to the Far East, London to Yokohama, is 4,200 nautical miles shorter via the NSR than the SCR (Schøyen and Bråthen, 2011). This advantage of shorter voyages can reduce ships' fuel consumption, thus significantly reducing shipping costs and providing the economic feasibility for the NSR to become an alternative route to the SCR. In addition, due to the accelerated melting of sea ice in the Arctic Ocean in recent years, the navigable time in the NSR has been extended, creating the conditions for more shipping activities in the NSR. Against this background, the number of transit voyages using the NSR has increased year on year in recent years. According to CHNL statistics, the volume of freight transported in transit along the NSR has increased from 1.281 million tonnes in 2020 to 2.027 million tonnes in 2021 (Figure 1). However, even with the year-on-year increase in freight volumes, the NSR freight volumes can still be almost negligible compared to those of the SCR. This demonstrates that the short voyage feature does not provide a significant cost advantage for the NSR under the existing route conditions and transport solution. However, these data also show that the NSR is an excellent navigable route for the current low volume of freight and that it is a route with transport potential.

In order to further develop the transport potential of the NSR and increase its influence, the Russian authorities are also responding to the current deepening demand for international economic exchange and trade. In economic cooperation, Russia has stepped up its efforts to develop energy projects in the Arctic region and actively seeks international cooperation with East Asian and Nordic countries to improve the regional economy and increase trade volumes. For example, it cooperates with China on gas projects and infrastructure development and conducts commercial transport and logistics seminars with South Korea and Norway (Milaković, 2018). In terms of waterway security, Russia has, on the one hand, strengthened its infrastructure and upgraded its port facilities; on the other hand, the Russian Ministry of Transport has deployed several maritime rescue coordination centres and search and rescue stations (SRS) along the NSR coast. The NSR Administration is also improving its ability to provide ice forecasts, hydro-meteorological information and other information to ships in transit. At the same time, Russia is accelerating the construction of more powerful icebreakers. These actions and plans aim to increase the volume of cargo at both ends of the NSR and improve shipping conditions on the NSR to achieve all-year-round navigation on the NSR in the future.

The above measures also underline the determination of the Russian authorities to develop the NSR and the inevitability of a shift in the transport solution of the NSR and a further increase in the volume of freight traffic in the future. In the light of this trend, the future development of the NSR is also being explored to create an attractive solution of logistics transport on the route. There has been no shortage of studies proposing new shipping modes for the NSR to make it an influential shipping route in recent years. However, determination and ambition are not enough, as low costs only attract shipping companies and other stakeholders. Is the NSR transport solution economically feasible? Furthermore, what factors will determine its economic feasibility? These are the key questions that will determine whether the NSR will meet the needs of inter-regional trade and whether it will be competitive enough to compete with other routes such as the SCR and the Asia-Europe Railway. These questions, however, have not been thoroughly studied, and there is still plenty of room for exploration.

This paper seeks to fill the research gap of one of the transport solutions envisaged to be implemented on the NSR, exploring its economic feasibility and the factors influencing it.

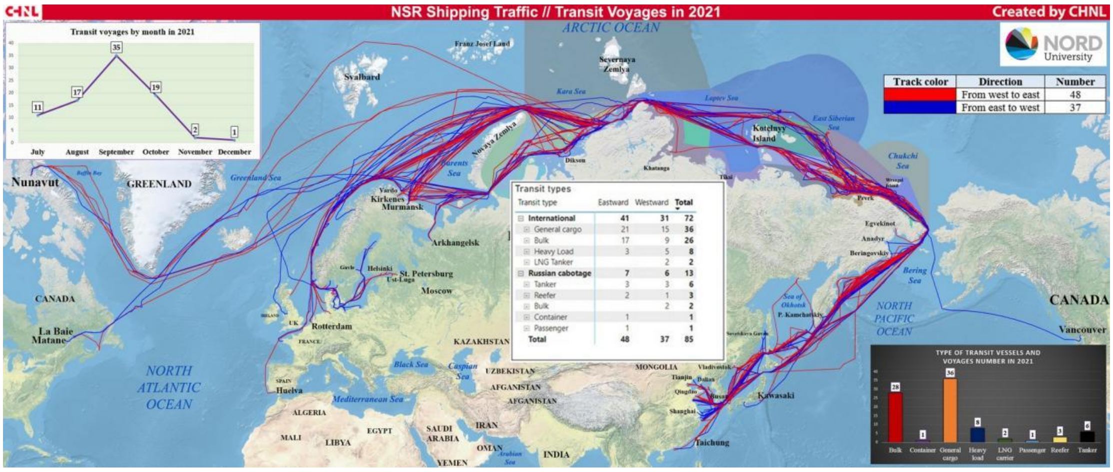

Figure 1. *NSR transit in 2021(Source: CHNL)*

1.1 Problem Identification

The NSR transport solution explored in this paper establishes transhipment hubs at the ports at each end of the NSR and transports cargo between the two transhipment hubs on ice-class vessels. Specifically, the ports of Murmansk at the western end of the NSR and Petropavlovsk-Kamchatsky at the eastern end are selected to establish transhipment hubs to receive and transfer cargo. As an example, the port of departure is Shanghai, and the destination port is Rotterdam. A large non-ice class ship with full cargo departs from the port of Shanghai. It arrives at the eastern end at Petropavlovsk-Kamchatsky, where the cargo is unloaded and transferred to an ice-class laden ship for transport along the NSR to the other end of the NSR to the port of Murmansk, where it is then transferred back to a regular ship for the destination port of Rotterdam. In this solution, the cargo is divided into three stages to complete the Asia-Europe transport, with the two stages from the port of departure to the port of transhipment and from the port of transhipment to the port of destination being non-ice class vessels sailing in conventional waters, and the NSR stage being ice-class vessels.

The advantages of this transport solution are, firstly, reduced transport costs for the shipping companies. Instead of building expensive and under-utilised ice-class vessels to sail on the NSR, shipping companies can simply transport their cargo to a transhipment hub and hand it over to the NSR ice-class fleet for delivery. This saves both the cost of building high ice-class vessels and the cost of pilotage, which is currently a consideration when transporting on the NSR. Secondly, transport time is saved. Under this transport solution, NSR vessels with high ice class can travel at higher speeds, and this 'ferrying' also makes it easier to control the timing and volume of cargo transport, even on a fixed schedule throughout the year, making it possible to use NSR for liner transport.

Of course, the conditions for the operation of this solution are also very demanding, requiring not only that the two transhipment hubs have a sufficiently strong logistics capacity of the same level to handle and transfer large volumes of cargo. It also requires that the volume of cargo at both ends of the NSR be high enough for shipping companies to use the NSR for Asia-Europe transportation to make an excellent profit to maintain the shipping route and the ice-class fleet. These conditions are not being met at present. For example, the logistics capacities of the two ports are currently not at the same level; the port of Murmansk has a capacity almost 12 times that of Petropavlovsk-Kamchatsky (MorFlot. Register of Seaports.), and the corresponding conditions of port facilities are far superior.

Russia has taken action with the aim of gradually achieving these conditions. On the one hand, the construction of the Petropavlovsk-Kamchatsky port has been stepped up, and various favourable policies have been introduced to attract investment; on the other hand, the construction of an LNG terminal at the port of Murmansk has been started to coincide with the 'Yamal-LNG' project and the 'Arctic LNG-2' project to deliver LNG via NSR and stimulate the use of NSR (Figure 2). It is foreseeable that in the future, with further construction of ports and further development of energy projects in the Arctic, this transport solution will gain more scope and is expected to become a reality.

This paper will discuss the costs of NSR transport solution when the external hardware conditions are met, and the internal operations are mature and explore the key factors affecting the economic feasibility of this transport solution.

Figure 2. *LNG transportation along NSR (Source: NSRA)*

1.2 Research Objectives

The purpose of this study is to discuss a promising future solution of NSR transport. We investigate how this solution could provide transportation for Asia-Europe cargo when the conditions are right and whether this transport solution could effectively reduce shipping transportation costs between Asia and Europe. In the future, will this solution be attractive enough to gain the favour of shipping companies as a complementary route to SCR or even compete with it?

Therefore, the main research question this study aims to address is the following:

What are the key factors affecting the economic feasibility of the new NSR transport solution?

The idea behind this question is that if the NSR is to be fully utilised in this new transport solution when external conditions are right, it needs to be economically competitive and able to attract enough users to use it. Therefore, it is essential to identify which factors are influencing its economic viability so that it can be optimised in a targeted manner to achieve a larger scale of operation.

To answer the research question, several sub-questions must be answered:

- How can the economic feasibility of NSR new transport solution be measured?
- How can the impact of different factors on economic feasibility be clarified?

1.3 Research Design and Methodology

This paper uses quantitative and qualitative approaches to address the research questions and draw conclusions. Firstly, it qualitatively reviews and analyses the relevant literature, analyses and summarises the limitations and reasons for the current NSR shipping activities, identifies the hardware conditions that may be required for the future NSR and looks forward to the shipping activities of the NSR, under the new transport solution. Then, in order to illustrate the economic feasibility of the new transport solution, the shipping parameters and logistics parameters are selected regarding the relevant theories and studies on ship operating costs, and a cost model is developed for the new NSR transport solution, which is used to measure its economic feasibility. Further, to explore the impact of different factors on the new NSR transport solution, this study will set up different scenarios and assume different conditions to obtain different results by changing the corresponding variables in the cost model. Finally, the results and data will be analysed to clarify how different factors affect the economic feasibility to obtain the key factors affecting the economic feasibility of the new NSR transport solution.

1.4 Thesis Structure

Chapter 2 provides an extensive review and analysis of NSR shipping and shipping cost modelling research. Chapter 3 selects the cost parameters required for shipping and logistics activities to build the cost model. Chapter 4 uses the developed cost model to set up different scenarios, perform different experiments and vary the corresponding parameters for cost calculations. Chapter 5 reports in detail on the results obtained and analyses the data results. Chapter 6 summarises the study's findings, draws conclusions and provides further insight into the future development of NSR.

2. Literature Review

In order to answer the research questions of this paper, a review and overview of the relevant literature are presented in this chapter. The research in this paper is concerned with two main aspects: the design of a possible future transport solution for NSR and, on the other hand, the economic feasibility of such a solution. Therefore, in reviewing the past literature, firstly, a review of the relevant literature examining the past as well as the present economic aspects of NSR is collated using the keywords 'NSR' and 'economic feasibility' to analyse the current economic performance of NSR The literature was reviewed to analyse the current economic performance of NSR. Secondly, the keywords 'NSR shipping' and 'Arctic shipping' are used to collate and analyse research on the different transport solutions of NSR. Finally, Keywords such as 'shipping cost model', 'transport cost', and 'profitability' are used to review the literature on transport and shipping costs to explore the methods of a cost analysis of transport solutions.

2.1 Is NSR economical

In the vast majority of studies on the economic feasibility of NSR, a comparative analysis of the economics of NSR and SCR has been chosen (Lasserre, 2014).In terms of navigation time, the NSR route can significantly reduce the maritime voyage between Asia and Europe; in terms of technological development, the technology of icebreakers and double-acting ships is becoming more mature; and in terms of the channel environment, the sea ice in the Arctic Ocean is decreasing every year and the navigable time is increasing.

Several studies have expressed a degree of recognition of the economics of NSR.
Verny et al. (2009) designed a schedule for container transport by ice-class ships

using the NSR. They verified year-round container transport's technical and economic feasibility along the NSR. However, in the study, the speed estimates for ships sailing along the NSR were overly optimistic. They did not consider the commercial risk of delays associated with transporting on a defined schedule, which lacked realism. In contrast, Liu et al. (2010) analysed the feasibility of using NSR for ice-class ships for only a few months and SCR for the rest of the year for container transport. Xu et al. (2011) analysed the use of NSR for container ships during the summer months and recognised the advantages of NSR in terms of fuel cost savings but neglected NSR costs in their study.

The paper, as mentioned above, acknowledges the feasibility of using NSR for year-round or seasonal container transport. However, it is also clear that certain factors are ignored in the study, such as the cost of NSR, the cost of ice-class vessels, the speed restrictions imposed by NSR on vessels, etc. The full feasibility of NSR has been questioned in some of the more advanced studies described below, which take more factors into account. Srinath (2010) analyses the operating costs of ice-class vessels using NSR for both seasonal and year-round transport and concludes that it is not feasible at this time. Schøyen and Bråthen (2011) argued that NSR could not be used for liner shipping but seasonal bulk carriage due to the uncertainty in sailing schedules. Raza and Schøye (2014) analysed the operating costs of LNG vessels on NSR. They concluded that NSR is feasible due to its economic advantages over SCR. However, the cost analysis of fuel for LNG vessels was not thorough enough and ignored the use of heavy fuel oil for LNG vessels under no load. Pruyn (2016), by analysing the cost and duration of bulk carriers, concluded that the feasibility of NSR is extremely low due to speed and vessel size limitations. Similarly, Zhu et al. (2018) mention that the feasibility of NSR is influenced by the size of the vessel and low load factor, with higher environmental costs than SCR.

In a study of the feasibility of NSR considering additional factors, NSR is limited by its own navigational time, and sea ice conditions, resulting in a significant impact on vessel speed and size, which in turn affects voyage duration and loading rates, making it impossible to carry out containerised and oversized shipments. This has led to the limited viability of NSR in the current situation.

Lasserre (2014) provided a summary and analysis of studies assessing the economic feasibility of shipping along the Arctic between 1991 and 2013. Subsequently, Meng et al. (2016) also reviewed and summarised studies on Arctic shipping routes' navigational feasibility and commercial feasibility. Further, Gleb and Gin (2021) updated the results based on the above, centred around the NSR. The comparison found that 60% of the studies concluded that currently, NSR is not economically feasible. Overall, the use of NSR is not profitable. These reviews also mention that NSR is feasible in more simplified studies, and as the models become more complex and more factors are included in the current natural and economic environment, the use of NSR becomes heavily restricted.

2.2 New explorations of NSR

Although the feasibility of NSR is currently limited, and most shipping companies are reluctant to experiment further with the use of NSR (Lasserre, 2016), the exploration of the use of NSR for transport does not stop there. As the political, economic and natural environment changes, there is a possibility that the restrictions on the use of NSR could be broken. Many studies have seen new transport solutions and future possibilities for the use of NSR. One of the most widely studied solutions of combined NSR use is the combined NSR-SCR operation solution.

Furuichi and Otsuka (2015, 2018) present a comprehensive cost estimation approach for a combined shipping scenario such as NSR-SCR, analysing the feasibility of container transport under this solution. They also mentioned that the shortened voyage of NSR reduces CO2 emissions and may attract the interest of operators or ship owners from a green shipping perspective. However, the study does not further analyse how the economics of this combined solution would be affected by the trend towards larger containers. The study also points out that combined NSR-SCR operations are better suited to the high-value and time-sensitive cargo market. As for the transportation of crude oil in the Arctic, Faury (2019) developed a profit decision model to analyse the benefits of transporting crude oil under the NSR-SCR transport solution in the face of NSR coastal oil supply and SCR route oil demand, taking into account global warming. In terms of natural environmental factors, Xu (2018) analysed the cost of container transport under the combined NSR-SCR transport solution based on a dynamic consideration of the extent of sea ice and concluded that this combined solution of operation is more economical than using SCR alone. The study took a specific vessel type and did not consider the cost changes associated with higher ice-class vessels. Similarly, in a study of the impact of sea ice on the NSR route, Gleb and Gin (2021) introduced ice thickness and conditions into a traditional cost comparison to further quantify the impact of sea ice on navigation costs and analyse the annual profitability of combined NSR-SCR use.

The above study explores the combined NSR-SCR transport solution in the light of changing economic and natural factors, demonstrating new possibilities for shipping companies to utilise NSR. There are some limitations and difficulties associated with this combined transport solution, such as the significant difference in freight volumes between the two shipping routes, NSR and SCR, resulting in limited loading rates for vessels using this transport solution. There is also a lack of infrastructure and a trade-off between the cost of ice-breaking pilotage and building high-ice class vessels.

In recent years, international development and cooperation along the Arctic have increased with the changing international political and economic situation. The Russian authorities are paying increasing attention to the use of the NSR, and infrastructure development along the NSR is being stepped up. Discussions on possible future transport solutions of the NSR are also gradually increasing.

Milaković (2018) explored possible future transport solutions on the NSR, proposing several possible future operational ways for transit shipping along the NSR. He also mentions the establishment of transit hubs at both ends of the NSR as a possible future operational solution but does not elaborate on the design. Sevastyanov (2020) and Kravchuk (2020) discuss the logistic transport capabilities of the NSR in recent years and Russia's policy to develop these capabilities further while designing a solution of Arctic shipping based on shuttle transportation between two logistic hubs, further refining this shipping solution. However, the study focuses mainly on the theoretical justification of this shipping solution in terms of the policies of the Russian authorities and international cooperation. However, it does not provide a qualitative economic analysis of this shipping solution.

This paper further specifies and elaborates on this shipping solution, builds on the NSR operational concept devised by Kravchuk (2020), develops an economic cost model and analyses the factors affecting the feasibility of this shipping solution.

2.3 Economic cost analysis

In the economic analysis of NSR, most studies have chosen to develop shipping cost models and conduct quantitative studies. For shipping cost modelling, Stopford (2009) divides the annual operating cost into three components: Operating cost, Voyage cost and Cargo handling, each of which depends on several components, such as Crew wages, Fuel consumption, Port charge, Speed, etc. The number of components covered in a shipping cost model is significant. Therefore as many components as possible are added to the model when it is built to obtain more accurate results. However, different model components will have different effects on the results.

Therefore, when a specific economic cost analysis is carried out for a particular case, not all components are analysed, but some are selected as variables to be studied. Verny et al. (2009) and Lasserre (2014) analyse transport costs for a particular vessel type, the container ship. Liu et al. (2010) analysed operational costs, Xu et al. (2011) and Schøyen and Bråthen (2011) analysed fuel costs, and Xu (2018) and Gleb and Gin (2021) explored the impact of sea ice, among others. In addition, sensitivity analyses are carried out in some studies to clarify the impact of certain variables on costs. For sensitivity analysis, Lasserre (2014) selected four variables - fuel cost, NSR tariff, sailing speed, and load factor. The results showed that these four variables have different degrees of impact on costs. Depending on the distance travelled, the effect of the same variable may vary from route to route. Wan (2018) selected four variables, namely fuel cost, NSR tariff, insurance, and load factor, and conducted a sensitivity analysis for two different scenarios: chartered and owned vessels. Raza (2014) selected two factors, NSR fee and charter rate, conducted a sensitivity analysis for NSR and SCR routes, and concluded that charter rate had the most significant impact.

In most shipping models, however, only shipping costs are considered. Other processes and influences in the logistics process are not considered due to the study cases' fixed routes and transport solutions. In a complete logistics chain, other cost factors should also be considered. For example, Jansson and Shneerson (1985) made a breakthrough by suggesting that in addition to vessel costs, inventory costs should also be taken into account when determining the optimal fleet size. Based on this study, Pope and Talley (1988) further investigated the effect of inventory cost, clarified that different inventory models apply to different shipping models, and described the methods and limitations of using inventory cost to determine the optimal ship size. By analysing the relationship between factors and costs such as safety stock, maximum inventory position and lead time under a particular model, the optimum value of maximum inventory position is obtained, and inventory cost can be further used to determine the optimum ship size. The study results also show that although the relationship between inventory cost and optimum ship size can be obtained in a model with explicit conditions, such conclusions are not general . Inventory cost is more applicable to calculating optimal load size than optimal ship size. Creazza et al. (2010) study the transportation of finished goods from the factory at the place of production to the warehouse at the place of destination and elaborate on the logistics costs by taking into account Handling, Inventory carrying and order processing components outside the maritime segment. The costs of handling and storage in the warehouse and processing orders are taken into account and calculated, thus providing an overall logistics cost analysis of the entire transport process.

Inspired by these studies, this paper looks at other factors in the logistics chain and shipping costs and includes them in the economic cost model for a more comprehensive analysis.

2.4 Summary

A comprehensive review and analysis of the above literature show that NSR alone for transit across borders, especially between Asia and Europe, is not universally economical under existing conditions. The use of combined NSR-SCR transport is feasible. However, it is not yet accepted by most shipping companies due to insufficient infrastructure development and unbalanced loading rates.

Although the economic feasibility of using NSR for transit across borders is currently not as good as possible, further political and economic developments, both in terms of coastal infrastructure and ship technology, will remove some of the current barriers to NSR shipping activity in the future.

For this reason, it can be argued that the possibilities of using the NSR for shipping activities have not been fully explored and that there is still much room for development. The economic feasibility of some of the ideas that have been put forward also deserves further scrutiny. Therefore, this study will build on the ideas given in some studies and explore a new possibility that has not been thoroughly discussed in the literature before but has potential.

This paper focuses on the future operation solution of a transshipment hub at both ends of the NSR and builds on previous research to further design the solution. A more comprehensive quantitative analysis is carried out, taking shipping costs and other logistics costs into account. The factors affecting the economic feasibility of the NSR new transport solution are also explored, providing a basis for future research into the development of this solution.

3. Methodology

This study describes a new transport solution using NSR: conventional ships carrying cargo departs from the port of origin, Shanghai, and arrive at the NSR's eastern hub, the port of Petropavlovsk-Kamchatsky. Here the cargo is transferred to an ice-class vessel for ferrying along the NSR to the NSR's western hub at the port of Murmansk. Here the cargo is transferred to conventional vessels for the destination port of Rotterdam.

This paper will combine quantitative and qualitative methods to investigate the economic feasibility of the new NSR transport solution. Firstly, a cost model is developed. Based on the existing literature, the cost of the new NSR transport solution is divided into three components: shipping cost, handling cost, and inventory cost, and then the new NSR transport solution is compared with SCR. Different scenarios were set up, and the corresponding variables in the cost model were changed to calculate the costs of the new NSR transport solution and the traditional SCR transport solution under different conditions. Finally, the data differences are analysed, and conclusions are drawn.

3.1 Cost modeling and components

In this paper's new NSR transport solution envisaged, a one-way transport between Asia and Europe consists of three voyages and two transits. The three voyages are two regular voyages and one NSR voyage, while the two transits are two loadings and unloading at the transshipment hub ports of Petropavlovsk-Kamchatsky and Murmansk. Therefore, in order to comprehensively analyse the overall logistics costs of the new NSR transport solution, the paper divides the logistics costs into three components: shipping cost, handling cost, and inventory cost, taking into account that the focus of the solution is on transshipment and ferrying, as follows：

$$LC = C_S + C_H + C_I$$

The following sub-section describes each of these elements in detail.

3.1.1 Shipping cost (C_S)

Shipping cost is incurred in maintaining a ship in operation and navigation. It consists mainly of depreciation, insurance, crew, maintenance, fuel, route, and port costs.

3.1.1.1 Depreciation (D)

Depreciation of a ship is an annual charge at a depreciation rate over a certain period to compensate for the wear and tear of the ship or equipment as it gradually wears out, becomes less effective and loses value over the years. The depreciation cost of a ship is related to the ship's price. The difference in cost between NSR and SCR vessels is mainly due to the cost of new ships. Ships on the NSR need to be strengthened to become ice-class as they pass through ice floes, so the cost of new ships is higher and rises with the ice class of the ship; ships on the SCR and other regular waters do not need to have their hulls strengthened, so the cost of new ships is relatively low. In this paper, the straight-line depreciation method is used to calculate the depreciation cost and a depreciable life of 20 years is assumed (Lasserre, 2014).

3.1.1.2 Insurance cost (I)

The insurance costs explored in this paper consist of three categories of insurance: hull and machinery insurance (H&M), protection and indemnity insurance (P&I) and other insurance. According to the data provided by COSCO, the current market rates for H&M and P&I are 1.4% and 1.7%, respectively (Wan, 2018). Therefore, shipping activities along SCR can be charged at this rate; for shipping activities along NSR, insurance costs are higher due to poorer channel conditions and greater navigational risk, but no consensus has been reached yet. In this paper, we choose the study with a high level of acceptance and premium NSR's H&M and P&I by 50% accordingly (Lasserre, 2014).

Other insurance, mainly referring to piracy insurance premiums for SCRs. For ships sailing with SCR, they pass through areas where piracy is rampant, such as the Gulf of Aden, before entering the canal from the Indian Ocean north through the Red Sea, and are therefore subject to a different piracy insurance premium, typically taken at 0.125%-0.2% of the ship's price. For ships sailing on NSR, piracy insurance premiums do not need to be considered as the route is safe due to the small number of countries sailed through and the stability of the situation.

3.1.1.3 Crew cost (C)

Crew costs consist mainly of basic wages, auxiliary wages, meals, sailing allowances, bonuses and wage surcharges. Compared to ships using SCR for transportation and those sailing in regular waters, ships using NSR have higher crew wages due to poorer sailing conditions. When calculating this, a 10% premium is commonly applied to crew costs for NSR (Lasserre, 2014; Wan, 2018).

3.1.1.4 Maintenance cost (M)

Maintenance costs include the vessel's contents, lubricant costs, terminal costs, and spare parts. For ships sailing in the SCR and other regular waters, annual maintenance costs are typically taken as 1.095% of the ship's cost; for ice-class ships sailing in the NSR, maintenance costs are at a 20% premium (Furuichi, 2015).

3.1.1.5 Fuel cost (FC)

Fuel costs are pivotal in cost modeling. In previous studies, fuel costs have accounted for a significant portion of the total costs. Fuel costs are determined by the amount of fuel and the price of fuel, which in turn is related to vessel type, vessel speed and whether or not the vessel is sailing in ice floating waters.

For SCR and regular water navigation, the fuel cost is influenced by the price of fuel, as the route and range are fixed, and the amount of fuel does not vary much; for NSR, the amount of fuel varies according to the seasonal ice floes and the ice class of the vessel. Overall, the NSR has a significant advantage over the SCR in fuel costs due to the much shorter voyage. This advantage will continue to increase as international oil prices rise.

However, international oil prices are susceptible to international situations, the policies of international organizations and other unavoidable factors such as pandemics. Moreover, changes in international oil prices directly impact the cost of fuel for shipping. Therefore, to better explore the impact of fuel costs, the fuel usage and fuel costs for NSR and SCR under different scenarios will be discussed in the next chapter.

3.1.1.6 Cost of shipping routes (TF)

For the comparative analysis of NSR and SCR, the route costs explored in this paper are the transit fees for NSR and SCR.

For the transit fees of NSR, it is considered that the new transport solution of the NSR discussed in this paper is based on the condition that the NSR waterway facilities are mature and the infrastructure is well established. In order to increase the competitiveness of the NSR, the Russian authorities' transit fees for the NSR will also be oriented towards attracting freight volumes. Again, the impact of changes in NSR transit fees on costs will be discussed in the next chapter.

3.1.1.7 Port cost (PC)

For this paper, port charges consist of entry fees, berthing fees, etc., while cargo movement and handling are not included. In the transport solution discussed here, the NSR and SCR have the same port of origin and destination, with two hub ports in the new NSR transport solution and three ports of call in the SCR. Thus, SCR makes one more port of call than NSR on each voyage.

3.1.2 Handling cost (C_H)

Handling cost in this paper refers to the cost of loading and unloading cargo at the ports of Petropavlovsk-Kamchatsky and Murmansk under the new NSR transport solution. In the new NSR transport solution, the cargo is loaded twice and unloaded twice at both transshipment hub ports. For simplicity and focus, the handling costs at both solutions' port of origin and destination are ignored, as is the potential for loading and unloading at the port of call.

3.1.3 Inventory cost (C_I)

Under the new NSR transport solution set out in this paper, the two hub ports of Petropavlovsk-Kamchatsky and Murmansk have the same size of logistics capacity.
Taking the current logistics capacity of the port of Murmansk as a standard, the area of covered and opened warehouses exceeds 300 thousand square metres. With the further development of the logistics capacity of both ports, their warehousing capacity will be enhanced. In the NSR new transport solution discussed in this paper, two

transshipment hubs are set up so that goods need to be stored temporarily at the transshipment points before being shipped east or west. The loss of value of the goods stored temporarily at the two transshipment hubs is defined in this paper as the inventory cost, precisely calculated as the depreciation of the value of the goods at different values over different periods. In particular, the cost of storage at the terminal after the regular arrival of the cargo and the cost of demurrage for other reasons are not part of the inventory cost in this paper, in both the NSR new transport solution and the SCR traditional shipping solution.

3.1.4 Summary

Based on the factors in each of the above components, the cost model over an operational time T can be summarised as follows.

$$LC = \frac{(D+I+C+M)\times T}{12} + FC + TF + PC + C_H + C_I$$

Of these, depreciation (D), insurance (I), crew costs (C), and maintenance costs (M) can be considered fixed costs within the shipping cost and are generally calculated annually. The calculation of the other parameters requires additional factors to be considered. The values and calculations for each parameter in the model are described in the next chapter.

3.2 Scenario design

After the cost model is built and the basic parameters are determined, different scenarios are simulated by changing different parameters. Furthermore, compared with the SCR traditional shipping solution, the cost of the two shipping solutions under different scenarios is calculated, and the impact of different factors on the cost of the new NSR transport solution is discussed.

3.2.1 Baseline scenario

An overview of the new NSR transport solution and SCR traditional shipping solution is given; a representative 5,000 TEU vessel is selected. The parameters are reasonably valued and substituted into the cost model to obtain the shipping costs of the new NSR transport solution and the SCR traditional shipping solution under the baseline scenario.

3.2.2 Fuel change

Based on the baseline scenario, all other parameters are held constant, changing the fuel price parameters. Two scenarios with high fuel prices and low fuel prices are set up and substituted into the cost model for each calculation.

3.2.3 Tariff change

Based on the baseline scenario, all other parameters are held constant, and the tariff for NSR is changed. Calculations are carried out by substituting into the cost model.

3.2.4 Load factor change

Based on the baseline scenario, all other parameters remain the same, and the load factor under the new NSR transport solution is changed and substituted into the cost model.

3.2.5 Insurance change

Based on the baseline scenario, all other parameters remain the same. The insurance costs for the different segments under the new NSR transport solution are changed and substituted into the cost model for calculation.

4. Scenario setting

4.1 Selection of route

The traditional route between Asia and Europe via the Suez Canal is currently one of the largest shipping routes in the world and is also one of the sea routes in China's 'the Belt and Road' strategy. However, the congestion of the Suez Canal and the unstable situation in the Strait of Malacca have posed certain risks to this traditional route; at the same time, with the change of sea ice in the Arctic Ocean in recent years, the Arctic route is expected to be fully navigable. The value of the Arctic route as a possible alternative route between Asia and Europe is gradually emerging.

The Arctic Passage, shown in Figure 3, can be divided into three routes in terms of orientation and direction: Northeast Passage (NEP), Northwest Passage (NWP) and Trans Polar Passages (TPP) also known as the Central Route. The Northeast Passage is growing faster and has developed into a small, established commercial route. Commercial use of the Northwest Passage is still experimental. The Trans Polar Passage (Central Route) is still being assessed and explored. This section will provide an overview of the various routes in navigable Arctic waters at this stage and explain the reasons for selecting the NSR route as a potentially viable route between Asia and Europe.

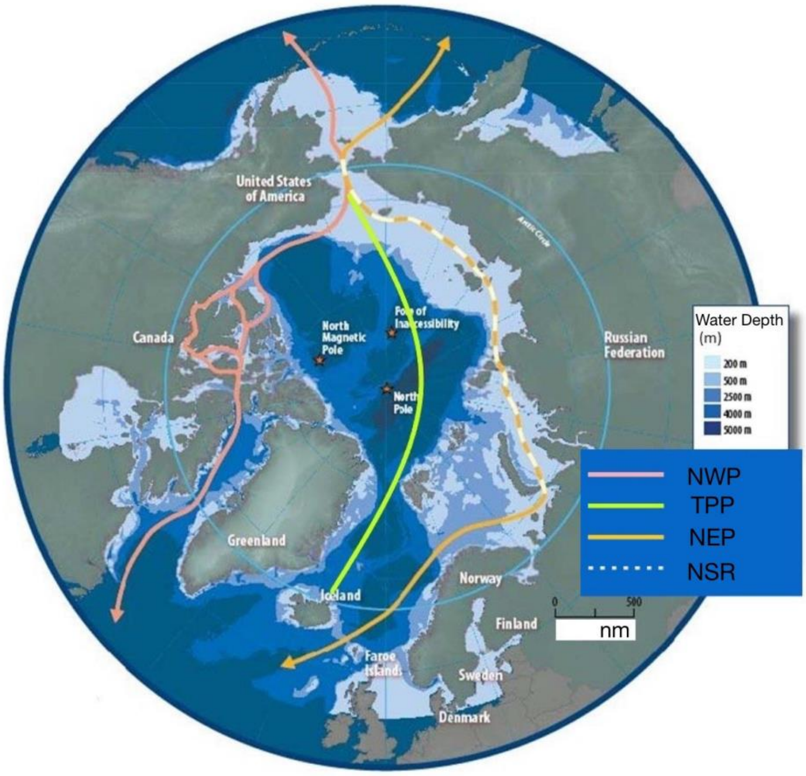

Figure 3. *Arctic route*

4.1.1 Northeast Passage

4.1.1.1 Definition of the Northeast Passage and its main routes

The Northeast Passage refers to the maritime transport route in the Arctic Ocean through the northern coastal waters of Russia and Norway, connecting the North Atlantic Ocean with the North Pacific Ocean. Specifically, the Northeast Passage (from west to east) starts from the North Cape in northern Norway in the west and passes through the Barents Sea, the Kara Sea, the Laptev Sea, the East Siberian Sea, the Chukchi Sea and east to the Bering Strait, a total length of 2,800-3,200 nautical miles, with an average of 3,000 nautical miles. The Northern Sea Route (NSR), as defined by Russia's new 2013 law, is located within its Exclusive Economic Zone (EEZ), starting from Novaya Zemlya in the west, passing through the Kara Sea, Laptev Sea, East Siberian Sea, Chukchi Sea and ending in the Bering Strait in the east, with an average length of 2,550 nautical miles (the length of the route varies from one route to another, varying between approximately 2,200-2,900 nautical miles). The extent of the Northeast Passage and the Northern Sea Route overlaps considerably, and for ships in international transit traffic, the Northern Sea Route can be seen as a major section of the Northeast Passage. As the Barents Sea in northern Norway and north of the Kola Peninsula is ice-free all year round, the name Northern Sea Route, which does not include the Barents Sea leg, better highlights the difference between the Northeast Passage and the traditional warm water route.

The Northern Sea Route passes through the islands of Novaya Dhabi, the Northland Islands, the Novosibirsk Islands and Wrangel Island. Different routes are formed depending on whether they cross these archipelagos or the inter-island straits. Depending on the depth of the water, there are deep-water and shallow-water routes. Vessels pass through different routes depending on the ice conditions. According to the "Arctic Navigation Guide (Northeast Passage)" published by the Polar Research Institute of China, which has conducted many scientific expeditions in the Arctic, the Northeast Passage can be categorized into four types of routes depending on the navigation method: coastal route, intermediate route, transit route and trans-polar route. According to statistics, the intermediate route is currently the most used route, which is: from the port of Provignya through the Bering Strait into the Chukchi Sea, through the Drang Strait on the south side of Wrangel Island and then into the East Siberian Sea, along the north side of the Novosibirsk Islands through the Laptev Sea and then through the Velikiski Strait, continuing south-west to the north side of the port of Dikson and then north-west along Novaya Zemlya to the Barents Sea.
The routes of the Northeast Passage are summarised in Figure 4.

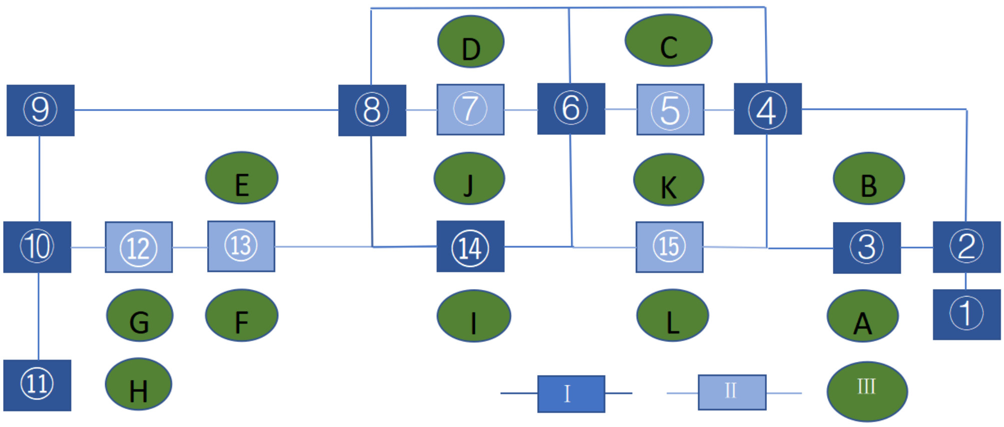

Figure 4. *Main routes of NEP (Source: Author)*

①-⑮are Bering Strait, southern Chukchi Sea, Drang Strait, East Siberian Sea, Sannikov Strait, Laptev Strait, Shokalsky Strait, Kara Sea, north-eastern Barents Sea, north-western Barents Sea, Norwegian Sea.

A-L stands for Chukotka Autonomous Region, Wrangel Island, Novosibirsk Islands, Northland Islands, Novaya Zemlya, Nenets Autonomous Region, Kola Island, Norway, Tymmel Peninsula, Bolshevik Island, Dalakhov Island, Sakha Republic.
I-III stands for deep water route, shallow water route, island or mainland.

4.1.1.2 Sea ice and navigational period

In the last 20 years, the sea ice in the Northeast Passage waters has been melting faster and greater, and there is a large inter-annual variation in sea ice distribution. Currently, navigation is possible from July to September for two to three months each summer. According to preliminary research from Arctic scientific expeditions (citing data from the China Polar Research Centre)

The formation of interglacial lakes along the Laptev Sea in June laid the foundation for the early opening of the Northeast Passage. It was a prerequisite for forming an extended waterway in the Laptev Sea sector towards the center of the Arctic Ocean at the end of August. Severe ice conditions in the sea area around Wrangel Island were a key constraint to the opening of the Northeast Passage during the summer. The Eurasian sector of the Arctic Ocean forms an almost ice-free route at about 80-82°N, driven by the Pacific Ocean inflow and influenced by the northward development of interglacial lakes along the Russian coast.

Studies of the spatial and temporal variability of Arctic sea ice based on satellite remote sensing show that the Arctic sea ice starts to melt heavily in late June each year, reaching a minimum area of sea ice by mid-September. By late October, the sea surface starts to freeze rapidly and is gradually covered by sea ice. Overall, the Arctic shipping route shows a trend of decreasing sea ice in summer. The number of navigable days in the Northeast Passage shows an increasing trend from year to year, with the start of navigation being spread out, with the earliest date being 20 July 2011 and the latest being 2 September 2005, while the end of navigation is relatively concentrated, mainly in the middle and early part of October. In the study of sea ice trends in the Arctic, three different emission scenarios, high, medium and low, all simulate that the area and thickness of sea ice in the Arctic shipping lanes will continue to decrease, especially under the high emission scenario, there will be little or no ice in the Northeast Arctic shipping lanes in the summer of 2030, providing conditions for the smooth operation of the new shipping routes.

4.1.1.3 Historical development and current status of NSR

The exploration and opening of the Northern Sea Route (NSR) of the Northeast Passage dates back hundreds of years and is linked to the Russian colonization of Siberia and the Far East and the exploitation of resources such as furs for trade. The real use of the Northern Sea Route as a maritime transport route began during the Soviet era. During World War II, the Northern Sea Route was used as a logistical route for the Soviet and Allied forces supporting the Eastern Front. After the war, with the development of industrial raw materials such as Siberian ore, the Northern Sea Route developed significantly, with several nuclear-powered icebreakers and ports being built and put into service, and the ice route from Dudinka to Murmansk operating on a year-round basis, reaching its first historical peak of 6.58 million tonnes in 1987. After the collapse of the Soviet Union, the volume of freight on the Northern Sea Route declined sharply. In 1991, a new policy of opening the Northern Sea Route to international traffic was introduced to encourage international ships to use it in transit to reverse the serious decline in the volume of freight on the Northern Sea Route. Although international users had little response to the new policy, studies to prepare for shipping began to be initiated.

Some of the more important Northern Sea Route research programs of the 1990s included the International Northern Sea Route Research Programme (INSROP, 1993-1999), co-sponsored by Japan, Russia and Norway, and the Arctic Demonstration and Exploratory Voyage (ARCDEV), initiated by the European shipping community. Voyage). In 2009, two merchant vessels of the German company Beluga Shipping made their maiden voyage on the Northern Sea Route, which successfully introduced the Northern Sea Route and started a new cycle of rapid growth in cargo volumes. Shipping companies successfully launched commercial voyages for bulk carriers, container ships, tankers and passenger ships, four types covering the main types of maritime cargo, fully confirming the economic and technical feasibility of the Northern Sea Route.

In the years that followed, the freight volume on the Northern Sea Route rose rapidly from rock bottom. The Russian Northern Sea Route Authority reported that in 2016, total freight volumes reached 6.9 million tonnes, surpassing the previous historical peak. In recent years, the use of the NSR for domestic transport in Russia has risen to a new level. According to the Ministry for the Development of the Russian Far East and the Arctic, cargo turnover along the NSR has already reached 32.97 million tonnes in 2020 and 34.85 million tonnes in 2021.

The NSR is receiving increased attention in terms of transit transport as trade activities between Asia and Europe, especially energy trade such as natural gas, intensify. 2017 saw the publication of China's "Vision for Maritime Cooperation in the Construction of " the Belt and Road," which for the first time identifies the Arctic shipping route as one of the three main sea routes of "the Belt and Road." Since then, China has intensified its exploration of the Arctic route, with COSCO merchant vessels and polar research vessels from the Polar Research Institute of China carrying out more frequent activities in the Arctic. According to the Centre for High North Logistics (CHNL), the number of NSR transits and cargo volumes has increased yearly over the past few years, with an explosive increase in 2020, doubling cargo volumes compared to 2019. Such figures also show the role of the NSR as an alternative route between Asia and Europe and its potential for further growth in the future, given the impact on global supply chains in the context of the epidemic and volatile international oil prices.

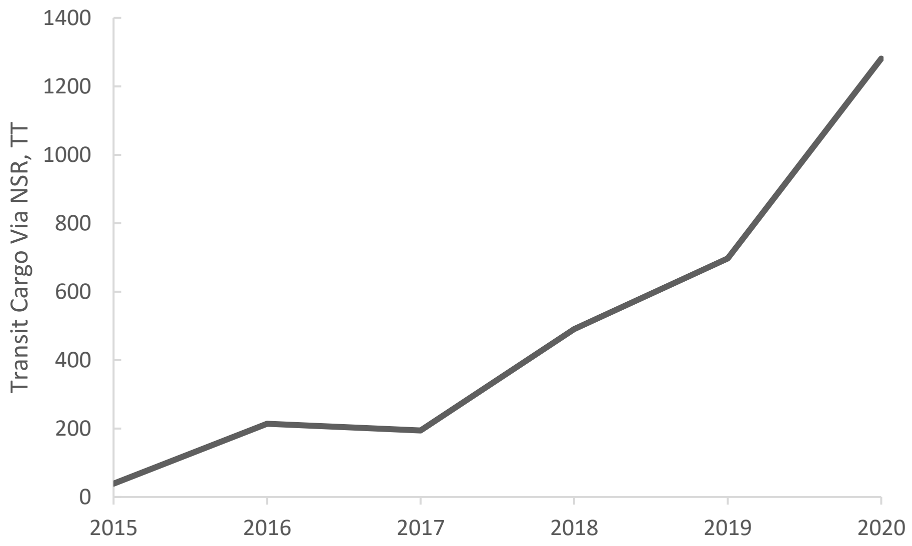

Figure 5. *Transit cargo via NSR (Source: Author)*

4.1.2 The Northwest Passage and the Trans Polar Passage

4.1.2.1 The Northwest Passage

The Northwest Passage is a seaway that connects the North Pacific Ocean with the North Atlantic Ocean, mainly along with the northern coast of the North American continent through the waters of the Northern Class Islands of Canada and the northern waters of Alaska, USA. It is located roughly in the inshore waters of the Arctic Ocean between 169 degrees West and 60 degrees West longitude. The Northwest Passage runs roughly east-west, with the main section located in the 36,000-island Canadian Arctic Archipelago waters. These waters consist of numerous straits, bays and shoals of varying sizes. Compared to the Northeast Passage, the topography of the Northwest Passage is more complex. Moreover, due to the more severe ice conditions in the Northwest Passage, the short opening period, the scarcity of commercial vessels, the lack of demand for transit shipping and other constraints, the hydrographic mapping of many areas within the passage is very inadequate, making it more difficult to use the Northwest Passage for navigation activities.

4.1.2.2 Trans Polar Passage

Trans Polar Passage, also known as the central channel, refers to the west from the northern waters of the Norwegian Svalbard archipelago, through the central area of the Arctic Ocean near the geographical North Pole, through the Chukchi Sea, east to the Bering Strait sea route, if the northern end of the Greenland Sea Flam as the starting point, the total length of 2300 nautical miles. The western side of the Central Passage (towards the Canadian Arctic Archipelago) is not currently navigable due to the yearly accumulation of ice. The eastern side (towards the Russian mainland) has lighter sea ice conditions, similar to the Northeast Passage, and is most current year ice, even in winter. Because the summer sea ice in the Trans Polar Passage is far more frequent than in the Northern Sea Route, and it is farther from the Russian coastline and follows the same course as the Northern Sea Route, few commercial vessels are currently attempting it. However, with the new Russian law limiting the boundaries of the Northern Sea Route to the waters of its 200 nautical miles exclusive economic zone, the high seas status of the waters of the Trans Polar Passage is no longer in dispute. This is in contrast to the more controversial status of the Northeast Passage and the Northwest Passage under international law. Under the international law of the sea, the Trans Polar Passage is free for international vessels to navigate in all circumstances. This is the most prominent advantage of the Trans Polar Passage. If the sea ice continues to retreat towards the Canadian side in the future, the Trans Polar Passage will also become a navigable international shipping route.

4.1.3 Summary

Of the three shipping routes in the Arctic Seaway, the Northeast Passage has a clear advantage. On the one hand, in terms of navigational conditions, the sea ice distribution in the Northeast Passage is more suitable for ships to navigate. The other is that in terms of maritime security, the Russian authorities have a strong construction and development plan for the infrastructure along the NSR.

Once the hardware conditions have been largely met, the advantages of the Northeast Passage are reflected in the cargo volumes that have been gradually rising in recent years.

The epidemic, which has been raging since 2020, has had a huge impact on the global supply chain, causing fluctuations in sea freight prices along traditional shipping routes. At the same time, the NSR's freight volumes have increased rather than decreased, reflecting its potential and future development as an alternative route to the traditional routes between Asia and Europe. Based on the above, the NSR is chosen as the route to be studied, and a possible future transport solution of operation is envisaged and analyzed.

4.2 Voyage selection

In order to better illustrate the economic feasibility of the new NSR transport solution, the paper will select the important route between Asia and Europe, Shanghai-Rotterdam, and compare the cost of the new NSR transport solution with the traditional route between Asia and Europe via the Suez Canal over a five-month period. The selected voyages are described in this section.

4.2.1 The new NSR transport solution

The new NSR transport solution is described in the previous section. In this solution, the two gateway ports at each end of the NSR, Murmansk and Petropavlovsk-Kamchatsky, will act as transshipment hubs, taking on receiving and transferring cargo between the two ends of the NSR. This paper assumes that a 5,000 TEU container ship carrying cargo departs from the port of Shanghai and sails to the hub port of Petropavlovsk-Kamchatsky at the eastern end of the NSR, where the cargo is discharged. The cargo was then transferred to an Ice Class vessel of the same class, which departed from the port of Petropavlovsk-Kamchatsky and sailed along the NSR to the port of Murmansk, another hub port at the western end, where the cargo was discharged. Finally, the cargo is transferred to another regular container ship and sails to the port of Rotterdam, the destination port, to complete the transport. The complete route is shown in the figure below.

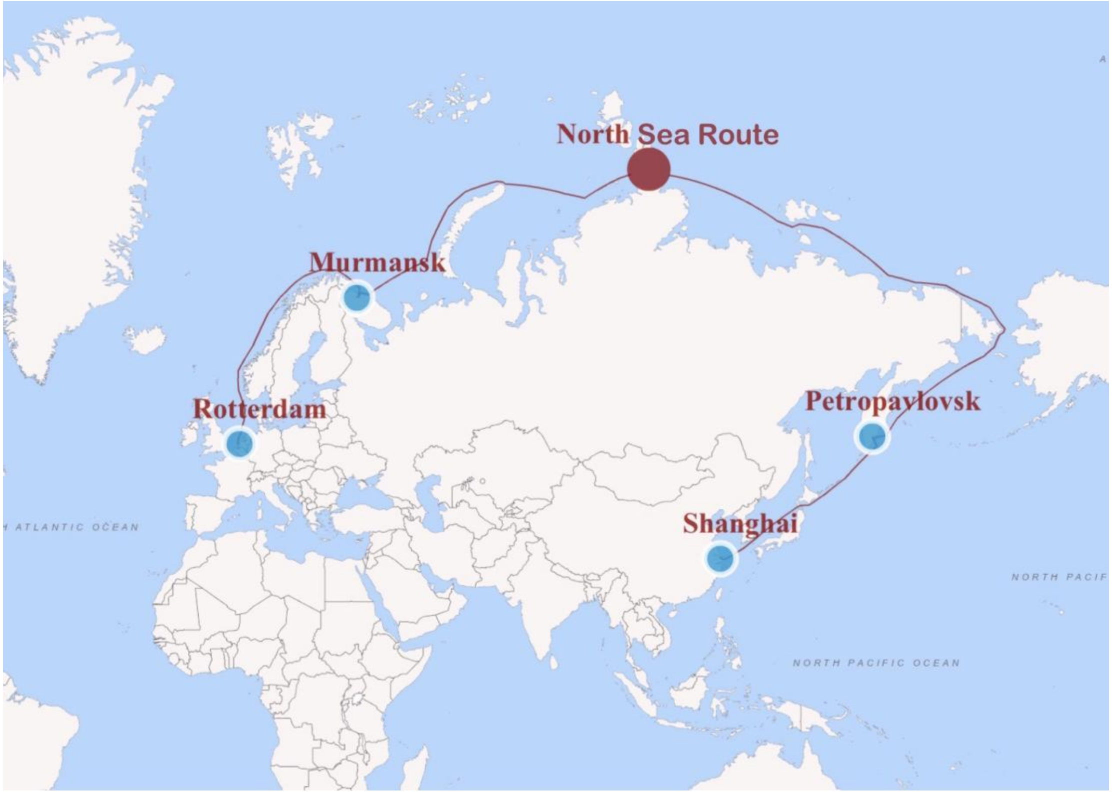

Figure 6. *Voyage from Shanghai to Rotterdam under the new NSR transport solution (Source: Author)*

In the new NSR transport solution, there are three segments from the port of departure to the port of destination, including two segments for regular vessels and one segment for ice-class vessels. Using McDistence mapping and calculations, it is possible to obtain the following table for each segment and type of vessel under the new NSR transport solution, for a voyage of 8316.5 nautical miles.

segment	Distance（nm)	type of vessel
Shanghai-Petropavlovsk	2268.7	regular vessel
Petropavlovsk-Murmansk	4398.5	ice-class vessel
Murmansk-Rotterdam	1649.3	regular vessel

Table 1. *Distance and vessel type for each segment in SCR and NSR transport solution*

4.2.2 Traditional transport solution via SCR

In the traditional transport solution via SCR, a 4250 TEU Panamax container ship carrying cargo departs from the port of departure in Shanghai via the South China

Sea, the Strait of Malacca, the Indian Ocean, the Red Sea, across the Suez Canal, the Mediterranean Sea, the Strait of Gibraltar, the English Channel and finally arrives at the port of destination in Rotterdam. The complete voyage is shown on the figure below.

Figure 7. *Voyage from Shanghai to Rotterdam under the traditional SCR transport solution (Source: Author)*

Mapping and calculations using McDistence indicate that the route is 10,608.4 nautical miles in length, and the vessels are regular.

4.3 Taking and calculation of model parameters

Based on the route determination, this section will take values or calculate the fixed parameters in the cost model and other relevant parameters.

4.3.1 Navigable time

There is a significant difference in the navigable time between the NSR and SCR traditional routes: the SCR traditional route is not subject to seasonal restrictions. It can be maintained all year round, whereas the NSR cannot be navigable all year round due to the constraints of the route, with a navigable time of around three months per year. According to Centre for High North Logistics (CHNL) statistics, the NSR's navigable time has slowly increased in recent years. In 2020, the NSR's navigable time began on 20 July and ended on 17 November, with an overall navigable time of almost four months. In this paper, the cost study of the new NSR transport solution considers the trend towards better navigable conditions for the NSR and sets the navigable time for the NSR at five months.

4.3.2 Ship type and speed

The NSR has a unique navigational environment. Taking into account the shallow depths of the Kara Strait, the Shokalsky Strait, the Sannikov Strait, the Laptev Strait, and the complex distribution of ice floes in the navigable waters of the NSR, ships carrying out navigational activities in this channel are subject to many restrictions. As a result, most of the vessels currently active on the NSR are small to medium-sized vessels. This paper selects a 4,250 TEU Panamax container ship and an Arc4 ice-class ship of the same size for the research. With an overall width of less than 32.3m, the ship is less restricted by the shipping lanes. It has a moderate packing capacity, making it the mainstream small and medium-sized container ship in the current shipping market. The speed of the ships sailing in the NSR is also restricted. In this paper, a speed of 20 knots is chosen for conventional ships and 16 knots for ice-class ships, within the range of economical speeds.

4.3.3 Duration and number of voyages

According to the conditions and parameters specified in the previous section, we can obtain the following: for the new NSR transport solution, the distance traveled by a regular ship is 3,918 nm, and the distance traveled by an ice-class ship is 4,398.5 nm, and the total distance traveled is 8,316.5 nm. There are two transshipment ports between the port of departure and the port of destination, where the cargo is loaded, unloaded, and temporarily stored, with a docking time of 2 days at each port and a delay time of 1 day at the transshipment port. In the SCR transport solution, the voyage of a regular ship is 12,608.4 nm. There are 3 ports of call between the port of departure, and the port of destination, each port of call is 2 days, and the Suez Canal delay is 3 days. The speed is 20 knots for regular ships and 16 knots for ice-class ships, and the navigation period is 5 months, from summer to autumn.

The length of a single voyage in the new NSR transport solution is 27 days, with five voyages in five months, while a single voyage in the SCR transport solution is 37 days, with four voyages in five months.

4.3.4 Ship prices

Since 2021, countries worldwide have gradually opened their embargoes and resumed trade activities under the first wave of the pandemic. As a result, the global economy has rapidly rebounded, and market demand is picking up rapidly. This has been reflected in the maritime market, where pressure on ship markets and port terminals has increased in the face of such strong demand. There was also severe congestion in ports on both sides of the Pacific due to strict anti-epidemic policies in Asian ports and labor shortages. The dual impact of the market and the ports caused container rates to escalate, and at one point, it was even 'hard to find one container.'

In response to the rising market performance in container prices, shipowners have taken further action by placing more orders for container vessels. 2021 saw orders for 561 newbuilding container vessels, more than the 114 vessels in 2020 and 107 vessels in 2019 combined. Under the influence of the surging newbuilding orders, individual shipyards have significantly increased the price of newbuilds as their construction capacity exceeds demand. Take the 4,250 TEU Panamax container ship selected for this paper as an example: in 2020, the price of a newbuilding vessel is US$23.6 million. In 2021, this price soared to US$65.5 million. That is an increase of more than 1.5 times (data from VesselsValue).

As the impact of the pandemic wanes, the high demand for containers from trade activities is slowing down, but congestion in many of the world's ports is still relatively severe. There is still a high degree of uncertainty about the future direction of the ship price market. Therefore, the closest year's newbuilding price for a 4,250 TEU Panamax container ship, i.e., US$65.5 million, is chosen in this paper. For ships sailing in waters with ice floes, the hull structure will need to be strengthened to accommodate ice navigation. This results in an increase in cost for ice-class ships compared to regular ships. In previous studies, the cost increase for building an ice-class ship of the same size compared to a regular ship has ranged from 6% (Dvorak, 2009) to 120% (DNV, 2010). The difference is due to the different cost models developed by the authors and the different classes of ice-class ships selected. For the transshipment transport solution explored in this paper, ice-class ships traveling between the two hub ports of Murmansk and Petropavlovsk-Kamchatsky is a well-established transport solution, with good navigational aids along the coast and an excellent navigational environment. In previous studies, a premium of 20% (Wan, Lasserre), or US$78.6 million, was generally chosen for a 4,250 TEU Panamax container ship of Arc4 ice class. However, since ice-class ships and regular ships jointly complete the transport in the NSR transport solution set in this paper, to make the results more reasonable, the ship price premium in the NSR transport solution is adjusted to 10%, i.e., US$72.05 million.

4.3.5 Depreciation

This paper uses the straight-line depreciation method to calculate the depreciation charge. The annual equivalent depreciation charge for a ship is calculated by subtracting the salvage value from the ship's value and dividing it by the depreciable life of the ship. The formula for calculating salvage value is as follows.

$$Demo\ Value = LDT \times Subcon\ Scrap\ Price$$

LDT : The net tonnage of a ship, i.e., the weight of the ship itself excluding cargo, fuel, crew, etc. The LDT for a regular container ship of 4250 TEU is 17,000t. The tonnage of an ice-class ship of the same size is 20% more than a regular ship.

Subcon Scrap Price: The price of scrap in the subcontinent. Based on data from the VesselsValue 2021 ship scrapping report, the higher of these prices, i.e., 620 USD/LDT (India), was selected as the scrap price in this paper. The whole structure of a scrap ship is valued as 100% scrap steel for ship scrapping activities.

The depreciable life was chosen as 25 years.

4.3.6 Crew costs

According to the ship's manning requirements, 20 crew members are set in this paper. Regarding COSCO (2018) and the data on container ship crew wages published by the Shanghai Shipping Exchange, the average wage is selected as US$5,000 per person per month after adjustment in this paper. As the operating environment of the crew working on ice-class ships is harsher and more challenging to operate, the technical requirements for the crew are also higher. Thus the salary level of the crew working on ice class ships is higher than that of the crew working on regular ships. In this paper, the wage premium for crews of ice-class ships is set at 10%. (Wan, Lasserre)

4.3.7 Fuel costs

The cost of fuel a ship needs to spend on a voyage is determined by two main factors: the amount of fuel and the price of fuel. The fuel consumption rate and the number of days sailed calculate the amount of fuel. The number of days sailed depends on the distance traveled and the ship's speed, while the fuel consumption rate is more complex and is determined by the following formula.

$$F = k_1 V^3 + k_2 \quad (YAO, 2012)$$

Where F refers to the fuel consumption rate in tons/day, V refers to the ship's speed in knots, k1 and k2 are coefficients determined by the size of the container ship. The container ship selected in this study is 4250 TEU, and the corresponding k1 and k2 are 0.006732 and 55.84, respectively.

The fuel consumption rate for sailing in a conventional ship can be calculated to be 109.696 tons/day. The engine power will be higher for the ice-class ships due to the additional heating and ice-breaking functions that the ice-class ships need to undertake, thus having a higher fuel consumption rate than regular ships.

Some studies have ignored the difference in ice class of ships and have directly discounted the fuel consumption rate of ice-class ships by 8% (Wan, Lasserre, Furuichi). In contrast, some studies have further explored the link between the ice-class size of a ship and its fuel consumption rate (Erikstad, 2012). In this paper, the premium is adjusted to 5% based on the selected ship's ice class of Arc4. In addition, the transshipment transport solution with two hub ports in this paper also increases the waiting time of ships in port. Therefore, the amount of fuel consumed by the auxiliary engines while the ship is waiting at anchor in port cannot be ignored, with a fuel consumption rate of 10 tons/day while at anchor.

In contrast, changes in bunker prices are more unpredictable. Since 2020, international crude oil prices have plummeted due to COVID-19. Moreover, as the global economy recovers and major economies emerge from the worst of the epidemic, shipping activity picks up, and oil demand gradually picks up. Furthermore, with international oil prices rising further due to the recent Russia-Ukraine conflict, bunker oil market prices have been climbing to record highs. According to Ship&Bunker, in 2019, before the epidemic, the average price of IFO380 was US$420 per tonne, the average price of VLSFO was US$580 per tonne, and the average price of MGO was US$700 per tonne.

The average price of IFO380 was US$747.5 per tonne, an increase of 1.78 times, while the average price of VLSFO was US$924.5 per tonne, an increase of 1.59 times, and the average price of MGO was US$1,307.5 per tonne, an increase of 1.97 times. The high increase in fuel prices has led to a concomitant increase in shipping costs, which has impacted the shipping market. This paper sets out different scenarios to explore the impact of fuel prices on the economic costs of shipping under different circumstances, using the strong fluctuations in the price of bunker oil for ships as a reference.

4.3.8 Transit costs

In this paper, the transit fees of NSR and SCR are discussed. The transit fee of SCR can be calculated according to the official Suez Canal standard, and the transit fee for a 4,250 TEU container ship through the Suez Canal is about 250,000 USD. (Suez canal official website) In contrast, the NSR transit fees have changed several times. Some studies prior to 2017 (Lasserre,2014,Sinha,2017, CHNL, etc.) mention that the NSR tariff collection is without any indicator and can be adjusted ad hoc. The relevant Russian authorities will negotiate and bargain for a lower tariff to be granted to some shipping companies, thus stimulating consumption to improve the competitiveness of NSR. In this context, some studies will consider possible discounts to estimate when setting NSR tariffs. (Wan, 2018) Furthermore, following the abolition of compulsory pilotage, in 2017, the NSR authority's official website has adopted a similar calculation to that of the Suez Canal transit fee for ice-breaking assistance. The fees payable by ships passing through the NSR are determined by the ship's gross tonnage, the ice class, the season of navigation, and the navigation zone.

In the new NSR transport solution in this paper, the ice-class vessels sail between the two trans-shipment ports and cover all navigation zones of the NSR. Considering that the ice floes in the various navigation zones of the NSR vary from season to season, this paper adopts a classification model (Sibul,2021) based on the parameters of navigation time, number of voyages, and ice class of the ship as described in the previous section. It makes new settings for the required transit in the new NSR transport solution.

In the new NSR transport solution, an Arc4 ice-class ship can make five one-way voyages in the five months from July to November, an average of one voyage per month. The ice thickness during the July-November period is shown in Figure 8.

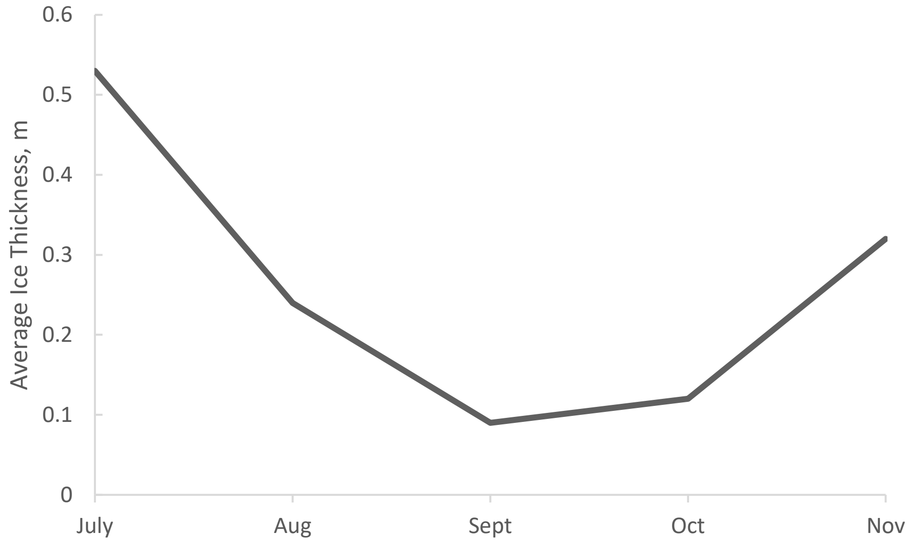

Figure 8. *Changes in ice thickness from July to November (Source: Author)*

In July, after a cold winter, the ice thickness in the waters of the NSR channel began to abate but was still relatively thick. This is also the most challenging month for navigational conditions during the navigable period and is set to 'difficult mode.' During the 'difficult mode,' ships must receive ice-breaking assistance in all seven of NSR's navigational zones to ensure safe navigation. According to the NSR website, the cost of passing through the seven navigation zones in summer for Arc4 ice-class vessels is 893.68 RUB per tonne.

During the warmer months of August, September, and October, when the ice floes are thin and navigational conditions are optimal, they are set to 'easy mode.' In this 'easy mode,' Arc4 ice-class vessels can safely navigate the NSR on their own ice navigation capabilities without additional ice-breaking assistance. Therefore, there are no additional transit costs.

As the temperature drops into November, the ice floes become more abundant in the NSR channel waters, and the ice starts to thicken again, setting it to 'general mode.'

During 'general mode,' Arc4 class ice-class vessels must receive ice-breaking assistance in four of NSR's navigational zones. Again, according to the NSR official website, the cost for an Arc4 ice-class vessel to pass through the 4 navigational zones in the autumn is 714.95 RUB per tonne.

The above grading of the difficulty of navigation at different times of the year gives the single transit fee to be paid by an Arc4 ice-class container ship passing through the NSR for the three modes and the total transit fee to be paid over a five-month navigable period. The specific formulae are as follows.

$$P_{NSR} = \begin{cases} 0,\ m \in [8,10] \\ C_1 \times GT, m = 11 \\ C_2 \times GT, m = 7 \end{cases}$$

Where P_{NSR} is the transit fee payable by a ship for a single passage through the NSR, m is the month of sailing. GT is the net tonnage of the ship. C_1 and C_2 are coefficients for different sailing difficulties, indicating the fee payable per tonne in the normal and difficult modes, respectively, determined by the ice class of the ship, the sailing season, and the navigation zone (NSR official website).

The ice-class of the 4250 TEU container vessel selected for this paper is Arc4, with a gross tonnage of 30,000 tonnes. In the general mode, C_1 is 714.95 RUB/ton, and C_2 is 893.68 RUB/ton.

By substituting the formula, the total charges to be paid from July to November are as follows.

$$\sum_{m=7}^{11} P_m = 0 + 30000 \times (714.95 + 893.68) = 48{,}258{,}900\ rub$$

The exchange rate between the RUB and the USD has fluctuated due to the recent

Russian-Ukrainian conflict and movements in oil prices. The RUB price has continued to rise, reaching 64.92 RUB per USD. In 2021, the average exchange rate will be around 73 roubles to 1 US dollar. The value of C_1 and C_2 are also in a state of flux. According to data from previous research, the value for the same Arc4 ice-class vessel is 429.97 RUB/ton for C_1 and 536.21 RUB/ton for C_2. (Wan,2018). It can be seen that compared to four years ago, the values for both C_1 and C_2 have risen to 1.7 times their original values, which can also be used as a reference when exploring possible future levels of NSR shipping costs.

4.3.9 Handling cost (C_H)

In the SCR transport solution, ignoring the intermediate ports of call, complete loading and unloading are done in a single voyage. However, in the new NSR transport solution, two additional loading and unloading activities are carried out on each voyage compared to the SCR transport solution. Two loadings and two unloadings will take place at the two hub ports. The costs incurred for loading and unloading are determined by the loading and unloading rates at the ports and the number of containers. For the loading and unloading rates, which are influenced by the recent congestion in the world ports, the March 2022 figure for the port of Shanghai is US$100 per container. In this paper's NSR new transport solution, ignoring possible port congestion, the two hub ports are used as full-fledged transshipment hubs, and the handling rate is adjusted downwards to US$50/TEU. For the number of containers, the load factor is further considered as an influencing factor. The vessel selected in this paper is a 4250 TEU container vessel, but the vessel will not be fully loaded in actual transportation but has a specific load factor. Taking the route chosen in this paper from the port of Shanghai to Rotterdam as an example, there is a significant difference between eastbound and westbound load rates, and the load rate of SCR is slightly higher than that of NSR. Under the new NSR transport solution, the load factor of container vessels rises as the level of cargo volume rises.

Based on previous studies and data, the load factors are adjusted: the load factors for SCR and NSR are the same, with an eastbound load factor of 60% and a westbound load factor of 80%. As explained previously, the NSR new transport solution can complete five one-way voyages within a five-month navigation period. According to CHNL statistics, the number of the west to eastbound transit trips for NSR in 2020 is 28, and the number of east to westbound trips is 17, which is 1.6 times more eastbound than westbound. Therefore, the NSR transport solution is set for 5 voyages, of which 3 are westbound, and 2 are eastbound. SCR can complete 4 one-way voyages, set for 2 eastbound and 2 westbound.

4.3.10 Inventory cost (C_I)

In the SCR transport solution, the ship and the cargo carried are the same, and they have a simultaneous nature. However, in the new NSR transport solution, there is a separation of ship and cargo. Take the specific route chosen in this paper as an example: A regular container ship arrives at the port of Petropavlovsk-Kamchatsky with its cargo, discharges it here, and leaves. The cargo is temporarily stored in the Petropavlovsk-Kamchatsky port awaiting loading by an ice-class container ship on the NSR segment. The ice-class container ship then sails with the cargo to the port of Murmansk, the hub port at the western end of the NSR, where it is discharged and departs. The cargo is again temporarily stored in the port of Murmansk, awaiting the arrival of regular container ships for loading and sailing to the destination port. The amount of ice-class ships and capacity available on the NSR segment and the arrangement and coordination of regular container ships by liner companies in the new NSR transport solution will impact the delay times at the hub ports.

Delay times at hub ports can put pressure on storage at the port and result in additional value loss for the cargo stored there. In this paper, the depreciation cost incurred when cargo is temporarily stored at the hub port is calculated and defined as the inventory cost, which is calculated as follows:

$$Inventory\ cost\ (C_I) = Depreciation\ rate \times Days \times Value$$

Where Days is the time the cargo is temporarily stored at the hub port, depreciation rate and value are the depreciation rate and value of the cargo, respectively, which varies depending on the type of cargo.

According to official data published by NSR, the main types of cargo currently transported by NSR are oil, gas, ore, and steel, which is in line with previous studies that have concluded that NSR is competitive in transporting bulk commodities. (P, O,2015) In addition, frozen fish and meat, and other general cargo are also part of the cargo currently transported by NSR. With the strong promotion of NSR by the Russian authorities, Asian and European shipping companies have successively shown interest in using NSR and have gradually started shipping activities for transporting different cargoes. In addition to tankers and bulk carriers with high transport activity, the frequency of container ships is also increasing. Relying on the electronics and manufacturing industries of Asian countries, these container ships transport mostly frozen fish and electronics. In addition, container ships can transport a wide variety of cargoes with widely varying values, such as expensive precision instruments and apparatus, electronic products, pharmaceuticals, and general merchandise of relatively low value. The difference in commodity properties and value of the cargo results in a significant difference in the value of the container and hence in the Inventory cost.

In this paper, the average value of each container load is taken to be US$17,699, based on data published by the World Shipping Council (WSC). The average value of the cargo is depreciated at a rate of 0.03% per day. On a one-way eastbound or westbound voyage, the cargo is temporarily stored at the two hub ports of Petropavlovsk-Kamchatsky and Murmansk for one day. The total storage time for cargo at the hub ports was 10 days over five months of navigation.

4.4 Scenario setting and parameter changes

In the previous section, the navigation model was constructed, and the basic calculations of the model parameters in the costs were performed. In this subsection, different scenarios will be set up. The calculations and values taken in the previous section will be used to vary the corresponding parameters to explore the impact of different factors on the NSR shipping costs.

4.4.1 Baseline mode

In order to provide a better general description of the costs of the new NSR transport solution, the parameters in the cost model are taken as average and general values in the baseline mode. The navigational parameters are set to the values that would be expected in good navigational conditions. In order to make the benchmark mode more general, some parameters that are affected by the epidemic and other factors, such as fuel prices and transit costs, are referred to the market values prior to the epidemic. The baseline mode describes the cost performance of the new NSR transport solution under general conditions and is intended to inform subsequent changes to different scenarios.

4.4.2 Fuel changes

Fuel is an essential factor in the cost of shipping. Changes in the price of fuel and the choice of fuel can impact the cost of shipping caused by fuel consumption. In order to visualize the impact of fuel changes on shipping costs, four scenarios have been developed: a low fuel price mode, a high fuel price mode, and two lower sulphur modes.

Scenario 1 is the low fuel price mode. This scenario is set against the backdrop of the global crude oil price crash, which began in March 2020, when international crude oil prices plummeted due to friction between OPEC and non-OPEC producers, led by Russia, over crude oil production policies at the start of the global Covid-19 rampage. Bunker prices for ships have also fallen sharply. The price of IFO 380 at the Port of Rotterdam, for example, had fallen to US$105 per tonne in April 2020 and hovered around US$250 per tonne for several months after that before gradually recovering in late 2020. In Scenario 1, the IFO380 price of US$250 per tonne is chosen to explore the performance of NSR shipping costs under a possible low fuel price scenario due to the international situation.

Scenario 2 is a high fuel price mode. This scenario is against the backdrop of rising global crude oil prices, which have soared since the Russia-Ukraine conflict in 2022. As a result of this, ship fuel prices have also increased. In scenario 2, the IFO380 price of US$750 per tonne (ship&Bunker, April 2022) is chosen to explore the shipping costs of the new NSR transport solution under the high fuel price mode.

Scenarios 3 and 4 are lower sulphur scenarios. This scenario is set against the backdrop of implementing the IMO's sulphur limit, which will reduce the maximum sulphur content of ship fuel from 3.5% (bunker weight) to 0.5% as of 1 January 2020. However, IFO 380 is still widely demanded in practice as ships fitted with scrubber towers are allowed to use higher sulphur fuels. In the NSR's navigation zone, however, the location in the Arctic requires greater caution regarding the emission of polluting gases. In scenario 3, regular ships use IFO380 as fuel at US$420 per tonne. Ice class ships use VLSFO with 0.5% sulphur content as fuel at US$580 per tonne. The sulphur content of the fuel is further restricted in scenario 4. VLSFO is used as fuel for regular ships, and MGO with a sulphur content of 0.1% is used as fuel for ice-class ships at

USD 700 per tonne.

4.4.3 NSR transit fee changes

As mentioned earlier, in the new NSR transport solution, the transit cost of NSR is determined by the month of navigation, the zone of navigation, and the ice class of the ship itself, which affects the difficulty of navigation. The difficulty of navigation is the reason for the difference in factors C_1 and C_2. Based on the official data published by NSR and the possibility of future NSR route development, two additional scenarios have been developed based on the baseline mode.

Scenario 1 is a low fee mode in the context of NSR offering discounts to navigable vessels. After the technical facilities along the coast have been improved and the new NSR transport solution has matured, to attract more customers and increase the competitiveness of the NSR waterway, the NSR authorities may grant a certain degree of discount and reduce the waterway fees. The low fee mode picks up a 20% discount under the baseline mode.

Scenario 2 is the high fee mode, with NSR's higher transit fees as the backdrop. The operation of NSR new transport solution may also face various challenges, such as being affected by changes in the international situation. In 2022, for example, the transit fees for NSR have repeatedly increased. The high fee mode is chosen to be twice as high as the baseline mode regarding current transit costs.

4.4.4 Load factor changes

The SCR and NSR load factors take the same value in the baseline mode, with load factors of 60% and 80% for eastbound and westbound, respectively. To explore the cost performance of the NSR at lower load factors, an NSR low load factor mode is set in the baseline model. The load factors for NSR eastbound and westbound are 50%

and 70%, respectively.

4.4.5 Insurance changes

At present, the number of vessels and the volume of cargo passing through the NSR is still tiny compared to other busy maritime transport corridors. As a result, there is no standardized insurance charge for vessels sailing the NSR. In Chapter 3, the criteria for insurance costs on traditional SCR routes are explained. Since SCR routes' insurance costs are relatively stable, similar fixed values have been taken for SCR insurance rates in most studies. In some studies comparing insurance costs for the NSR with those for the SCR, a 50% premium is commonly applied to the NSR. Such a premium is due to the remote Arctic location of NSR, which inevitably affects the speed of assistance following an accident. Political uncertainty may also have an impact on the progress of insurance claims. However, as NSR shipping activities have become more frequent in recent years and the marine environment has improved, some insurers have publicly stated that they do not charge additional protection and indemnity insurance (P&I) for NSR shipping activities.

As for Hull & Machinery (H&M) insurance, the cost of NSR is higher than SCR due to the varying degrees of hull strengthening required to adapt the vessel to ice navigation and the need to install some other equipment to ensure safe navigation.
Overall, as NSR shipping activity is still a relatively new type of trade, its risks and prices are still open to debate. In the benchmark mode in this paper, both protection and indemnity insurance (P&I) and hull and machinery insurance (H&M) for NSR is at a 50% premium compared to SCR. Two scenarios are set up to describe the possible insurance changes under the NSR new transport solution.

Scenario 1 is the low insurance mode, describing the cost performance when low NSR insurance. Based on the baseline mode, NSR's protection and indemnity insurance (P&I) is in line with SCR, and H&M's hull and machinery insurance (H&M) is at a 20% premium to SCR.

Scenario 2 is the high insurance mode and depicts the cost performance of NSR when insurance is higher. Based on the baseline mode, NSR's Protection and Indemnity Insurance (P&I) and Hull and Machinery Insurance (H&M) are both at a 65% premium.

4.5 Summary

In this chapter the navigation parameters in the new NSR transport solution are selected and calculated as shown in the following table .

Navigation parameters	NSR	SCR	Remarks
Ship type	4250TEU	4250TEU	Panamax container ships
Ice Class	Arc4	/	
GT	36000	30000	NSR + 20%
LDT	20400	17000	NSR + 20%
Distance (nm)	8316.5	12608.4	NSR ： regular ship 3918nm; ice – class ship 4398.5nm.
Navigation period (days)	150	150	
Speed(knots)	20；16	20	NSR : regular ship 20knots; ice – class ship 16knots.
No. of ports of call	3	4	NSR : Includes 2 transshipment ports
Docking time per port (days)	2	2	
Delay time per transshipment port of （days）	1	/	
Suez Canal delay (days)	/	3	
Total time in port	8	11	

(days)			
Regular ship navigation time (days)	8	26	
Ice class ship navigation time (days)	11	/	
Ship navigation time (days)	19	26	
Total time for a single voyage (days)	27	37	
No. of navigations	5	4	
No. of eastbound	2	2	
No. of westbound	3	2	
Eastbound load factor	60%	60%	
Westbound load factor	80%	80%	
TEUs in a single eastbound	2550	2550	
TEUs in a single westbound	3400	3400	
Total TEU	15300	11900	

Table 2. *Navigation parameters of NSR and SCR transport solution*

Having determined the basic navigation parameters, the parameters in the economic cost model were further interpreted and calculated by taking the values and calculating them, as summarised in the table below.

Cost parameters		NSR	SCR	Remarks
Ship Price (,000 USD)		7205	6550	NSR + 10%
Depreciation (USD)		Straight-line		over 25 years；Subcon scrap price : 620 USD/LDT
Insurance	H&M	2.1% Ship Price	1.4% Ship Price	NSR + 20%
	P&I	2.55% Ship Price	1.7% Ship Price	NSR + 20%
	Other Insurance	0	0.2% Ship Price	SCR: Pirate insurance
Cost per crew （USD/month）		5500	5000	Crew of 20；NSR + 10%

Maintenance（year）	1.32% Ship Price	1.1% Ship Price	NSR + 10%
Fuel costs	Determined by fuel consumption and fuel prices		See above for detailed calculations
Single transit fee（,000 USD）	Calculated for different navigational difficulties	230	-
Port charges（,000 USD/ port）	15	15	NSR : Includes 2 transshipment ports
Handling cost (USD/TEU)	50	/	
Inventory cost	Determined by depreciation rate, value of goods and storage time	/	See above for detailed calculations

Table 3. *Cost parameters of NSR and SCR transport solution*

5. Results and data analysis

In this chapter, the primary cost calculations for the new NSR transport solution and the SCR transport solution will be carried out based on the navigation and cost parameters calculations in the previous section. The economic feasibility of the new NSR transport solution will be analyzed by comparison. Then, a sensitivity analysis of the cost parameters is carried out to obtain the factors that significantly influence the costs. Finally, cost calculations are carried out for the different scenarios of fuel changes, transit fee changes, load factor changes, and insurance changes for the new NSR transport solution and the SCR transport solution, respectively, and cost analysis is carried out for different scenarios may arise in the future.

5.1 Cost comparison in the baseline mode

Based on the navigation and cost parameters identified in the previous section, a cost analysis of the new NSR transport solution in the baseline mode versus the SCR transport solution is shown in the table below.

Cost parameters		NSR	SCR	Remarks
150 Days				
Ship Price (,000 USD)		7205	6550	NSR + 10%
Depreciation (,000 USD)		916	990.033	over 25 years；Subcon scrap price : 620 USD/LDT
Insurance (,000 USD)	H&M	63.044	38.208	NSR + 20%
	P&I	76.553	46.396	NSR + 20%
	Other Insurance	/	5.458	SCR: Pirate insurance
Crew cost（,000 USD）		550	500	Crew of 20；NSR + 10%
Maintenance（,000 USD）		39.628	30.021	NSR + 10%
Fuel costs (,000 USD)		4034.106	6220.511	

Transit fee（,000 USD）	743.36	1000	64.92 roubles per US dollar
Port charges（,000 USD）	45	60	15000USD/port
Handling cost (,000 USD)	3060	/	50USD/TEU
Inventory cost（,000 USD）	812.384	/	
Total cost(，000 USD)	10340.075	8890.627	
No. of navigations	5	4	
Cost per navigation（，000 USD）	2068.015	2222.657	
Total TEU	15300	11900	
Transport costs per TEU（USD）	675.822	747.112	

Table 4. *Cost analysis of the NSR and SCR transport solution over 5 months*

A cost comparison shows that although the new NSR transport solution has a 34% shorter distance compared to the SCR transport solution, it does not result in a total cost saving. In the baseline mode, the total cost of the NSR transport solution is US$10.34 million, which is 16.3% higher than the SCR transport solution of US$8.89 million, putting it at a disadvantage in terms of the total cost.

However, since the NSR transport solution allows for one more voyage than the SCR transport solution over a five-month navigation period, the NSR transport solution is 6.9% lower than the SCR transport solution when discussing the cost of a single voyage. In addition, the extra voyage allows for more containers to be transported in the NSR transport solution than in the SCR transport solution, and the cost per TEU in the NSR transport solution is 9.5% lower than in the SCR transport solution. This result is also related to the consistency of the NSR and SCR load factors in the baseline mode, the impact of which will be discussed and analyzed later in the paper. Regarding navigation time, the NSR transport solution has 27 days per voyage due to the shorter distance traveled, 27% shorter than the SCR, a clear advantage.

The breakdown of the components of the cost components of the two solutions is shown in the following chart.

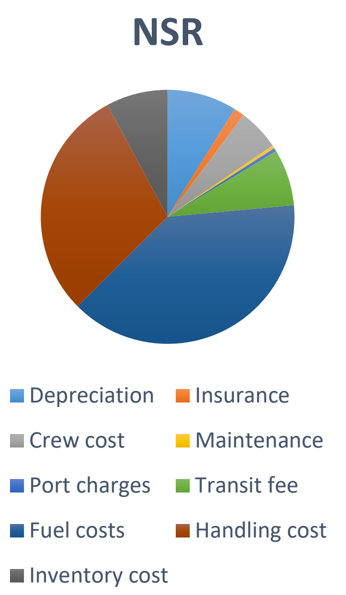

Figure 9. *Cost components of NSR*

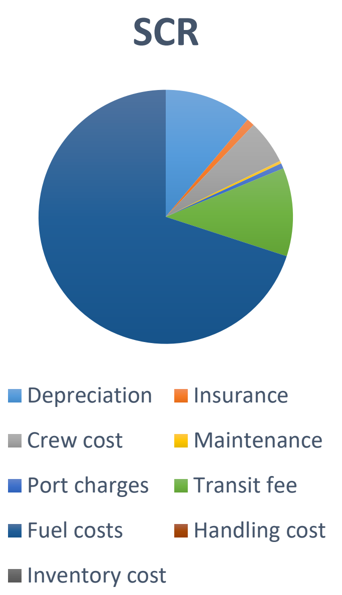

Figure 10. *Cost components of SCR*

As can be seen, fuel costs are the most significant factor in both the NSR and SCR transport solutions. In the NSR transport solution, fuel costs account for 39% of the total costs; in the SCR transport solution, fuel costs are even higher at 69.9%, accounting for most of the total costs. The cost factors that are more significant in both the NSR and SCR transport solutions are depreciation and transit fee, which account for $743.36 million or 7.2% of total costs for NSR and $1 million or 11.3% of total costs for SCR. the NSR transport solution has a significant advantage over the SCR transport solution in terms of transit fee. This factor is also discussed later in this section.

The smaller factors are insurance costs, maintenance costs, and port costs. Insurance costs are higher in NSR than in SCR, creating a potential scope for future reductions, which will be analyzed in the scenario discussed below.

Handling cost is the second most crucial factor in the NSR transport solution after fuel cost, accounting for 29.6% of the cost, reflecting the impact of the additional handling operations in the NSR transport solution due to the transshipment between the two hub ports. This reflects the cost impact of the additional handling operations at the two hub ports in the NSR transport solution. Similarly, at 7.9%, inventory cost reflects the impact of temporary cargo storage at the hub port in the NSR transport solution.

5.2 Sensitivity analysis of cost components

This subsection will conduct a sensitivity analysis based on the underlying analysis of the cost components above, varying some of these variables separately. This leads to further exploration of the impact on the costs of the NSR and SCR transport solutions when the different factors are varied. The cost factors were chosen to focus on their share in the two transport solutions. In particular, depreciation costs related to the price of the vessel are mainly influenced by the price of the vessel, which is a fixed asset with slight price variation and therefore not discussed in the sensitivity analysis. Maintenance, insurance, crew, and port charges are also not discussed in the sensitivity analysis as they represent a relatively low proportion of the cost components. Using the baseline mode as a basis and varying the significant factors in the cost components, a sensitivity analysis was carried out of the variance in total costs and the variance in costs per TEU. The results are shown in the two tables below.

Variable	-50%	-30%	-20%	0	20%	30%	50%
Fuel costs	-2542.650	-2105.368	-1886.681	-1449.448	-1012.167	-793.527	-356.245
NSR transit fee	-1077.768	-1226.440	-1300.776	-1449.448	-1598.120	-1672.456	-1821.128
Handling cost	80.552	-531.448	-837.448	-1449.448	-2061.448	-2367.448	-2979.448
Inventory cost	-1043.256	-1205.733	-1286.971	-1449.448	-1611.925	-1693.163	-1855.640

Table 5. *Sensitivity analysis of the total cost difference between the NSR and SCR transport solutions. The cost difference is calculated as SCR minus NSR , 000 USD.*

Variable	-50%	-30%	-20%	0	20%	30%	50%
Fuel costs	-58.243	-6.430	19.480	71.290	123.103	149.010	200.822
NSR transit fee	95.582	85.865	81.007	71.290	61.573	56.714	46.997
Handling cost	171.290	131.290	111.290	71.290	31.290	11.290	-28.710
Inventory cost	97.838	87.219	81.909	71.290	60.671	55.361	44.741

Table 6. *Sensitivity analysis of the cost difference per TEU between the NSR and SCR transport solutions. The cost difference is calculated as SCR minus NSR , USD.*

Sensitivity analysis allows the extent to which changes in variables affect cost variances to be obtained. As the results show, changes in fuel costs have the most significant impact on the cost variance. When the change in fuel cost was 20%, the impact on cost variance was 72.7%; when the change in fuel cost was 50%, the change in cost variance was even more significant at 181%. This illustrates the high sensitivity of the cost variance to changes in fuel costs. The effect of fuel variation on cost variance in the sensitivity analysis shows that the total cost variance between SCR and NSR decreases with higher fuel costs, indicating that the total cost advantage of SCR decreases with higher fuel costs. Higher fuel costs also result in a higher cost per TEU difference between the SCR and NSR transport solutions, suggesting that the advantage of NSR increases with higher fuel costs. As the sensitivity analysis is based on the cost model in the baseline mode, which is harmonized in terms of fuel selection for both transport solutions, fuel costs are discussed later in the scenario analysis.

In addition to fuel costs, changes in Handling costs have a relatively significant impact on cost variances. When the change in a Handling cost is 50%, the change in cost variance reaches 140%. The sensitivity analysis of the total cost difference shows that the only positive difference between SCR and NSR occurs when the Handling cost decreases by 50% when the total cost of SCR is higher than that of NSR, which also indicates that the total cost advantage of SCR decreases when the Handling cost decreases and may even be higher than the total cost of NSR. Thus, reducing the Handling cost at the two hub ports can effectively reduce the cost in the NSR transport solution and improve the competitiveness of NSR in the face of SCR.

Changes in two variables, NSR transit fee, and Inventory cost, can also affect the cost differential to some extent. When the NSR transit fee is reduced by 50%, the variance in costs changes by 34%. As the NSR transit fee decreases, the cost advantage of NSR increases, and the advantage of SCR decrease; when the NSR transit fee increases, it decreases the cost advantage of NSR. However, for the total costs in the baseline mode, changes in NSR transit fees do not negatively affect the difference in total costs in the two transport solutions. A more specific scenario analysis of NSR transit fees is also presented later.

Similarly, the cost variance changes by 37% for a 50% change in Inventory cost. As the Inventory cost decreases, the cost advantage of NSR increases. Again, the impact of a change in Inventory cost on the cost variance is more negligible in the baseline mode.

Overall, a sensitivity analysis of the cost differential between the NSR and SCR transport solutions in the baseline mode shows that: the cost differential is more responsive to the variables Fuel cost and Handling cost and less responsive to the variables NSR transit fee and Inventory cost. However, in the baseline mode, the parameters are taken more conventionally to make the results more generalizable. The different situations that may exist with NSR and SCR are also not treated differently. The values used in the sensitivity analysis are also broad. For all these reasons, and in order to compare the cost differences between the NSR and SCR transport solutions in more detail, this paper sets out to explore the cost performance of the two transport solutions under different conditions in more specific scenarios.

5.3 Scenario analysis

In the previous chapter, a selection of parameters from the cost model were used to set up various possible scenarios in detail. For possible changes in fuel costs, 4 scenarios were set up: a low fuel price mode, a high fuel price mode, and two lower sulphur modes. For possible changes in NSR transit fees, 2 scenarios are set: low fee mode and high fee mode. For possible changes in load factor, 1 scenario was set: NSR low load factor mode. For possible changes in insurance costs, 2 scenarios were set: low insurance mode and high insurance mode. The specific values taken and the results of the cost per TEU calculations are shown in Table 7.

Scenarios		SCR	NSR	Differential	Change rate （SCR;NSR）	Remarks
1	Baseline mode	747.112	675.822	71.29	0;0	
2	low fuel price	473.296	569.100	-95.804	-36.7% ; -15.8%	SCR & NSR: IFO380, 250USD/ton
3	high fuel price	971.127	882.989	88.138	+30%; +30.7%	SCR & NSR: IFO380, 750USD/ton
4	lower sulphur mode 1	747.112	729.335	17.777	0； +7.9%	Regular ships:IFO380, 420USD/ton Ice-class ships:

						VLSFO,580USD/ton
5	lower sulphur mode 2	801.864	816.401	-14.537	+7.3%; +20.8%	Regular ships:VLSFO, 580USD/ton Ice-class ships: MGO,700USD/ton
6	low fee	747.112	666.105	81.007	0; -1.4%	20% Discounts
7	high fee	747.112	724.407	22.705	0; +7.2%	2 times
8	NSR low load factor mode	747.112	776.76	-29.648	0; +14.9%	Eastbound load factor：50% Westbound load factor：70%
9	low insurance	747.112	674.154	72.958	0; -0.3%	NSR：P&I + 0 ，H&M + 20%
10	high insurance	747.112	676.704	70.408	0; +0.1%	NSR：P&I + 65%, H&M +65%

Table 7. *Change in cost per TEU for different scenarios, USD.*
Differential refers to the value of SCR minus NSR and represents the difference in cost. Rate of change refers to the percentage change in cost compared to the baseline mode.

The impact of different changes in fuel costs on the costs of the NSR and SCR transport solutions can be seen by describing four scenarios with different changes in fuel costs. In the low fuel price scenario, the impact of the NSR transport solution on the total cost of fuel savings due to shorter voyages is significantly reduced, with the cost per TEU being 95.804 USD higher in the NSR transport solution than in SCR.

In the low fuel price scenario, the NSR transport solution is too costly to be economically feasible compared to the SCR transport solution. Conversely, the advantage of the NSR transport solution in terms of fuel costs is further amplified in the high fuel price mode. The NSR transport solution saves 88.138 USD for each container transported, making it economically feasible for shipping companies to choose the NSR transport solution for transportation in the high fuel price scenario. While the first two scenarios show in a more general way the impact of high and low fuel prices on the costs of the two transport solutions, the following two scenarios are more realistic and describe what the future might look like for both the SCR and NSR transport solutions in the context of the shipping industry's trend to promote a cleaner environment.

Firstly, in scenario 4, the IMO imposes a strict requirement for ships sailing in the Arctic to use a fuel with a sulphur content of 0.5% or less, VLSFO, while regular ships sailing in regular waters can continue to use a higher sulphur content, but less expensive fuel such as IFO380, if the ship is equipped with desulphurization equipment. This is also in line with the current IMO regulations for ship fuels. The cost per TEU in the NSR transport solution is lower than in the SCR, which is still economically feasible.

In scenario 5, a further limitation is placed on the sulphur content of marine fuels. Regular ships in regular waters must use VLSFO with a sulphur content of 0.5% or less, and ice-class ships in the Arctic are required to use MGO with a sulphur content of 0.1% or less.With this set-up, the price difference between the two fuels used in the SCR and NSR transport solutions widens further, eventually causing the advantage of the NSR transport solution to disappear. The cost per TEU in the NSR transport solution is 14.537USD higher than in the SCR transport solution.

Overall, a decrease in overall oil prices will reduce the cost advantage of the NSR transport solution, while an increase in oil prices will increase the cost advantage of the NSR transport solution. However, possible future stricter emission regulations for ships sailing in the Arctic and the value differential between high clean fuel and regular fuel could have an impact on the competitiveness of the NSR transport solution.

The impact of NSR transit fees on costs is described by two scenarios, a low fee mode and a high fee mode. In scenario 6, it is set up that the NSR official gives a 20%

discount on transit fees for incoming and outgoing vessels to attract more vessels to use the NSR transport solution. In scenario 7, the NSR official charges double the transit fee for incoming and outgoing vessels. As can be seen, when the NSR transit fee is reduced, the cost per TEU is correspondingly reduced, and the cost advantage of NSR over SCR increases; when the NSR transit fee is increased, the cost increases, and the cost gap between NSR and SCR narrows. In general, however, the impact on total costs when NSR transit charges change, regardless of whether they are discounted or doubled, is not significant, consistent with the results obtained from the sensitivity analysis in the previous section.

Changes in the NSR load factor can also have a non-negligible impact the cost comparison results between the two transport solutions. The NSR and SCR transport solutions are set to have the same load factor in the baseline mode. However, in Scenario 8, when the NSR load factor is set to a lower value, the cost per TEU increases significantly beyond that of the SCR transport solution, making the NSR transport solution economically infeasible. Therefore, to maintain the cost per TEU advantage of NSR, the NSR load factor needs to be kept at a high value. Although there are no additional ports of call in the NSR transport solution than in SCR, this may reduce the load factor of the NSR transport solution to some extent. However, the short voyage duration and a high number of voyages in the NSR transport solution can compensate for the lack of ports of call to a certain extent. It is expected that the load factor will be on par with that of the SCR transport solution in future operations.

For the insurance cost of NSR, low and high insurance modes were set for calculation, respectively. Under the low insurance mode of scenario 9, the total cost per TEU in the NSR transport solution is reduced by only 0.3% in the face of no premium for indemnity insurance (P&I) and a 20% increase in hull and machinery insurance (H&M). Under the high insurance mode of scenario 10, with no premium for indemnity insurance (P&I) and a significant increase of 65% for both hull and machinery insurance (H&M), the total cost per TEU also increases by only 0.1%. Thus, in the new NSR transport solution, the impact of NSR insurance costs on total costs is almost negligible compared to other factors. This result also explains the positive attitude of some insurers towards NSR insurance, as the cost of insurance may not affect the economic feasibility of NSR transport when it comes to shipping company decisions.

6. Conclusion

This chapter will summarise the research. Starting with the main findings of this study and the limitations, the main work done in this study and the answers to the research questions are described. It also provides an outlook on the future development of the subject of this paper and makes some suggestions for subsequent related research.

6.1 Main findings

6.1.1 Exploration of a new transport solution for NSR

With the improvement of the navigable environment in the Arctic and the strong development of infrastructure along the NSR waterway by the Russian authorities, several explorations and ideas for new transport solution in the NSR have been proposed. This paper selects one of these concepts and designs a possible future solution of operation for the NSR.

In this new transport solution, instead of navigating the ice zone of the NSR themselves, shipping companies' vessels would transport cargo to the two hub ports of Murmansk and Petropavlovsk-Kamchatsky, located at either end of the NSR, where the cargo would be transferred to an ice-class vessel and ferried to the other end of the NSR. The cargo is then transferred again to the shipping company's conventional vessels and sailed to the destination port to complete the transport. In previous studies, most of the transport solutions of NSR have been studied as NSR operating alone during the navigable period or as a joint NSR-SCR operation. In this paper, a new NSR transport solution is based on a triple combination of NSR-led,ice-class fleet ferrying, regular vessel assistance, and transshipment at the hub port. This transport solution avoids the wastage of ice-class vessels operating in regular waters in previous studies of joint NSR-SCR operations. It increases transport efficiency by pooling the capacity of NSR's ice-class vessels into an ice-class fleet.

The new NSR transport solution places high demands on both the ice-class fleet and the infrastructure along the NSR coastline. Also, it requires sufficient cargo capacity to be available at both ends of the NSR to ensure that this transport solution is not 'empty.' The smooth operation of the new transport solution of the NSR will therefore require significant support from the Russian government, which is in control of the NSR, including the establishment of an ice-class fleet and further construction of the hub port. As the further development and utilization of the NSR can reach out to neighboring ports and regions, boosting economic growth along the coast, especially in the regions where the hub ports are located, as well as using the NSR's shipping activities to address the need to transport energy and other commodities, the Russian authorities have been seeking to develop the NSR in conjunction with Asian and European countries in recent years, hoping to develop the NSR project through international cooperation.

This has paid off, with China, Japan, and Korea in Asia and Denmark in Europe responding to Russia's NSR project and completing many NSR shipments, making it possible for the NSR to operate on a larger scale in the future.

6.1.2 Answers to the research questions

After defining the new transport solution of NSR, this paper identifies the research question to explore the possibility of this solution operating maturely in the future: What are the key factors affecting the economic feasibility of the NSR new transport solution? In order to answer this question, two further sub-questions are set: How can the economic feasibility of this transport solution be measured? How can the impact of different factors on economic feasibility be clarified?

First, the sub-question of the measurement of economic feasibility is answered. This paper designs an Asia-Europe route between Shanghai Port and Rotterdam Port, selects shipping parameters, identifies possible cost elements in various aspects of the new NSR transport solution, and constructs a cost model. The cost model also covers the cost elements in the traditional SCR transport solution. Therefore, the cost performance of Shanghai - Rotterdam in the traditional SCR transport solution is used as a comparison to measure the economic feasibility of the NSR transport solution. The cost model was developed and calculated to derive the cost performance of the new NSR transport solution under general conditions.

The total cost of the new NSR transport solution is higher than that of the SCR transport solution for the five months of navigation time selected for this paper. However, the sailing period is considerably shorter, resulting in more sailings than the SCR transport solution and, therefore, a lower cost per TEU than the SCR transport solution. Overall, the NSR transport solution is not economically feasible due to the higher costs than SCR in terms of total costs. However, the new NSR transport solution has advantages in terms of costs per container and overall time costs in individual container costs and transport times.

Then, based on the cost model, the sub-question of the impact of different factors on economic feasibility is answered. Specific scenarios were set up to analyze further the factors that may affect the economic feasibility of the new NSR transport solution, taking into account the realistic situation. As the total cost of NSR in the new transport solution is not economically feasible in the baseline mode calculations, in order to better demonstrate the possible impact of different factors on the NSR new transport solution, the cost per TEU in the NSR new transport solution was selected. The key factors affecting the economic feasibility of the new NSR transport solution were derived through sensitivity analysis and calculations in the scenario analysis. These three factors, fuel cost, Handling cost, and load factor, are the key factors affecting the economic feasibility of the new NSR transport solution. In addition, unlike previous studies on the impact of NSR, the cost of NSR transit fees and the cost of insurance do not significantly impact the cost of the new NSR transport solution. This shows that under the new NSR transport solution, shipping companies may not be too concerned about the official transit fees charged by the NSR and the insurance premiums required by the insurance companies when making decisions.

The research questions of this paper can be answered by answering two sub-questions. What are the key factors influencing the economic feasibility of the new NSR transport solution? Fuel cost, Handling cost and load factor are the key factors influencing the economic feasibility of the new NSR transport solution.

Firstly, the critical element that accounts for the most significant proportion of the cost components of the new NSR transport solution, and the one that has the most influence on cost changes, is the cost of fuel. The most significant advantage of the new NSR transport solution over the traditional SCR transport solution is the reduced distance traveled. The cost of fuel further determines whether this reduction in distance is magnified or reduced in cost terms. In the new NSR transport solution, ice-class ships consume less fuel than regular ships due to their lower speed, so the discussion of fuel costs is mainly focused on fuel prices. As can be seen in the scenario analysis, the cost advantage of the NSR transport solution diminishes with higher fuel prices. The potential for stricter emission regulations in the Arctic in the future will also impact fuel costs, as the difference in fuel costs between the NSR and SCR transport solutions will vary when the two transport solutions are faced with different fuel choices. As navigation restrictions in the Arctic become more restrictive, shipping companies will need to do careful calculations to ensure that the most economical transport solution is chosen.

Secondly, the second largest factor in the new NSR transport solution is the Handling cost, which arises due to the loading and unloading of cargo in transit between two hub ports. The Handling cost is flexible as the rate per TEU varies depending on the port. In the future, it may be reduced as transshipment and handling operations at the two hub ports mature, and port officials may offer some discounts to shipping companies in order to attract ships, similar to the way of tariffs charged by NSR in the past. The reduction in handling costs is also an effective way of reducing the costs of the new NSR transport solution.

Finally, the load factor of the vessels in the NSR transport solution is also a critical factor in its economic viability. The NSR transport solution can transport more containers in the same time frame with the same load factor. When the load factor of the NSR transport solution is lower, the advantage of completing more voyages in the same navigation time is diminished, and the economic feasibility of the NSR transport solution is reduced. Maintaining the load factor of vessels in the NSR transport solution is also necessary to ensure its economic feasibility. With the Russian authorities building up important ports at both ends of the NSR and the gradual improvement of the infrastructure along the NSR coast, the volume of goods that need to be transported at both ends of the NSR is expected to increase. With the new NSR transport solution in good operating condition, shipping companies are attracted by the advantages of faster sailing schedules and more voyages, increasing and keeping the shipload factor in the NSR transport solution at a high level.

In conclusion, the shorter voyage and transit time of the new NSR transport solution compared to the SCR does not necessarily make the NSR transport solution economically feasible. However, the economic feasibility of the NSR transport solution is strongly influenced by fuel costs, Handling costs, and loading rates. The economic advantage of the NSR transport solution is more significant when fuel prices are at a high level, the Handling cost at the hub port can be reduced, and the NSR loading rate is kept at the same level as the SCR loading rate.

6.2 Limitations

The study is based on an economic feasibility study of a transport solution that does not currently exist and has certain limitations. The main points are as follows.

Firstly, in terms of vessel selection, the more widely used Arc4 ice-class container ships were chosen, and the possible effects of different ice classes and ship types were not discussed further in-depth. In terms of route design and the design of navigation parameters, more complex ports of call were not designed in the NSR and SCR transport solutions in order to highlight the research issues and the different levels of loading and unloading operations that may exist at ports of call in the SCR transport solution were ignored. The issue of differences in container allocation due to the different container sizes used for different loading cargoes is not discussed further. In addition, values for some of the parameters in the cost model have been chosen for the ideal situation. For example, in practice, due to the capacity of the ice-class fleet and the scheduling of regular vessels, cargoes in the NSR transport solution may have to wait longer at two hub ports, resulting in an enormous Inventory cost. Ships in the SCR transport solution may also be delayed longer due to the blockage of the Suez Canal, etc.

These limitations may impact calculating a specific value in the cost model. However, it is still possible to use this study to provide a more evident exploration of the cost components and influencing factors in the new NSR transport solution.

6.3 Outlook for future research

This paper is concerned with the economic feasibility of the new transport solution of

NSR. Future research could continue this transport solution or explore more possible transport solutions of NSR.

The research on the new transport solution of NSR could be further refined based on this paper. For example, the paper does not consider the freight volumes at either end of the NSR and the capacity of the hub ports, and the capacity of the ice-class fleet. In the following study, it is possible to discuss what volumes of freight need to be achieved at both ends of the NSR in order for the NSR transport solution to be economically feasible. At the same time, further research can also be done on liner shipping companies' route coordination and load allocation planning for container vessels.

Secondly, this paper only examines the costs of the new NSR transport solution, based on which the profitability of the NSR transport solution can be explored about the freight rates of the container ships, and more practical profitability issues can be investigated. Finally, further research could be carried out on some of the influencing factors not discussed in this paper. For example, the differences in transport between ships of different sizes, types, or ice classes; other possibilities for Arctic emission requirements, such as limits on greenhouse gas and nitrogen oxide emissions, etc. In addition to the new transport solution of NSR studied in this paper, other solutions of NSR operation could also be explored. For example, the economic feasibility of using very high ice-class cargo vessels to sail independently on the NSR without any pilotage or ice-breaking services could also be explored.

Finally, the development of the NSR is a trend for the future and presents new opportunities and challenges for shipping companies and other stakeholders alike. In recent years, the Russian authorities have made significant efforts to develop the ports and infrastructure around the NSR. However, with the changing international situation, there is also a risk that the NSR could be considered a politically unstable area. In the event of unstable shipping routes, cargo transportation, emergency relief, and claims afterward will all be significantly affected, which will inevitably affect the choices of ship owners and cargo owners. The advantages of the new NSR transport solution will only be fully realized in the future when the ports and other facilities around the NSR are mature and there is an international agreement on the use of the NSR for shipping activities.

7. Bibliography

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