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Liangkun Xu

Qing Yu

RESEARCH ARTICLE

Performance Analysis: Using the Northern Sea Route as an Alternative to Traditional Routes

Liangkun Xu, Qing Yu*

Navigation College, Jimei University, Xiamen, China

Abstract

The grounding accident of M/V EVER GIVEN in the Suez Canal causes a catastrophic loss on shipping companies. Alternatively, previous studies have presented encouraging findings of the remarkable benefits of time and cost saving in the Northern sea route (NSR) due to extend the ice-free time and shorten the distance. Ships using the NSR could shorten as much as 40% of the sailing distance from China (Shanghai) to Europe (Rotterdam) compared with the traditional route via the Suez Canal. This paper investigates the economic potential of using the NSR as a cost-effective route in comparison with Suez Canal Route (SCR) between China and Europe. To achieve this target, the study evaluates the net profit for the SCR fleet and NSR fleet by involving the factors, e.g., bunker price, ice condition and ship loading rate, etc. The case-study results show that the NSR fleet is not profitable compared to the SCR, due to the limited cargo transport capability and ice restriction. Only if the loading rate for SCR fleet is lower than some threshold value or the bunker price is high enough, the NSR turns to be profitable.

Keywords: Northern Sea Route (NSR), Liner FLeet, Performance Analysis, M/V EVER GIVEN accident

1. Introduction

On March 23rd, 2021, M/V EVER GIVEN, one of the biggest Ultra-Large container vessels in the world, ran aground in the Suez Canal blocking the canal for seven days and led to more than one billion loss of U.S. dollars for facility damage and other claims. As an alternative commercial route to the traditional Suez Canal Route (SCR) [1], the Northern Sea Route (NSR) is becoming a potential scheme as the weather and navigational conditions change. The NSR is a sea route between the Far East and Europe that is shorter than the Suez Canal Route. With the regular use of NSR for commercial purposes, the potential of shipping via the NSR is being discussed in the world's media and by researchers [2]. A literature review that summarized most of the research related to the NSR before 2014 demonstrated that research on the commercial use of the NSR had attracted increasing scholarly attention [3]. However, after years and years, the commercial uses of NSR are still questionable for the shipping industry, even though the economic benefit of NSR is being highlighted by academics and journalists. Thereby, it is worth investigating the reasons behind the hypothesis and understanding the real demands in the practice.

According to early studies [4], the development of the NSR in the nineteenth century had placed a greater demand on safety research. Major developments in areas such as the environment, commercial usage possibility and financial interests could be summarized in three stages, as follows (also see Table 1).

Before the twentieth century, the NSR was strategically considered as an alternative route from the Far East to Europe with some uncertainties. Experts were more concerned about the infrastructure and the facilities of the NSR [5] or considered the differences among the Northern Sea Route, the Northwest

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* Corresponding author.
E-mail address: qing.yu@jmu.edu.cn (Q. Yu).

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Table 1. *A review of NSR studies.*

Year	Authors	Title	Journal	Objective	Open window	Ship type	Conclusion
1992	Wergeland, T.	*Commercial Requirements for a Viable Shipping Operation along the NSR*	INSROP Work Paper	Single trip for ship via NSR and Panama	N/A	N/A	The cost of the Panama Suez and NSR has been examined and NSR is not profitability based on scenario
1996	Mulherin, N. et al.	*Development and result of a Northern Sea Route Transit Model*	*CRREL Research Report.* US Army Corps of Engineers	Single trip ice-class ship cost by using NSR	Apr.−Oct.	Three ice-class ship type are considered(PC4 to PC7)	The cost of each trip from different place via NSR have been analyzed
2000	Ragner L.	*Northern Sea Route Cargo Flows and Infrastructure −Present State and Future Potential*	N/A	73 models are quoted to make a comparison	A year	bulk or container ships	At that time to invest the NSR is not profitable.
2006	François J. and Guy E.	*Supply and demand for the Eastern Canadian Arctic Sealift*	Maritime Policy & Management	Canadian Arctic	Based on annual demand	Dry bulk and general cargo	Compare to Suez, the NWP cost about 14.2% −33% less, but under some condition.
2006	Dermot L., Judson B. & Reid J.	Arctic tanker risk analysis project	Maritime Policy & Management	The risk of oil shipment by tankers in the Canadian Arctic	Multi	Tanker	The hazards of Arctic route have been identified and protection measures were proposed.
2007	Somanathan, S. et al.	*Feasibility of a Sea Route through the Canadian Arctic*	Maritime Economics & Logistics,	Compare operation costs per TEU for regular service	A year	4500 TEU Container ship-CAC3/PC2	The cost of trip via Panama is 8% cheaper than the NY route and NWP route is about 10% cheaper than the St John's route.
2009	Somanathan, S. et al.	*The Northwest Passage: a simulation*	Transportation Research Part A,	Assess costs of regular service on the NWP route	A year	4500 TEU Container ship-CAC3/PC2	Average cost per container: NWP 13$ per TEU cheaper than St-John's route and 84$ expensive than NY route.
2009	Khon, V. et al.	*Perspectives of Northern Sea Route and Northwest Passage in the twenty-sirst century*	Climatic Change	The navigation season for the Northern Sea Route (NSR) and Northwest Passage (NWP)	from 3 to 602 months for NSR and 2−402 months for NWP	N/A	The NSR from Western Europe to the Far East may be up to 15% more profitable in comparison to Suez Canal transit by the end of 21st century.
2010	Liu, M. and Kronbak, J.	*The potential economic viability of using the Northern Sea Route (NSR) as an alternative route*	Journal of Transport Geography	Compare operation costs for regular service	NSR used for 3, 6 or 9 months	4300 TEU container ship4300 TEU container ship, ice-class 1B	The time interval of open window decide the NSR profit and 9 month is the minimum if NSR profitable.

(*continued on next page*)

Table 1. (continued)

Year	Authors	Title	Journal	Objective	Open window	Ship type	Conclusion
2011	Hua, X. et al.	*The potential seasonal alternative of Asia Europe container service* via *Northern Sea Route under the Arctic sea ice retreat*	Maritime Policy & Management	Assess fuel costs	Summer	Conventional 10,000 TEU container ship, no ice-class No NSR fee	The fuel consumption of the ship navigating at NSR could saving 5% compare to traditional route.
2011	Schøyen, H. and Bråthen, S.	*The Northern Sea Route versus the Suez Canal: cases from bulk shipping*	Journal of Transport Geography	Optimize fuel consumption efficiency and fuel costs to assess transit costs	Summer	Conventional bulker verse ice strengthened (not specified) bulker insurance cost based on E3 = 1A = PC7	The fuel consumption of ship navigating at NSR could improve 1.5%.
2012	Kikkert P.	*Promoting National Interests and Fostering Cooperation: Canada and the Development of a Polar Code*	Journal of Maritime Law & Commerce	the law and climate change in the Arctic region	N/A	N/A	Canada's attempt to regulate shipping in the Arctic region through the implementation of a mandatory
2013	Smith C., & Stephenson, S.	*New Trans-Arctic shipping routes navigable by midcentury*	Proceedings of the National Academy of Sciences	Study the climate model impact for the open water ship crossing the arctic	September	ice-strengthened (Polar Class 6) ships	NWP and NSR were both considered as alternative route.
2014	Frédéric L.	*Case studies of shipping along Arctic routes. Analysis an profitability perspectives for the container sector*	Transportation Research Part A	Models of Arctic shipping considered for the review	N/A	N/A	The changing tendency of cost model for NSR, main parametres were presented.
2014	Farrã, A.	*Commercial Arctic shipping through the Northeast Passage: routes, resources, governance, technology, and infrastructure*	Polar Geography	The potential of Arctic routes as an alternative to the Suez Canal	N/A	N/A	Technological and infrastructure investments may require for further development for the Arctic area.
2016	Gritsenko D.	*A review of Russian ice-breaking tariff policy on the northern sea route 1991−2014*	Polar Record	A review of Russian ice-breaking tariff policy tendency, that impact the NSR route	N/A	N/A	The ice-breaking fees play a key role for the NSR utilization rate.
2016	Pruyn, J.	*Will the northern sea route ever be a viable alternative?*	Maritime Policy & Management	Dry bulker transport via the Northern Sea Route (NSR)	Two years	Dry Bulker	The NSR is a very unlikely alternative to the conventional Suez route.
2018	Xu et al.	*Economic feasibility of an NSR/SCR-combined container service on the Asia−Europe Lane: a new approach dynamically considering sea ice extent*	Maritime Policy & Management	Economic feasibility between NSR and SCR under dynamic sea ice conditions.	The open window in the year of 2015	Container	NSR is more economical than SCR when if the NSR tariffs is lower.

2018	Lin and Chang	*Ship routing and freight assignment problem for liner shipping: Application to the Northern Sea Route planning problem*	Transportation Research Part E: Logistics and Transportation Review	Route planning related factors	A voyage trip	Container	Navigation skill, bunker price, delay penalty and service commitment are the primary factors that affect the NSR's commercial practicability.
2019	Theocharis et al.	*Feasibility of the Northern Sea Route: The role of distance, fuel prices, ice breaking fees and ship size for the product tanker market.*	Transportation Research Part E: Logistics and Transportation Review	Route planning related factors	Round voyages at summer and autumn season	Tanker	Examining the feasibility of the NSR against the oil product tanker segment at the tactical/operational level.

Passage and the Central Route [6]. The research results revealed that the NSR is not profitable compared with the Panama channel and the Suez channel routes based on scenario analysis, mainly on account of the presence of ice, the required equipment technology and communication restrictions [7]. The cost of each voyage through the NSR was also analysed in detail. In this paper, the requirement for ice-class ships is discussed, depending on which the vessels through the NSR should be reinforced with a bow structure and other elements as a minimum requirement. This requirement imposes an extra cost on ship owners, therefore the NSR was not considered as a profitable route but a possible one.

Russia opened the NSR for commercial use following with the ice melting, developments in navigational technology, and the extension of the NSR open window, after which the main questions about the NSR were no longer concerned with feasibility but rather with profitability. Many studies have turned their focus to the financial advantage afforded by the NSR, but the lack of scholarly agreement was conspicuous. In the beginning, many studies investigated the advantage of the NSR, but a possible result demonstrated that investment in NSR trips was not profitable because of the considerable expenses of the hull and machine, high administration costs, and potential navigation risk [8]. Others suggested NSR can be more profitable due to the time and fuel saving. For instance, based on a fuel consumption model, a study [9] stated that the NSR could produce savings of 5% in fuel consumption compared to traditional routes, although the fuel consumption of ships navigating through the NSR could improve by approximately 1.5% due to ice resistance [10]. In the meantime, to maintain ship safety, many studies have identified the hazards of using the NSR and other Arctic routes and have proposed some protection measures [11]. A voyage in the NSR undertaken for individual developments often involves an important issue of ship type as different they require different safety measures. The financial assessments for different ship types in the Arctic route and Suez channel route could be different under different route open windows. For instance, assuming the NSR is freely for year-round uses, the study argued that both the Northwest Passage and the NSR cost less than other traditional routes [12] and that the NSR from Western Europe to the Far East may be 15% more profitable compared to the Suez Canal transit [13]. However, the assessments are purely based on hypothesis in the modelling process. The results predicted from the optimistic hypothesis may not agree in the shipping industry.

Recently, studies have mainly focused on such factors of the NSR as the impact of extra administration cost [14], the changing tendency of the cost model [3] and regulatory issues [15]. Based on cost factors, some previous studies have compared and contrasted shipping costs in ordinary routes versus the NSR and accordingly formed models to calculate the direct costs of consumption under different routes. Few studies have also compared the Northwest Passage [16] and other potential routes in the Arctic Ocean waters, illustrated the partial advantage of the NSR over other routes [17], whereas other studies have argued that the potential of the Arctic route is overstated [18]. Some studies have conspicuously proposed that the development of the NSR will be closely related to the Chinese shipping market. The advantage of the shorter sailing distance between Europe and China is mentioned, but the calculation of the financial benefit for an NSR voyage might provide a different perspective on the future development of the NSR.

In terms of the modelling approaches used in NSR study, several examples are discussed in a systematic review of the literature on the basis of comprehensive and unbiased searches of the relevant studies (i.e. Theocharis et al., 2018). The study notes that different modelling approaches are applied to analyse the NSR, such as operational research and cost modelling (Zhao et al., 2016b), empirical case studies (Lasserre, 2019), structural econometric modelling (Xu and Yip, 2012), etc. Theocharis (2019)reviews the different types of models that analysing the profit of NSR and highlights a significant increasing trend of publications appears. While, it suggests that although the NSR is competitive than the traditional route, it is more suitable for bulk rather than liner shipping due to the short open window for NSR. The economic potential of an NSR liner is worthy discussed in further studies.

Due to the harsh environmental condition in the NSR, a voyage through the Arctic route could be influenced by many factors; one is the speed limit affected by the ice condition and the associated speed reduction that influences not only the turnover time for a container fleet but also the ship's fuel consumption. Some previous studies modelled the effect of the average speed on ship safety, normally within a specified period of time called the "open window"; for example, a year-round open window or a summer open window. To ensure the safety of a ship navigating through the NSR, the average speed should be between 7 and 11 knots for a year-round trip and the safe speed for a summer open window should be less than 17 knots and optimally between 13 and 15 knots [19]. While, Xu et al. (2018) discussed the potential service to link Shanghai and Rotterdam by using NSR and SCR. The study noted that the profit margins of NSR are dynamic, changing with the levels of the ice-cover and safe speed. It claims that the NSR is more economical than SCR when if the NSR tariffs is lower.

Although these studies provide useful findings to consider the ice impact on profit margin, the benefit loss caused by ship speed reductions has not been carefully analysed in a comprehensive manner (e.g. ship fleet). Hence, fully understanding the financial advantage and disadvantage of NSR could help to uncover a fuller view of the economics of using the new route. For this aim, Lin and Chang (2018) propose a general time-space network-based mathematical formulation to assess the economic route planning for liner shipping. The importance of navigation skill, bunker price, delay penalty and communication are highlighted as these factors showing higher effects on the practicability of NSR. Theocharis et al. (2019) analyse the feasibility of the NSR. In their study, the related factors of distance, fuel prices, ice breaking fees and ship size are covered to investigate the possibility of using NSR in the tanker market. The findings support that the profits for an individual tanker are considerable, identifying the key impact factors are fuel price and ice breaking fees.

In light of the above discussion, as most of the previous study research the profit of an individual ship that using NSR, lack comprehensive investigation of profit advantage of using a liner fleet in NSR, this paper utilises an integrated assessment to examine the relative financial advantage of using a liner segment in the NSR versus the Suez route. Moreover, although several factors (e.g. fuel price, administration fees, safety speed, etc) have been discussed in previous study, the study considers the benefit loss that caused by the speed reductions, which is rarely noted by previous studies. The result findings provide a novel view on the commercial uses of container fleet in the NSR waters.

The rest of the paper is organised as follows. Section 2 discusses the major impact factors in NSR that related to ship profit margin. Considering all the factors, Section 3 proposes several algorithms to calculate the profit margin of ships. Section 4 studies a real case of liner between Shanghai port and Rotterdam port and the result are discussed in Section 5 and at last, a conclusion is drawn.

2. Major impact factors on NSR

2.1. Open window

The temperature in the Arctic region has notably increased, and ice melting has accordingly accelerated. The direct result of a longer ice-free period and the shrinking of the ice layer thickness is an increase in the availability of the NSR. In accordance with relative statistics, the average temperature in the arctic area increased by approximately 3 °C from 1860 to 2009, thereby reducing the ice layer for the entire year. Recently, the ice cover decreased by 60% relative to 1979 [20].

A study from ACIA (Arctic Climate Impact Assessment) predicts that the ice-free period of the NSR would be longer than one hundred days in recent years. At the same time, the thickness of the ice layer has gradually shrunk year after year, and accordingly, the distribution range of the multi-year ice has been drawing back to the polar center. Scholars in related fields who adopted a positive view towards this phenomenon estimated that in 2050 the Central Arctic Ocean (CAO) would be available for shipping [21]. Correspondingly, the open window of the NSR has been defined as the number of days that the ice cover is less than 15% [22], which is selected as the threshold value of open window for ships free sailing in NSR waters without an icebreaker. Consequently, this calculation indicates that the NSR is free for navigation during the summer, which implies an extended open window in the future.

2.2. Extra facilities

Vessels operating in special weather conditions in the Arctic region face a variety of hazards that are not likely to occur under ordinary conditions, such as polar blizzard wind, polar cyclone, hypothermia, and floating ice. These conditions all have an adverse effect on the ship operation that may directly threaten the ship safety. Therefore, extra requirements of vessel equipment are necessary.

Meanwhile, the polar code IMO (International Maritime Organization) also requires ships in NSR waters fitted with sufficient security and fire precaution equipment [23]. In addition to the IMO, IACS (International Association of Classification Societies) puts forwards requirement for vessels equipment and facilities operating in the icing area. For example, as mentioned in the report of the ABS (American Bureau of Shipping), the equipment for the Arctic region must address the problem of winterization; corresponding coating and heating equipment is therefore required to guarantee the normal operation of the pipelines [24].

Moreover, communication is another concern that should be addressed. GMDSS communication equipment aims at maintaining the vessel security and emergency communication. However, in the Arctic region, due to the limitation of satellite coverage areas, INMARSAT satellites can only work in areas located no higher than 76° northern and southern latitude. Hence, for vessels sailing on the CAO route, ships should be equipped with MF/HF radio to guarantee normal safety communication and reliable DSC (Digital Selective Calling on MF) emergency communication.

2.3. Fuel consumptions

The cost saving on vessel fuel is one of the main factors that make the NSR attractive. The shipping industry is deeply affected by fluctuations in the oil price of international shipping [25]. In this case, the future trend of international oil prices will directly affect the economic benefits of developing the NSR for investors. If the prices of international oil decrease, ship owners will be more willing to use the familiar SCR instead of investing in the NSR.

There are many methods for calculating fuel consumption from different views. The present fuel consumption formula has been improved by finding a formula that shows the relation between displacement and fuel consumption [26]. A function used in the study provides a straightforward expression of fuel consumption for the voyage approximated by using the following equation

$$f_{(V)} = c \cdot d \cdot V^2 \quad (1)$$

where $f_{(V)}$ is the total fuel consumptions (tons)? The c is the converting speed factor to fuel consumption, subjecting to several factors such as the type of engine, the propeller efficiency, resistance, etc. The d is the total distance, and V is the average speed. The fuel consumption curve by size and speed for container ships is presented in Fig. 1 (Notteboom & Cariou, 2009).

2.4. Administration fee

This section uses the Russian NSR fees as an example. The Russian ice-breaking fee is affected by ice class, vessel size, the passage and the types of support required. The basic charge depends on the ship size. In the early 1990s, the ice-breaking fees were on average 2 to 4 USD per ton of cargo while the volume of goods was between 2.5 million to 2.8

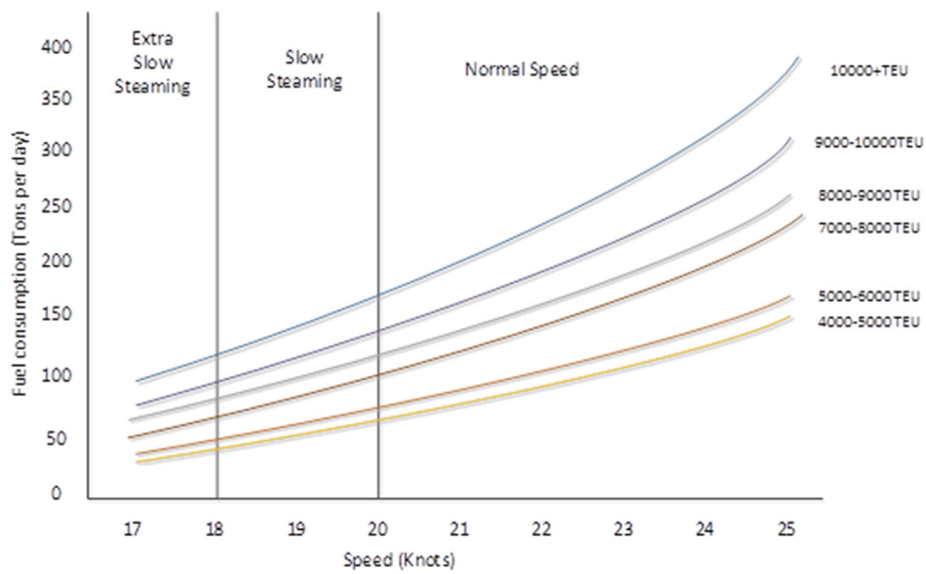

Fig. 1. Daily fuel consumptions under different speeds and sizes. Source: (Notteboom & Cariou, 2009).

million tons per year. In 2003, the subsidies from the Russian government stopped, and the Ministry of Economic Development and Trade released a statement on January 10th, 2003 "About Changes in Rates for Ice-Breaking Fleet Services in the NSR" and announced a new (higher) rate amounting to 23 USD per ton of cargo on average. In addition, the last official tariff schedule along the NSR is published in the year 2014 (Gritsenko and Kiiski, 2016), which can be found on the website: http://www.nsra.ru/en/home.html. The most recent charging fee for ice-breaking services for cargo shipped by the standard container is 893.68 RUB per ton, which is equivalent to 12.07 USD per ton. Thus, for a TEU with an estimated load of approximately 24 tons of cargo, its ice-breaking fees for shipping one TEU using the NSR will be 289.68 USD, which is extremely high in comparison with other cost elements. In the future, adopting national policies and a plan of introducing market mechanisms into the NSR will conspicuously affect the rates depending on the cargo volume and the financial resources for maintaining services of ice breaking. Moreover, pilotage may also be necessary in addition to ice-breaking service. In particular, two pilots will be placed onboard and the fees are available online and can be calculated directly.

2.5. Speed limitation

A ship navigating in the NSR could face extremely complicated ice conditions. To protect the ship's hull and ensure the machines operate safely, the ship should reduce its speed and take precautionary measures. For this reason, Wergeland [7] simulated the ice impact on the hull and machine. In the study, the maximum safe speeds for a non-ice class (PC6 or PC7) ship navigating without an icebreaker under different ice conditions were presented (see Table 2).

Table 2 indicates that when navigating in the NSR under ice-free conditions and clear weather, the proper navigational speed is 18 knots. If the weather condition turns bad and the ice layer becomes thicker (more than 0.25 m), reductions are needed.

3. Methodology

This section provides the calculation of ships' net profits under different situations. The net profit calculations are based on the following formula:

$$R_{net} = P - C \quad (2)$$

where R_{net} is the net revenue, P is the gross revenue and C is the cost for goods/service (i.e. the cost of providing the container transportation). The change in total gross profit during a period of time $T + T'$ is closely related to the container freight price $P_{freight}$, the shipment volume Q, and the ship speed V, and the route distance d, in which the T is the voyage time and the T' is the margin for loading/unloading, waiting or other time need for ship in a voyage loop. The gross profit can be calculated as follows:

Table 2. Speed limit and the ice thickness at NSR.

Ice Thickness (metres)	0	0	0.25	0.5	1	1.5	2.5
Weather Conditions	Clear	Fog					
Vessel Speed	18	15	13	10	8	6	6

Source [7].

Table 3. The details of ship voyages by using SCR or NSR during 120 days open window.

	SCR fleet under different loading rate	NSR under different ice Condition				
Ship Speed		Ice free	0.25	0.5	1	2.5
	20	18	13	10	8	6
Route Distance (nm)	10,200	7700 (2700 nm with ice and 5000 nm of ice free)				
Voyage Time (days)	21.3	17.8	20.2	22.8	25.6	30.3
Round voyage time (days)	42.6	35.6	40.4	45.6	51.2	60.6
Plus 20% voyage margin (days)	51.12	42.72	48.48	54.72	61.44	72.72
Ship number for a fleet (weekly liner)	7	6	7	8	9	10
Number of loops[a]	10	11	10	10	9	N/A
Total sailing days	511.2	469.92	484.8	547.2	552.96	N/A
Total transport TEU	120,000	132,000	120,000	120,000	108,000	N/A
Gross profit (USD)	150,000,000	165,000,000	150,000,000	150,000,000	135,000,000	N/A

[a] *Number of loops* $= \sum S_i N_j$ *(Si: ship i for weekly liner, Nj: number of loops finished by ship i).*

$$P = P_{frieight} Q \left[\frac{(T + T')V}{D} \right]_{floor} \tag{3}$$

The cost combines two aspects, the capital cost C_c and the operation cost C_o. Capital cost normally includes the contracting cost, equipment cost, classification cost, etc. According to IMO Polar code (available at: https://www.imo.org/en/OurWork/Safety/Pages/polar-code.aspx), the requirements of the ship navigating in the arctic area are special classification procedure and structure reinforcement. The operation costs C_o are much more complicated, containing the insurance cost C_i, the bunker price C_f, the crew member salary C_s and other dynamic costs C_{others}.

$$C = C_c + C_o \tag{4}$$

where

$$C_o = C_i + C_f + C_s + C_{others} \tag{5}$$

According to the Equation (1), the fuel consumption for a ship could be calculated as follows:

$$C_f = P_f c d_{i,i+1} V^2 \tag{6}$$

Here, P_f is the Bunker price. By considering the above methods, the net profit can be expressed as follows:

$$R_{net} = (P_c Q - (C_c + C_o)) \left[\frac{(T + T')V}{d} \right]_{floor} \tag{7}$$

4. Case study

4.1. Case descriptions

In this section, a case of liner between Rotterdam Port and Shanghai Port is studied. The open window for the NSR is 120 days from July to October. The distance of route via Suez Canal is approximately 10,200 nautical miles and the distance of route via NSR is approximately 7700 nautical miles, contains 2500–2700 nautical miles of ice-covered waters.

In light of the special requirement for an NSR trip, an ice-class ship may be required, and the particulars of the ship should meet the draft limitation and sea condition, which does not exceed 13 m. Hence, this study chooses a 6000 TEU container ship (e.g. Panamax-type ships.) for NSR and SCR. The daily charter rate is 20,000 USD approximately (Charter price from Shanghai Shipping Exchange). The case study assumes four ice conditions, ice-free, thicknesses of 0.25 m, 0.5 m and 1 m. The maximum safe speed of a ship navigating in ice-free water is 18 knots. Meanwhile, the ship speed for the SCR fleet is assumed as 20 knots, which is close to the slow steam speed in real practice [27].

4.2. Route loops and fleet schedule

The study supposes that the container fleets are operating as a weekly liner, considering the study under a container fleet level that the vessels are on a given maritime route and loop [28]. Due to the speed difference, distance difference and ice conditions, the loop time for NSR fleet is erratic. While, time for port operation, bunker, cargo loading or unloading operation is considered by plus 20% voyage margin for each round voyage. Consequently, the need of the ship number for each fleet under different ship speed is shown in Table 3.

Based on Table 3, the liner schedule for SCR and liner schedule for NSR under different ice conditions are manifested in Table 4.

Table 4. The container fleet schedule for SCR fleets and NSR fleets.

	Ice condition	Fleet ship numbers	Estimated Time of Departure (week)																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SCR	N.A	7	S1	S2	S3	S4	S5	S6	S7	S1	S2	S3	–	–	–	–	–	–	–
	0	6	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	S5	–	–	–	–	–	–
	0.25	7	S1	S2	S3	S4	S5	S6	S7	S1	S2	S3	–	–	–	–	–	–	–
NSR	0.5	8	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	–	–	–	–	–	–	–
	1	9	S1	S2	S3	S4	S5	S6	S7	S8	S9	–	–	–	–	–	–	–	–
	2.5	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

**S1, S2⋯Si: Ship name in the fleet.*

Table 4 reports that ten-round voyages could be completed and seven ships are required to guarantee a weekly liner for SCR during the 120 days open window. At the same time, one more round voyage can be completed by the NSR when ice-free. The required vessel number for the NSR fleet is six. When the condition turns bad, the required ship number and the number of loops drop. If the ice thickness exceeds a certain value, (i.e. 2.5 m) the NSR turns to be unavailable for weekly container liner.

4.3. TEU offering and incomes

The gross profits for SCR liner and NSR liner are calculated and displayed in Table 3. The total transport volume for SCR fleet during the open window is 120,000 TEU. Comparing to SCR fleet, the maximum transport volume for NSR fleet is 132,000 TEU under the optimal.

The liner freight rate between Rotterdam and Shanghai refers to World Container Index. In this study, the average freight price between Based on the market demand, the eastbound trip is popular and the average freight price is about 1700 USD per TEU and the westbound trip only costs about 800 USD per TEU. Hence these two benchmarks are selected. Then the total income for NSR fleets and SCR fleets could be estimated under different loading rates or ice conditions.

4.4. Capital cost and operation cost

The Following results separately reveal the bunker and the capital costs. Referring to the IFO380 bunker price from 20 ports between 2013 and 2019, a price interval between 300 USD per ton and 800 USD per ton is used [29] (bunker price available at: https://shipandbunker.com/prices/). The capital cost and other operation cost, for instance, crew, insurance, maintenance and administration refer to a research from Lasserre, F. (2019). Cost differences are quantified at the lowest reasonable level, and the NSR fleet has some extra costs due to some requirements of ice class and other conditions. The daily operating cost for NSR and SCR is indicated in Table 5.

The cost for a single ship multiplies the operation days and the vessel numbers to calculate the total cost (see Table 6).

Owing to the difference in the average speed of the container ship for SCR fleet and NSR fleet, the faster ship needs more fuel for an identical distance, which plays into the fuel cost.

After calculating the cost for NSR fleet and SCR fleet, the total net profit for liners using NSR route and for liners using the Suez route in a period of 120 days (from July to October) is obtained and demonstrated in Table 7, which proposes a detailed comparison of the net profit for NSR weekly liner along the various average speed compared with SCR liner.

5. Results and discussion

5.1. Impacts of bunker price on profit margin

The bunker price strikingly impacts the total profit margin. The fuel cost of a liner fleet under different speed and bunker price in NSR and SCR are presented in Fig. 2.

It can be found from Fig. 2 that the NSR is more fuel-efficient compared to the traditional route on account of the shorter distance. An increase in the bunker price makes the cost difference more obvious. With the rise in fuel prices and the stagnation of the market, a rising number of ship companies are using a slow steam speed to save fuel

Table 5. Daily operating cost for the ship using SCR or NSR.

	SCR	NSR	Ice factor[a]
Total Capital Cost per day	17,022	29,320	172%
Manning	2392	3833	160%
Insurance (H&M, P&I)	2300	4166	181%
Repairs and Maintenance	1380	2307	167%
Administration and Others	3251	5608	172%

[a] Ice factor = Column NSR cost/Column Suez cost.
Source [30].

Table 6. Cost list for the SCR fleet and the NSR fleet.

Ice Condition	SCR	NSR				
	N/A	0	0.25	0.5	1	2.5
Charter cost[a] (USD)	10,224,000	9,398,400	9,696,000	10,944,000	11,059,200	N/A
Capital cost (USD)[b]	8,701,902	13,778,336	14,214,627	16,044,232	16,213,119	N/A
Channel/route surcharge (USD)	1,753,860	9,161,130	8,328,300	8,328,300	7,495,470	N/A
Fuel consumption (Tons)	79,551	53,867	51,174	48,615	46,185	N/A
Fuel cost = 300 USD per Tons	23,865,395	16,160,245	15,352,233	14,584,622	13,855,390	N/A
Fuel cost = 800 USD per Tons	47,730,789	32,320,491	30,704,466	29,169,243	27,710,781	N/A
Total cost (Fuel cost = 300 USD per Tons)	44,545,157	48,498,112	47,591,160	49,901,154	48,623,179	N/A
Total cost (Fuel cost = 800 USD per Tons)	68,410,551	64,658,357	62,943,393	64,485,775	62,478,570	N/A

[a] *Charter cost for SCR fleet (6000 TEU):10,000 USD per days. Charter cost for NSR fleet (6000 TEU):10,000 USD per days.*
[b] *Capital cost = Number of loops*capital cost for single ship (per day) × voyage time.*

Table 7. Profit balance for the SCR fleet and NSR fleet.

	SCR fleet	NSR fleet under different ice Condition			
		Ice free	0.25 m	0.5 m	1 m
Ship Speed (knots)	20	18	13	10	8
Gross profit (USD)	150,000,000	165,000,000	150,000,000	150,000,000	135,000,000
Total cost (USD)	44,545,157	48,498,112	47,591,160	49,901,154	48,623,179
(Bunker price = 300/800 USD/Tons)	68,410,551	64,658,357	62,943,393	64,485,775	62,478,570
Net profit (USD)	105,454,843	116,501,888	102,408,840	100,098,846	86,376,821
(Bunker price = 300/800 USD/Tons)	81,589,449	100,341,643	87,056,607	85,514,225	72,521,430

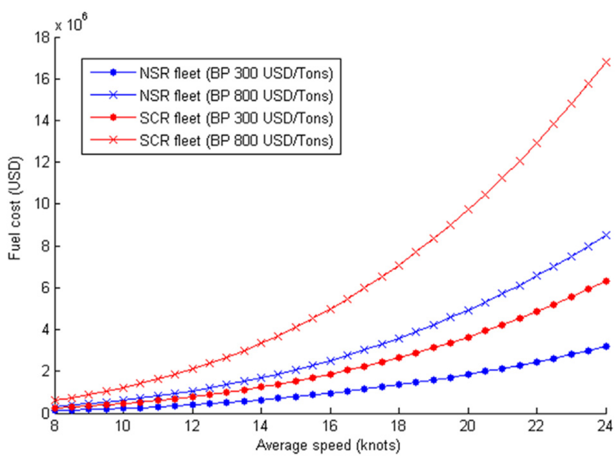

Fig. 2. Fuel cost for the SCR fleet and the NSR fleet under different average speed.

costs. The rising bunker price boosted the advantage of the NSR in that the shorter route of the NSR means that more fuel can be saved, thereby increasing per voyage profit.

Then we combine the total loops for the fleets and the single trip profit to get the total net profit for a fleet. It was quite evident from the case study that the profit difference between the NSR and the Suez route varies with different factors but mainly the bunker price, and the ice condition. As the complicated ice conditions reduce the ship sailing speed, a short distance route may have more days and more required ships to maintain the weekly liner on account of the reduction caused by ice. Thereby, increasing the cost of the crew, heating, extra facility, administration cost and other extra cost. The NSR fleet would be relatively high according to some requirements and environmental conditions at NSR. Figure 3 (a) and (b) indicate the trade balance for the NSR fleet and SCR fleet when the bunker price is 300 USD per tonnage and 800 USD per tonnage separately.

It is observed that the NSR fleet takes more advantages as the distance for NSR is shorter and the NSR fleet is more cost-saving. However, lower bunker price decreases the operation cost for the fleet in NSR and extends the net profit, so that the competitiveness of NSR is reduced. The result also shows high bunker price could not totally change this matter but narrowsthe gap between NSR fleet and SCR fleet.

Moreover, it is impossible for a large ship to use NSR due to the draft limitation and ice condition. The SCR fleet takes a advantage of cargo transport capability compares to the NSR fleet. In general, the single transport capacity of SCR liner is about three times more than NSR liner. If the market demand cannot support high loading rate for SRC liner, using of NSR fleet is superior as the capacity is still maximum and the NSR fleet becomes a profitable option instead of SCR.

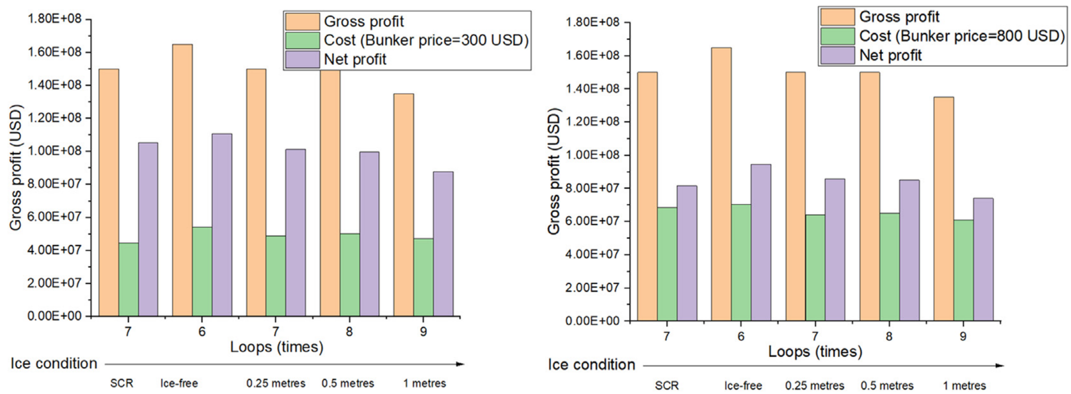

Fig. 3. Gross profit, cost and net profit between NSR and SCR.

5.2. Limitations of using NSR

Generally speaking, investors fix more focus on the profit than cost when the market is prosperous, oppositely, when the market is sluggish, cost-saving methods are more concerned. Thus, if the maritime market becomes a seller's market, the cargo transport capacity for the SCR fleet turns to its profitability immediately, the profitability for NSR fleet is far behind compared to the SCR fleet. When the maritime market becomes a buyer's market, which says the cargo loading rate for container fleet falls down to a certain extent, the small ship and closer NSR route could be a better alternative. While, NSR could benefit some liquid or dry cargo but it is limited by the natural/navigational condition in arctic waters (e.g. harsh climate, poor facilities and critical weathers). These limitations not only increasing the cost of using NSR but also restricting of transporting some cargos that are temperature sensitivity.

However, as this research illustrates certain result that related to the recent index of the economic and maritime market, and we give an access to evaluate the preference of different routes by inputting the time-efficient database to the proposed model, although brought some findings on the feasibility of the liner using the NSR as an alternative option, the study has its limitations. First, the database such as bunker price, freight price and the daily charter cost is varying continuously, the result based on the time-dependent data may not completely subject to the market changes. Second, the conditions of the impact factors are still updating and changing, the severe environment at NSR could increase the difficulty for the container ship, whether the facilities and infrastructures at NSR meet the requirements is still a problem as well. Consequently, all the results and discussions rests upon some unpredictable and variable circumstance so that some of the outcomes are beyond our understanding. Thus, due to the paucity of the database and resource on this subject, further research on NSR from different aspects by using new methods and theories is necessary.

6. Conclusion

Global warming has transformed the NSR into an alternative route that connecting Europe and the Far East, thereby benefiting international transportation (e.g. between China and Europe). Meanwhile, it is worth noting that the ongoing change in the maritime market and international trading are tending environment and economic friendly, so that reinforce the advantage of NSR. This alternative route could offer a good option of saving distance and time between Far East and Europe.

The main purpose of this paper was to estimate the financial advantage of the NSR. To that end, some major factors have been discussed from different perspectives. A profit difference formulation was studied. In the analysis, the impact magnitudes of ice, the bunker price on profit margin were discussed in a fleet level and a case study of a voyage between Europe and China was calculated to evaluate the financial performance of the NSR route.

The results offer interesting findings. The cost of conveying a container fleet as a weekly liner for NSR is not significantly effective, only if the ice is free at NSR. This is because of the following reason: mainly, complicate ice conditions will reduce the ship sailing speed, which requires more ships to maintain the weekly liner. Meanwhile, operational cost and extra facility of the liner would be relatively high according to some requirements and environmental conditions at NSR. Despite the fact that the water depth for NSR is still an important question.

Moreover, more issues such as facilities investment, navigational environment, political issues remaining challenging. Therefore, in terms of the low fuel price, NSR becomes less attractive. Nowadays, new building container ships for Europe and Far East route are tending to more and more large, which significantly increase the efficiency of the container ship. Due to the water depth restriction, NSR could only accept Panamax type, which is not as efficient as large container ship used at SCR. Therefore, we could assume that based on the recent circumstance, NSR is not flavouring for a container liner. However, considering the further demand, NSR could be an option if the demand of maritime market is keeping a downward tendancy and the daily operating cost is too high. While the SCR is still the main option, the NSR appears to be another link that links Europe and Far East.

Conflicts of interest

No potential conflict of interest was reported by the authors.

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References

[1] Fu S, Zhang D, Montewka J, Yan X, Zio E. Towards a probabilistic model for predicting ship besetting in ice in Arctic waters. Reliab Eng Syst Saf 2016;155:124−36.
[2] Zhao H, Hu H. Study on economic evaluation of the Northern sea route: taking the voyage of yong sheng as an example. Transport Res Rec 2016;2549(1):78−85.
[3] Lasserre F. Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector. Transport Res Pol Pract 2014;66:144−61.
[4] Kiiski T, Solakivi T, Töyli J, Ojala L. Long-term dynamics of shipping and icebreaker capacity along the Northern Sea Route. Marit Econ Logist 2018;20(3):375−99.
[5] Mulherin ND, Eppler DT, Proshutinsky TO, Farmer L, Smith OP. Development and results of a Northern sea route transit model. Cold Regions Research and Engineering Lab Hanover NH; 1996.
[6] Wergeland T. Commercial shipping and the NSR. Pilot Project Report of the Fridtjof Nansen Institute; 1991.
[7] Wergeland T. Commercial requirements for a viable shipping operation along the NSR. Norway: INSROP Work Paper; 1992.
[8] Ragner CL. Northern sea route cargo flows and infrastructure−present state and future potential. The Fridtjof Nansen Institute, Report 2000;13:124.
[9] Xu H, Yin Z, Jia D, Jin F, Ouyang H. The potential seasonal alternative of Asia−Europe container service via Northern sea route under the Arctic sea ice retreat. Marit Pol Manag 2011;38(5):541−60.
[10] Schøyen H, Bråthen S. The Northern sea route versus the Suez canal: cases from bulk shipping. J Transport Geogr 2011;19(4):977−83.
[11] Stephenson SR, Brigham LW, Smith LC. Marine accessibility along Russia's Northern Sea route. Polar Geogr 2014;37(2): 111−33.
[12] Lee S-W, Song J-M. Economic possibilities of shipping though Northern Sea route. The Asian Journal of Shipping and Logistics 2014;30(3):415−30.
[13] Khon VC, Mokhov I, Latif M, Semenov V, Park W. Perspectives of Northern sea route and Northwest Passage in the twenty-first century. Climatic Change 2010;100(3−4): 757−68.
[14] Gritsenko D, Kiiski T. A review of Russian ice-breaking tariff policy on the northern sea route 1991-2014. Polar Rec 2016; 52(2):144.
[15] Kikkert P. Promoting national interests and fostering cooperation: Canada and the development of a polar code. J Marit Law Commer 2012;43:319.
[16] Somanathan S, Flynn PC, Szymanski JK. Feasibility of a sea route through the Canadian Arctic. Marit Econ Logist 2007; 9(4):324−34.
[17] Smith LC, Stephenson SR. New Trans-Arctic shipping routes navigable by midcentury. Proc Natl Acad Sci USA 2013; 110(13):E1191−5.
[18] Pruyn JF. Will the Northern Sea Route ever be a viable alternative? Marit Pol Manag 2016;43(6):661−75.
[19] Barros CP, Felício JA, Fernandes RL. Productivity analysis of Brazilian seaports. Marit Pol Manag 2012;39(5):503−23.
[20] Polvani LM, Previdi M, England MR, Chiodo G, Smith KL. Substantial twentieth-century Arctic warming caused by ozone-depleting substances. Nat Clim Change 2020;10(2):130−3.
[21] Hassol S. Impacts of a warming Arctic-Arctic climate impact assessment. Cambridge University Press; 2004.
[22] Parkinson CL. Spatial patterns of increases and decreases in the length of the sea ice season in the north polar region, 1979−1986. J Geophys Res: Oceans 1992;97(C9): 14377−88.
[23] Seo D-W, Kim D-H, Ha T-B. Enactment trend and implication of the polar code in IMO. Journal of Navigation and Port Research 2014;38(1):59−64.
[24] Kujala P, Goerlandt F, Way B, Smith D, Yang M, Khan F, et al. Review of risk-based design for ice-class ships. Mar Struct 2019;63:181−95.
[25] Lin S-CA. Fuzzy algorithm to evaluate competitive locations for international transport logistics system. J Mar Sci Technol 2016;24(2):125−34.
[26] Mersin K, Alkan G, Mõsõrlõoğlu T. A new method for calculating fuel consumption and displacement of a ship in maritime transport. Cogent Engineering 2017;4(1):1415107.
[27] Meyer J, Stahlbock R, Voß S, editors. Slow steaming in container shipping. 2012 45th Hawaii International Conference on System Sciences; 2012.
[28] Wang Y-J, Han T-C. Efficiency measurement for international container ports of Taiwan and surrounding areas by fuzzy data envelopment analysis. J Mar Sci Technol 2018; 26(2):185−93.
[29] Bai X, Lam JSL. A destination choice model for very large gas carriers (VLGC) loading from the US Gulf. Energy 2019;174: 1267−75.
[30] Verny J, Grigentin C. Container shipping on the northern sea route. Int J Prod Econ 2009;122(1):107−17.