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How attractive is the Northern Sea Route for container shipping? An economic model

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Every year, COSCO sends a vessel with containers through the Arctic. This year, Maersk followed suit with the voyage of the 3,956 TEU vessel, *Venta*. Meanwhile, Arctic shipping hubs are being planned, such as at the ice-free port of Murmansk.

Currently, cargo shipped through the Northern Sea Route (NSR) is composed of raw materials from oil and gas exploitation, a market subject to volatile prices and finite resources. However, sustainable economic development cannot not be based entirely on commodities with these characteristics and that depend on international market volatility. Thus, the shipment of manufactured goods along the NSR may be the next step in its evolution.

Academics agree on the general decline in ice extent and thickness; yet, variability in ice conditions and poorly charted bathymetry in shallow waters may hamper the development of the NSR as a periodic shipping lane for containers.

The aim of this article is to define the relevant market for a maritime company using the NSR, shipping manufactured goods from Asia to Europe, using a new approach to consider sea ice variability and to stress the relevancy of Murmansk as a container hub.

Based on historical environmental data and the POLARIS system, we look at the potential sailing period of ice class 1A vessels according to 3 scenarios: optimistic, intermediate, and pessimistic. We also considered that the vessel could sail directly to Rotterdam or transship the container in Murmansk before reaching Rotterdam.

For each scenario, we define the total cost of the navigation and the number of containers the vessel is able to load on a yearly basis, and hence the yearly loading capacity the NSR is able to provide for this vessel type.

Our results define (1) the transportation cost of a container between Rotterdam and Shanghai and (2) the potential transit time. Compared to the cost and transit time of container shipping by rail and via the Suez Canal route, we characterize the NSR market and the type of cargo NSR shipping should target.

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1. Introduction

Until now, the NSR is mainly used for the exportation of raw materials coming from the oil and gas fields of the Yamal peninsula and its neighbourhood.

Yet its 40% shortcut between the important economic regions of Europe and Asia has piqued the interest of academics and professionals. If this distance savings may be realized for bulk transportation, it may have even greater potential for containers that are highly sensitive to transit time.

However, the NSR faces numerous challenges. Some are related to its geography, such as ice, lack of ports, extra cost due to icebreaker escort, while others are external and are perceived as competitors, such as railroads between Shanghai and Rotterdam, also named the Belt and Road Initiatives project (BRI) and the Suez Canal Route (SCR).

Of the internal elements, ice likely has the highest impact. Due to its presence, vessels are unable to sail safely at their optimal speed, must be winterized involving additional cost, may not be able to sail during winter depending on the level of winterization. The presence of older, thick ice combined with insufficient vessel ice class may mandate the use of icebreakers, leading to additional cost. Low population density and the remoteness of oil and gas fields is the main reason for the low density of ports available for use as repair yards in case of an emergency, further complicating navigation along the route. Yet to enhance the economic attractiveness of this lane and gain in safety, some ports are being upgraded in order to be used as shipping “hubs” such as the case of Murmansk in the Kola peninsula or repair yards. Regarding the issue of a safe navigation, the use of an icebreaker, the reduction of the speed and the winterization of vessel are parameters that influence the way shipowner decide to manage the risk related to the Arctic.

Yet when exporting cargo from China to Europe, two other possibilities exist: the SCR and the BRI. The SCR is the main route used for trade between these two poles of the economic Triade. Schedules along the SCR are largely fixed and are more or less respected by carriers; in addition, unlike the NSR, the SCR is used year-round. The railroad is linked to the Belt and Road Initiative and may benefit from fixed schedules, but has a loading limited loading capacity and may be more expensive than either shipping route.

Thus, our analysis will focus on a comparison between the SCR, the railroad and the NSR based on cost and transit time. We will integrate the use of a hub in Murmansk and examine the amount of cargo an ice class 1A container is able to load annually, and which of the three options is faster and least expensive.

Following a literature review, we will present our model. Section 4 focuses on the presentation of the business case while section 5 presents our results. Finally, we will end this analysis with a short discussion and conclusion.

2. Literature review

As stressed by Theocharis et al. (2018) and Meng et al. (2017), the NSR has been the subject of frequent analysis in recent years, with most studies dealing with transportation of container vessels. While many studies compare the NSR to the SCR, relatively few examine the profitability of the NSR versus the BRI. Likewise, while most articles assessed the profitability of the NSR versus the SCR, results differ across analyses (Lasserre, 2014; Meng et al., 2017).

Speed of the vessel, fuel consumption, icebreaker fees, capital and operational expenditures are considered as the main expenditures when dealing with arctic navigation (Liu and Kronbak, 2010; Gritsenko and Kiiski, 2015; Lasserre, 2014; Eriskstad and Ehlers, 2010; Verny and Grigentin, 2009). If they are not steady and may change according to the ice conditions, except for Liu and Kronbak (2010), Faury and Cariou (2016) and faury and Givry (2017), most of cost analysis compute them as factors and not variables.

Few analyses focus on the impact of existing tools, and more precisely on the Polar Code, on Arctic navigation (Fedi et al, 2018a; Faury 2015; Fedi and Faury 2016; Dalaklis et al, 2018). In particular, the POLARIS system is a risk assessment tool providing guidance for optimal speeds for safe navigation, and is understudied despite being part of the Polar Code (Fedi et al, 2018b). In fact, as suggested by Marchenko (2014), unsuitable speed for the environment is the main cause of accidents in Arctic waters. Yet exception for Stoddard et al (2016) The POLARIS system has not yet been used to define the optimal pathway though the ice infested waters of the Arctic. Close to this analysis, Stephenson et al. (2014) stressed the existing variation of accessibility of the NSR according to different ice scenarios and ice class vessels, but did not examine economic factors.

Ragner (2000) considers that the lack of port infrastructure is the main reason for the low economic development of the NSR. Since the 2000s, numerous infrastructure projects have been completed or are

currently underway. Among them, the Murmansk Transport Hub (MTH), a free trade zone able to handle 1 million TEU in the coming years and connected via railroad to the Russian network and hence to Europe, is estimated to cost 117.4 Billion Rouble and provide 1,700 jobs (Trubkina, 2012). As explained by Kinossian (2016), the Arctic is at the core of the Russian state development strategy, with Murmansk at in the centre, mostly due to its relatively large population, existing industries, and infrastructure such as its large oil and gas tank along the shore (Grigoriev, 2015).

Articles comparing the NSR and the railroad are relatively fewer (Verny and Grigentin, 2009; Moon et al, 2015; Zhu et al, 2018). Verny and Grigentin (2009) compared the economic viability of the NSR versus the railroad with a constant speed. Moon et al (2015) highlighted that the main parameters that influence the choice of transport mode are the transit time and the cost. Zhu et al (2018) concentrated on the market share the NSR and the railroad may capture from the SCR. They compared a 4,500 TEU ice-class vessel versus a 15,000 TEU vessel navigating through the Suez Canal. Considering a fixed length of navigation of 180 days, they concluded that while open, the NSR may attract 20% of the SCR volume, while the railroad would only attract 0.02 %.

Our contribution leans on the integration of the POLARIS system, a risk management tool, within an economic model in order to analyze the profitability of the NSR compared to the railroad and the SCR, positing the use of Murmansk as a container hub to feed the European market as part of the financial strategy of shipowners.

3. Cost model

3.1. Model parameters

- R : total number of completed return trips per year from Shanghai to Murmansk.
- dod_0 and dod_F : first and last possible day-of-departure from Shanghai for a trip that can be completed without vessel being blocked, depending on the considered scenario.
- V_r^1 and V_r^2 : average sailing speed of the vessel during trip $r = 1, \dots, R$ while sailing on the NSR part of the route from Shanghai to Rotterdam (or to Murmansk) and vice-versa respectively [knots].
- V_r^3 : average sailing speed of the vessel during trip $r = 1, \dots, R$ while sailing in open water in both directions [knot].
- V^{DS} : vessel design speed [knot].
- D_r^1 and D_r^2 : average NSR distance of trip $r = 1, \dots, R$ from Shanghai to Rotterdam (or to Murmansk) and vice-versa respectively [nm].
- D_r^3 : total average distance of trip $r = 1, \dots, R$ in open-water (outside the NSR zones) in both directions, i.e. from Shanghai to Rotterdam (or to Murmansk) and vice-versa [nm].
- PT : total port time per trip [days].
- T_r : total duration of trip r including sailing and port times [days].
- dod_r^1 and dod_r^2 : day-of-departure of the vessel for trip $r = 1, \dots, R$ from Shanghai to Rotterdam (or to Murmansk) and vice-versa respectively.
- $CAPEX_r$ and $CAPEX_d$: Capital expenses corresponding to the vessel fixed cost or the chartering cost, per trip r or per day respectively [USD/trip] and [USD/day] respectively.
- $OPEX_r$ and $OPEX_d$: operational costs, including crew, insurance, stores, lubricants, repairs, and maintenance, per trip r or per day respectively [USD/trip] and [USD/day] respectively.
- C_b^A and C_b^M : bunker fuel price per ton used for the auxiliary and main engines respectively [USD/ton].
- F^A and $F^M(V)$: daily fuel consumption of auxiliary and main engines [ton/day]. $F^M(V)$ is a function of the sailing speed V .
- B_r^A and B_r^M : total fuel cost of the vessel per trip r for the auxiliary and the main engines respectively [USD/trip].
- B_r : total fuel cost of the vessel per trip r for both engines [USD/trip].

- IB_r : total NSR fee per trip r including transit and pilotage fees, as well as the cost of the use of icebreakers if needed [USD/trip].
- C_r : total cost per trip for one vessel r including capital cost, operational cost, bunker cost and NSR fees [USD/trip].
- C_y : total cost per year including capital cost, operational cost, bunker cost and NSR fees assuming that the vessel sails continuously during the period when sailing is possible even with icebreaker assistance between Shanghai and Rotterdam (or Murmansk) [USD/year].
- C_{TEU}^{Trans} : total cost per TEU container corresponding to transshipping and subcontracting the transportation of transshipped containers from Murmansk to Rotterdam and vice versa [USD/TEU]. This cost corresponds to the option of using the NSR with a transshipment in Murmansk.
- C_{TEU} : average total cost per TEU container transported from Shanghai to Rotterdam or from Rotterdam to Shanghai, including the transshipment cost for the option with transshipment [USD/TEU].
- K : total carrying capacity of the vessel [TEU].
- α_1, α_2 : utilization rate of the vessel capacity westbound and eastbound respectively [%].

It is worth noting that V_r^1, V_r^2 are calculated as an average constant speed throughout each NSR-leg of the trip (in the two directions) using the POLARIS system as explained in Section 1 and more precisely based on RIO. It is also clear that these average sailing speeds depend on the day-of-departure (dod_r^1) of trip r from Shanghai for V_r^1 and dod_r^2 from Rotterdam (or Murmansk) for V_r^2 . Moreover, V_r^3 is equal to the vessel design speed.

3.2. Transit time and number of trips

We assume that the vessel operates between Shanghai and Rotterdam (or Murmansk) starting from the first day of the period during which navigation is possible, even with icebreaker assistance, until the last day of that period. A trip that starts in Shanghai also ends in Shanghai.

The total duration of trip r is then calculated as follows:

$$T_r = \frac{D_r^1}{24 \times V_r^1} + \frac{D_r^2}{24 \times V_r^2} + \frac{D_r^3}{24 \times V_r^3} + PT \quad (1)$$

Therefore, based on the ice thickness scenario in the NSR, the day-of-departure of the second trip from Shanghai to Rotterdam (or Murmansk) is calculated as follows:

$$dod_2^1 = dod_1^1 + T_1 \quad (2)$$

For any further trip $r = 3, \dots, R$, the day-of-departure from Shanghai is then calculated as follows:

$$dod_r^1 = dod_{r-1}^1 + T_{r-1} \quad (3)$$

Equation (3) is then used to determine the value of the total possible number of trips per year R so that R is the largest possible integer for which:

$$dod_R^1 \leq dod_F \text{ and } dod_{R+1}^1 > dod_F \quad (4)$$

A trip that cannot be completed because of heavy ice conditions is not counted.

3.3. Cost calculation

The cost calculations in this section assume that one 1A ice-class vessel is used and for a round trip between Shanghai and Rotterdam or between Shanghai and Murmansk. For the option of a transshipment in Murmansk, we assume that the 1A vessel does a round trip between Shanghai and Murmansk and the containers are transported between Murmansk and Rotterdam using the service of a subcontracting company or a maritime liner. Therefore, in this case, to the total cost per TEU, the transshipment and subcontracting (transportation) cost, C_{TEU}^{Trans} , is added.

Given that the cost per trip varies from one trip to another, we calculate the total cost for all trips per year and use it to estimate the average total cost per TEU.

The total cost per trip, for the return trip $r = 1, \dots, R$ and for a departure on dod_r^1 is given as follows:

$$C_r = CAPEX_r + OPEX_r + B_r + IB_r \quad (5)$$

The total capital expenditures per trip are calculated as follows:

$$CAPEX_r = CAPEX_d \times T_r \quad (6)$$

The total operational cost per trip is calculated as follows:

$$OPEX_r = OPEX_d \times T_r \quad (7)$$

The total bunker fuel cost per trip for both engines is the sum of the bunker fuel cost from the main and the auxiliary engines:

$$B_r = B_r^A + B_r^M \quad (8)$$

with

$$B_r^A = C_b^A \times T_r \times F^A \quad (9)$$

and

$$B_r^M = C_b^M \times \left(\frac{D_r^1}{24 \times V_r^1} F^M(V_r^1) + \frac{D_r^2}{24 \times V_r^2} F^M(V_r^2) + \frac{D_r^3}{24 \times V_r^3} F^M(V_r^3) \right) \quad (10)$$

Where

$$F^M(V) = \frac{SFOC^M EL^M PS^M}{10^6} \times \left(\frac{V}{V^{DS}} \right)^3 \quad (11)$$

$SFOC^M$ is the specific fuel oil consumption of the main engine [in g/kWh], EL^M the engine load of the main engine [in %], and PS^M the power of the main engine [in kW].

Finally, IB_r is determined for each trip based on the RIO value on the of the day-of-departure of the trip dod_r^1 from Shanghai and dod_r^2 from Rotterdam (or Murmansk).

The total cost per year is then the sum of the cost of all the trips of one year:

$$C_y = \sum_{r=1}^R C_r \quad (12)$$

Finally, the total average cost per transported TEU container, assuming that the vessel sails with α_1 utilization rate from Shanghai to Rotterdam (or to Murmansk) and α_2 from eastbound is as follows:

$$C_{TEU} = \frac{C_y}{R \times (\alpha_1 + \alpha_2) \times K} \quad (13)$$

It is obvious that the total transportation capacity per year of a 1A vessel with a loading capacity of K TEUs is $R \times \alpha_1 \times K$ TEUs westbound and $R \times \alpha_2 \times K$ TEUs eastbound.

In case the TEUs are transported to (?)

4. Sailing speed in ice and navigability period

Navigation in the Arctic involves numerous challenges, of which the most important is ice. The presence of ice represents one of the highest risks for a vessel transiting along the Russian coast. Thus, in order to minimize risk, the use of specific vessels with stronger hulls and engine power may be necessary to withstand encounters with various concentrations of different types of ice, as well as the extreme cold.

To establish guidelines for safe navigation, the Polar Code considered three classes of vessels. The ‘‘A’’ and ‘‘B’’ classes are considered Polar Class vessels with the ability to sail year-round. Vessels with a class ‘‘C’’ are able to navigate within the Arctic but with a lower resistance to ice pressure and limited sailing period in polar waters.

The ability of a vessel to sail within the Arctic can be defined by numerous means (Fedi et al, 2019). Linked to the Polar Code, the POLARIS System provides a methodology for assessing risk in ice that includes the ice thickness, type, and concentration, the air temperature, and the ice class of the vessel. The result is an index that can be used by ship officers as a decision tool to assist in determining if the vessel is able to sail in this area, at what speed, and whether icebreaker assistance is required.

To obtain this information, we determine the Risk Index Outcome (RIO) of the vessel. The RIO is the combination of the Risk Index Value (RIV; Table 1) and the concentration of various types of ice encountered by the vessel as explained in equation (14).

$$RIO = (RIV_1 \cdot C_1) + (RIV_2 \cdot C_2) \dots \dots \dots + (RIV_n \cdot C_n) \quad (14)$$

Here, RIV_n indicates the ability of the vessel to maneuverer in a concentration (tenths) of a specific ice type encountered by the vessel (C_n).

Table 1: Risk Index Values

Ice Thickness upper limit (cm)		0	10	15	30	50	70	100	120	200	225	250	>250	
Category	Ice Class	Ice Free	New Ice	Grey Ice	Grey White Ice	Thin First Year Ice, 1 st	Thin First Year Ice, 2 nd	Thin First Year Ice, Ice	Medium First Year Ice	Medium First Year Ice 2 nd	Thick First Year Ice	Second Year Ice	Light Multi Year Ice	Heavy Multi-Year Ice
	A	PC1	3	3	3	3	2	2	2	2	2	2	2	1
PC2		3	3	3	3	2	2	2	2	2	2	1	1	0
PC3		3	3	3	3	2	2	2	2	2	2	1	0	-1
PC4		3	3	3	3	2	2	2	2	2	1	0	-1	-2
PC5		3	3	3	3	2	2	2	1	1	0	-1	-2	-2
B	PC6	3	2	2	2	2	1	1	0	-1	-2	-3	-3	-3
	PC7	3	2	2	2	1	1	0	-1	-2	-3	-3	-3	-3
C	IAS	3	2	2	2	2	1	0	-1	-2	-3	-4	-4	-4
	IA	3	2	2	2	1	0	-1	-2	-3	-4	-5	-5	-5
	IB	3	2	2	1	0	-1	-2	-3	-4	-5	-6	-6	-6
	IC	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-7	-8
	Not IS	3	1	0	-1	-2	-3	-4	-5	-6	-7	-8	-8	-8
		Operation permitted		Low speed		Ice Breaker escort		Ice Breaker escort at low speed		Operation not permitted				

Source: Authors based on IMO (2016)

Thus, with a RIV maximum at 3 and a minimum of -8, the RIO of a vessel can fluctuate between 30 (optimal conditions) and -80 (worst conditions).

Table 2. Risk Index Outcome Criteria

RIO _{SHIP}	Ice classes PC1-PC7	Ice classes below PC7 and ships not assigned an ice class
RIO ≥ 0	Normal operation	Normal operation
-10 ≤ RIO < 0	Elevated operational risk	Operation subject to special consideration
RIO ≤ -10	Operation subject to special consideration	Operation subject to special consideration

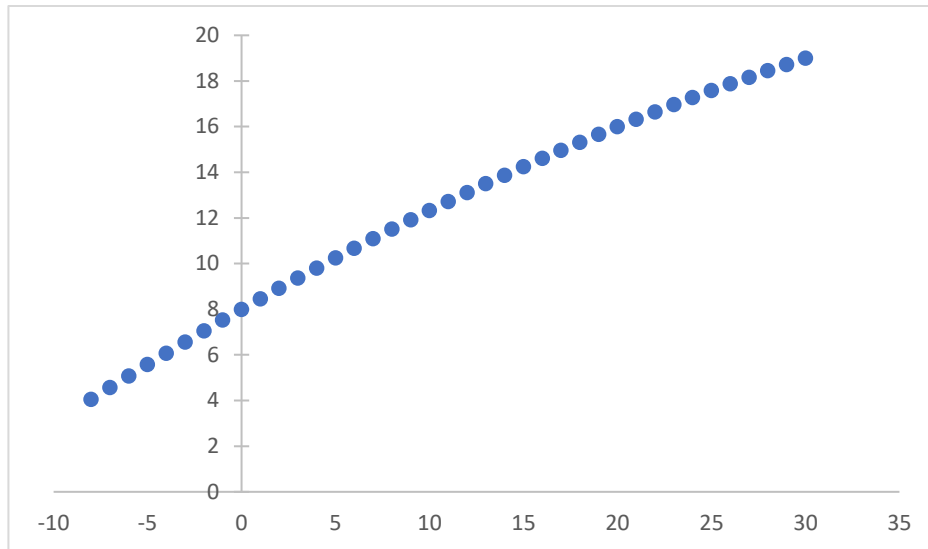
Source: IMO (2016).

The RIO computed indicates the level of risk faced by the vessel, as explained in Table 2, during its navigation. The definition of the risk level helps the vessel captain define the optimal speed for a safe navigation (Table 3) and whether an icebreaker is needed to sail through the area.

The IMO (2016) indicates that an ice class 1A is able to sail with a RIO between 30 and -10. Based on the ice class of the vessel and on the recommended speed (IMO, 2016), we assumed that the ship would sail at design speed when the RIO is 30, 8 kts when RIO=0 which represents the moment icebreaker assistance may be made mandatory by underwriters, and 3 kts when RIO = -10. Thus, the speed of the vessel is defined by equation (15) which integrates these three constraints.

$$V = -\frac{1}{300}x^2 + \frac{7}{15}x + 8 \tag{15}$$

Figure 3: vessels' speed according to their class and RIO when sailing independently or assisted by an icebreaker.



Source: Authors (2019)

4.1. Business case

As explained previously, most previous studies dealing with container transportation along the NSR compare its profitability with that of the Suez Canal Route (SCR). Because of the large differences in loading capacity, we examine the relevancy of the NSR compared to the railroad. We assume that the cost of shipping one TEU from Shanghai to Rotterdam would be 2,500 USD with a transit time of 18 days (Zhu et al, 2018).

Our business case relies on the use of an ice class 1A container vessel with a capacity of 3,600 TEU sailing between Shanghai and Murmansk. The choice of this type of vessel has been motivated by the example of the VENTA, a container vessel that sailed along the NSR in September 2018. Based on Clarksons database (2018) we were able to gather technical and economic information regarding the vessels as highlighted in Table 3.

Table 3: Economic and technical parameters

	Venta Maersk	Open water & SCR	Railroad
CAPEX (Mln USD) ^{o1}	38	38	
Daily CAPEX (USD) ¹	6,941	6,941	
OPEX (USD)	6,121	6,121	
TEU Capacity (TEU) ¹	3,600	3,600	
Loading factor Eastbound ³	45%	60%	
Loading factor Westbound ³	70%	87%	
GT (Ton) ¹	34,882	34,882	
Optimal speed (Kts) ¹	19	19	
Main engine power (Kw) ¹	19,620	19,620	
Main engine SFOC (g/kWh) ¹	170	170	
Auxiliary engine daily fuel consumption (Ton/day)	2000	2000	
Fuel cost (USD / Ton) ¹	441.05	441.05	
Time spent in port (days)	2	2	
Icebreaker fees	See Table 4		
Suez Canal fees Eastbound (USD) ⁴		173,169	
Suez Canal fees Westbound (USD) ⁴		173,594	
Murmansk Rotterdam freight rate (USD/TEU) ²		1,120	
Rotterdam Murmansk freight rate (USD/TEU) ²		523	

 Railroad freight rate (USD/TEU)

2,500

Source authors (2019) based on:

¹ Clarksons Database² <http://www.worldfreightrates.com/en/freight>³ Lasserre (2014)⁴ Suez calculator (2019)

Our business case relies on two scenarios to reach the final destination, Rotterdam. The first possibility is to tranship the goods in Murmansk on an open-water vessel on the remainder of the route to Rotterdam. The second option is to sail directly to Rotterdam from Shanghai. The use of Murmansk as a container transshipment hub is related to the intent of the Russian government to develop this port as an Arctic gateway, as indicated by the planned implementation of the Murmansk Transport Hub (MTH) that shall be able to handle 1 million TEU per year (The Ministry of Foreign Affairs of the Russian Federation, 2010). We also assumed that the vessel would spend two days in ports in order to load or unload container (Lasserre, 2014)

Due to the trade imbalance between Shanghai and Rotterdam, the loading factor varies as a function of the direction. We assume that vessels will sail at 70% capacity on the westbound route and 45% on the eastbound route.

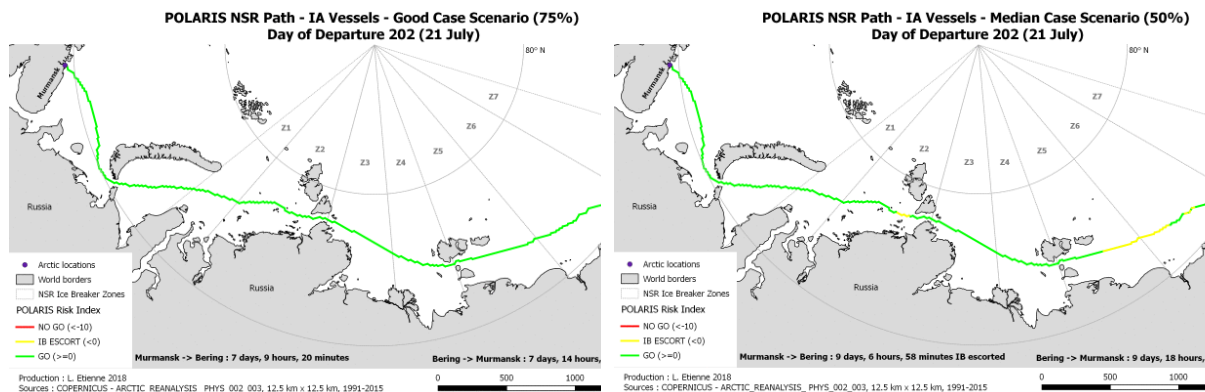
Unsuitable speed is a major cause of accidents (Marchenko, 2014). Thus, we define the speed according to the RIO of the vessel. To compute the RIO, we extract data from the European Copernicus database which has access to a full range of data on ice conditions worldwide. In this analysis, we use the TOPAZ4 Arctic Ocean Physics Reanalysis data collected via satellite for the period between 1991 and 2015. We used the ARCTIC_REANALYSIS_PHYS_002_003 dataset (von Schuckmann et al., 2017) which provides gridded ice thickness and concentration at 12.5 km resolution for 35 years.

To compute the RIO, we extract the ice conditions for XXX Cells over 25 years at daily scale for each year (365 days) and used the RIV of an ice class 1A vessel. Because underwriters require a defined route when agreeing to insure a vessel (Fedi et al, 2018), we assumed one static route connecting the Bering strait to Murmansk.

Based on the RIO values obtained along the grid cells of this route, the vessel speeds (Figure 4) for an ice class 1A with technical specificities of the Venta Maersk was calculated for three scenarios:

- The 75th best percentile in terms of navigation conditions (good case scenario);
- The median scenario;
- The 25th lowest percentile in terms of navigation conditions (bad case scenario).

Figure 4 shows the navigability risk assessment for three scenarios on the 21st of July. In the worst case, it would be technically impossible for an ice class 1A to safely cross the Arctic. On the other hand, in the median case, navigation of the entire route is feasible even if the assistance of an icebreaker may be required, assistance that would not be mandatory in the best-case scenario.



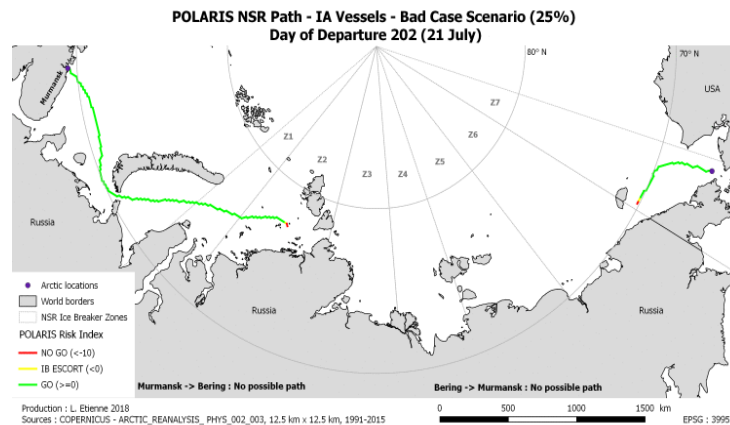


Figure 4: Navigability risk assessment July 21st for an IA vessel transiting the NSR. Legend: Red = No go; Orange = Ice-breaker escort; Green = Go.

Source: Authors (2019) based on Copernicus - Arctic_Reanalysis_Phys_002_003

Daily CAPEX definition

Our model assumed that the vessel has a life time of 15 years. During this period, the shipowner has two opportunities to utilize the vessel. One assumes that the shipowner may use the vessel elsewhere during periods of severe ice conditions. This assumption leads us to consider a daily CAPEX of 6,921 USD per day. The other assumes that ice-class vessel specificities prevent its use in open waters. In fact, the characteristics of the water has a negative impact of the manoeuvrability of the vessel, increasing fuel consumption. These technical considerations could lead to an oversupply of container vessels in the market during severe ice periods. In this case, the daily CAPEX would change in regards to the number of sailing days in each scenario.

Bunker price

As explained by Lasserre (2014), the bunker price is one of the main expenditures when sailing within the Arctic. In our case, we assumed a bunker price equal to the mean of the 380cst bunker prices at Rotterdam over the last 10 years from January 4th 2008 to September 21st 2018 (Clarksons Database, 2018).

Freight rate between Murmansk and Rotterdam

Our analysis is from the perspective of a shipowner willing to invest in and focus exclusively on the Arctic market. Thus, for the leg between Murmansk and Rotterdam, transportation would be subcontracted to another maritime company. Hence, the cost of shipping a container between Murmansk and Rotterdam is 1,120 USD and 523 USD in the opposite direction.

Regarding the cost of transportation for a container between Rotterdam and Shanghai, we grounded our analysis on the vessel characteristics of the Venta; i.e. 3,600 TEU loading capacity and an optimal speed of 19 kts (Table 3).

Icebreaker fees

The icebreakers fees depend on four types of parameters: technical, month, geography and economic (NSRA, 2018). The technical parameter includes the gross tonnage of the vessel and its ice class. Icebreaker assistance in winter or spring (between December and June) may represent an additional cost of 60% compared to the same assistance in summer or autumn. As explained by Liu and Kronbak (2010) and Marchenko (2014), the ice conditions change with natural variability. In addition, the NSR is comprised of seven zones (Figure 4) from Novaya Zemlya in the west to the Bering Strait in the East. For each area crossed escorted by an icebreaker, the vessel must pay fees as a function of the number of zone where the icebreaker was required. The fees are presented in Rub; thus, the exchange rate has an impact on the cost of the assistance. In our case, computed costs are shown in Table 4.

Table 4: icebreaker fees per zone for an ice class 1A vessel with an exchange rate of 0.149109 Rub for 1 USD (xe converter, 2019)

	icebreaker fees													
	Z1		Z2		Z3		Z4		Z5		Z6		Z7	
1st of july till 30rd of november	268,11	RUB	321,73	RUB	375,35	RUB	428,59	RUB	482,59	RUB	536,21	RUB	536,21	RUB
1st of december till 30rd of june	670,26	RUB	804,32	RUB	938,37	RUB	1 072,42	RUB	1 206,47	RUB	1 340,53	RUB	1 340,53	RUB
1st of july till 30rd of november	39,98	USD	47,97	USD	55,97	USD	63,91	USD	71,96	USD	79,95	USD	79,95	USD
1st of december till 30rd of june	99,94	USD	119,93	USD	139,92	USD	159,91	USD	179,90	USD	199,89	USD	199,89	USD

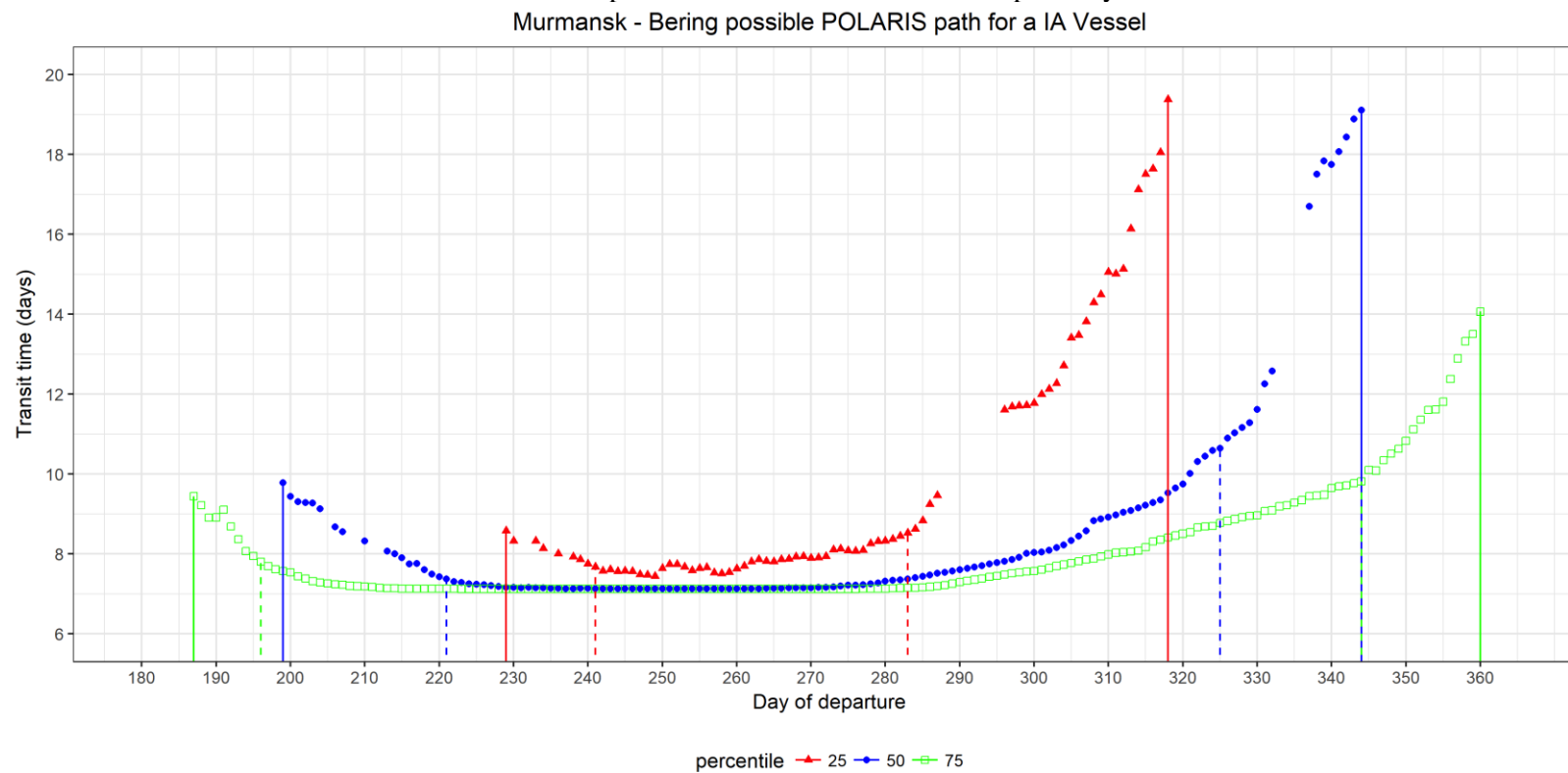
Source: Authors based on NSRA (2018)

5. Result

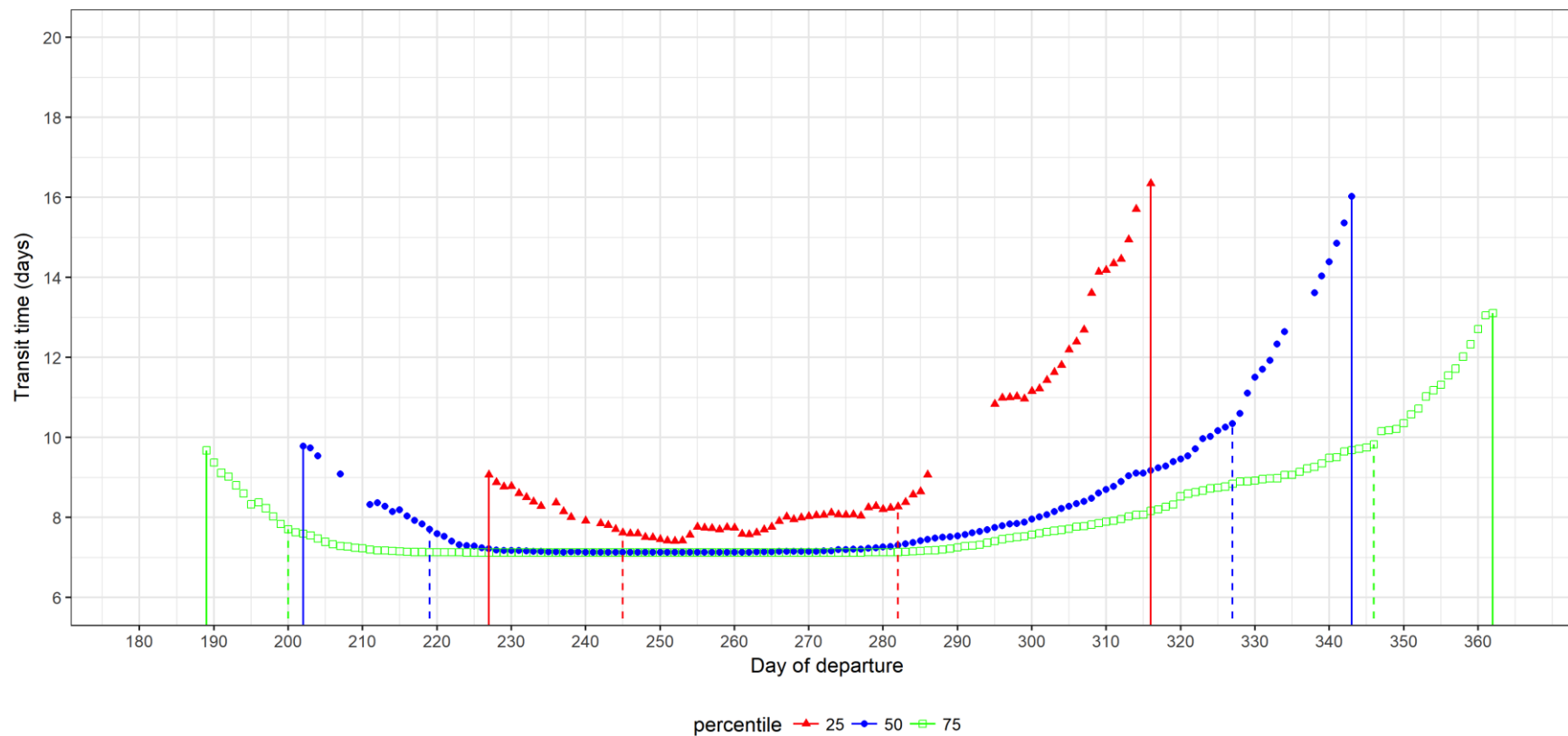
Results are presented according to five scenarios: three conditions of navigation (worst, median and best case) and two market conditions (year-round exploitation of the vessel, or only during the period of navigation along the NSR).

The navigation conditions have a direct impact on the length of the navigation period within the Arctic and thus the cost it may represent. When applied to the ice class 1A vessel, we obtain transit periods for three possible ice conditions as shown in Figure 5a and 5b.

Figure 5: Sailing duration and allowed navigability periods for a 1A vessel on the Bering-Murmansk route according to the day of departure, for the 25th, 50th, and 75th percentiles of ice conditions of the past 25 years.



Bering - Murmansk possible POLARIS path for a IA Vessel



Source: Authors (2019)

Figures 5a and 5b stress the impact of the ice conditions upon the length of navigability of an ice class 1A vessel in both directions. The dotted lines represent the potential length of navigation without icebreaker assistance and the solid line with an icebreaker.

In the worst case, regardless of direction, the icebreaker appears as a mandatory option for navigation. In the worst case, the vessel would sail 63 of 78 days assisted by an icebreaker when sailing from the Bering Strait to Murmansk, and 57 of 78 days assisted by an icebreaker in the opposite direction.

From the Bering Strait to Murmansk (B/M) in the median and best-case, the vessel would sail 135 days and 174 days respectively (including 27 and 35 days of icebreaker assistance, respectively, for each leg) and 137 days (27 with an icebreaker) and 175 days (35 with an icebreaker) from Murmansk to the Bering Strait (M/B).

5.1. Cost of the NSR according to ice conditions and length of depreciation period

Table 5a: TEU cost for Shanghai/Murmansk/Rotterdam with a daily CAPEX of 6,941 USD

	Number of journey		Number of days exploited	TEU LOADED		Average TEU cost		C _{TEU}	
	Westbound	Eastbound		Westbound	Eastbound	Westbound	Eastbound		
25%	HUB	3	3	112.6	7,560	4,860	1,811 USD	1,919 USD	1,865 USD
50%	HUB	5	4	160.3	12,600	6,480	1,947 USD	1,257 USD	1,602 USD
75%	HUB	6	5	191.5	15,120	8,100	1,791 USD	998 USD	1,394 USD

Source: Authors (2019)

Table 5b: TEU cost for Shanghai/Rotterdam with a daily CAPEX of 6,941 USD

	Number of journey		Number of days exploited	TEU LOADED		Average TEU cost		C _{TEU}	
	Westbound	Eastbound		Westbound	Eastbound	Westbound	Eastbound		
25%	DIRECT	3	2	111.3	7,560	3,240	1,090 USD	1,183 USD	1,137 USD
50%	DIRECT	4	4	170.2	10,080	6,480	547 USD	1,653 USD	1,100 USD
75%	DIRECT	5	4	187.9	12,600	6,480	820 USD	587 USD	703 USD

Source: Authors (2019)

The assumption of Murmansk as a container hub provides the possibility to transport 2,160 additional containers in the worst and median case and 4,320 containers in the best case compared to transporting containers directly to Rotterdam. This result can be easily explained by the additional distance covered by the vessel.

Regarding the number of days (Table 5) while the 1A vessel is in use, the use of a hub allows sailing 1.3 and 3.6 additional days in the worst and best case, respectively. In the median case with the use of a hub, if the number of containers transported is higher compared to the direct option, the number of days sailed is lower when the vessel stops in Murmansk. This result can be explained by the length of the last eastbound journey in the direct option. In the case of hub option, the last eastbound voyage take place on day 313 and the vessel spends 9.1 days sailing along the NSR, with time for another trip. If the company opts for the direct option, the last journey occurs on day 344 and, due to harsh sailing conditions, the length of the navigation period along the NSR lasts 19.1 days in addition to the 3.6 days of travel between Rotterdam and Murmansk.

If the use of a hub in Murmansk provides the possibility for the shipowner to use its ships for longer periods to transport more containers, the cost analysis is a little more complex, except in the median case. In the worst and best-case scenario, the use of Murmansk as a hub dramatically increases the cost of a container (Table 5) in both eastbound and westbound directions. The exception is the median case when sailing toward Shanghai. The ice conditions and the length of each journey provide the opportunity to sail for less time but to transport a larger number of containers. Because most of the cost varies according to the length of navigation period, the OPEX, CAPEX, fuel, icebreaker expenditures are

lower, explaining the difference between the eastbound median case using a hub versus the option linking directly to Rotterdam.

Table 6a: TEU cost for Shanghai/Murmansk/Rotterdam with a variable daily CAPEX

		Number of journey		Number of days exploited	TEU LOADED		Average TEU cost		C _{TEU}
		Westbound	Eastbound		Westbound	Eastbound	Westbound	Eastbound	
25%	HUB	3	3	112.6	7,560	4,860	2,101 USD	2,947 USD	2,524 USD
50%	HUB	5	4	160.3	12,600	6,480	2,103 USD	2,161 USD	2,132 USD
75%	HUB	6	5	191.5	15,120	8,100	1,915 USD	1,825 USD	1,870 USD

Source: Authors (2019)

Table 6b: TEU cost for Shanghai/Rotterdam with a variable daily CAPEX

		Number of journey		Number of days exploited	TEU LOADED		Average TEU cost		C _{TEU}
		Westbound	Eastbound		Westbound	Eastbound	Westbound	Eastbound	
25%	DIRECT	3	2	111.3	7,560	3,240	1,367 USD	1,862 USD	1,614 USD
50%	DIRECT	4	4	170.2	10,080	6,480	745 USD	1,945 USD	1,345 USD
75%	DIRECT	5	4	187.9	12,600	6,480	967 USD	880 USD	923 USD

Source: Authors (2019)

If the shipowner decides to wait for the NSR to reopen due to economic and technical parameters (Table 6a, 6b), then the extra cost per container would range from 124 USD and 1028 USD.

To conclude this section of our analysis, we stressed the strong impact ice conditions may have on profitability, as is well known. However, the risk management policy of the shipowner may also provide a different vision according to their interpretation of the data, which may affect their decision to enter the Arctic market.

5.2. Compared to the railroad and the SCR

The NSR, railroad and SCR are the main transportation corridors linking the Europe to Asia. For a company wishing to position itself within one of these markets, an analysis of the benefits and shortcomings in term of cost and transit time may be needed.

For a company wishing to position itself in the transportation market between the Asian and European markets, various routes exist with different constraints. To assess the cost of shipping a container between Shanghai and Rotterdam we assumed a vessel with the same specifications as the Venta. We added the Suez Canal fees as a function of the direction, which came to 173,594 USD traveling westbound and 173,160 USD traveling eastbound (Table 3). With a distance of 10,525 nm between the ports (Sea distance, 2019) and the vessel sailing at constant optimal speed, the transit time is 23,1 days. Thus, the vessel would complete 8 journeys westbound and 7 eastbound.

Therefore, the cost of a container from Shanghai to Rotterdam would cost 756 USD and 1123 USD from Rotterdam to Shanghai with knowledge that the vessel would transport 40,176 containers year-round.

According to Rodermann et al. (2014), Lasserre et al. (2018), and Verny and Grigentin (2009), the cost of transporting a container from north China to Western Europe is approximately 2,500 USD with a transit time of 18 days (Zhu et al, 2018).

Table 7a shows that the NSR is not always more expensive than the SCR, but it is clearly more economically advantageous than the railroad option, except in the worst case and if the vessel is used only during the period of transit along the NSR traveling Eastbound. Our model found that the NSR is already able to provide a more economical solution than the SCR in specific ice conditions (best-case) if the shipowner uses its vessel year-round and does not tranship its cargo in Murmansk.

Regarding the transit time, the railroad is by far the optimal option, with 18 days compared to 23.1 days though the SCR, and the changing transit time of the NSR option except in the westbound direction in the median and best-case if a hub is used. If the transit time of railroad and SCR option is constant, it is

definitely not the case for the NSR. Thus, in order to define an average transit time, we considered the number of days the vessel spends sailing divided by the number of journeys. However, looking at the average transit time provided by the north option, the NSR is globally more attractive than the SCR.

Except during extreme sailing periods, sailing along the NSR between the Bering strait and Murmansk takes less than 10 days in all ice scenarios (Figure 5a, 5b). This short transit time raises the question of the value of a hub at each end of the NSR and indicates the viability of the NSR as a potential transport lane with a shorter transit time than the railroad when ice conditions allow for safe navigation.

Table 7a: Cost comparison of NSR, SCR and Railroad

	Worst-case				Median-case				Best-case				SCR	Railroad
	Steady CAPEX		Variable CAPEX		Steady CAPEX		Variable CAPEX		Steady CAPEX		Variable CAPEX			
	hub	direct	hub	direct	hub	direct	hub	direct	hub	direct	hub	direct		
Westbound	1,811 USD	1,090 USD	2,101 USD	1,367 USD	1,947 USD	547 USD	2,103 USD	745 USD	1,791 USD	820 USD	1,915 USD	967 USD	756 USD	2,500 USD
Eastbound	1,919 USD	1,183 USD	2,947 USD	1,862 USD	1,257 USD	1,653 USD	2,161 USD	1,945 USD	998 USD	587 USD	1,825 USD	880 USD	1,241 USD	2,500 USD

Source: Authors (2019)

Table 7b: Transit-time comparison of NSR, SCR and Railroad

	NSR						SCR	Railroad
	Worst-case		Median-case		Best-case			
	Hub	Direct	Hub	Direct	Hub	Direct		
Westbound	16.4	21.1	16.4	19.3	15.9	19.3	23.1	18
Eastbound	21.2	23.9	19.6	23.2	19.3	22.8	23.1	18

Source: Authors (2019)

6. Discussion and conclusion

In addition to stressing the impact of ice upon the profitability of the NSR, this article highlights the economic impact of various risk management policies, the relevancy of Murmansk as a hub for container transshipping, the impact of depreciation in relation to the period during which a vessel is used, and the benefits and limitations of the NSR compared to the SCR and the railroad option.

Our model attempts to integrate as much as relevant data and parameters as possible. Yet, due to the complexity of this area, we are aware of some limitations. One of the main limitations is the use of a vessel with a TEU capacity equivalent to the vessel used along the NSR. We are aware that vessels sailing between Shanghai and Rotterdam call at numerous ports to load and unload containers. Our model is limited to comparing cost and transit time. Using such an example resulted in a shorter possible transit time without changing the navigation cost. Moreover, using a bigger vessel would involve different cost and thus tackle the question of the cost comparison.

Our results emphasize the importance of POLARIS as a way to define the technical and economic feasibility of navigation as a function of the risk perception of the shipowner.

If the use of an Arctic hub becomes relevant in order to increase the number of containers transported, we find that it also has a negative impact on the transportation cost of a container. Simultaneously, sailing directly to Rotterdam decreases the cost of a container.

Investing in ice class vessels is compulsory for safe, unassisted navigation in polar waters. However, the technical features of ice class vessels may not ease their use in other markets when the NSR is inaccessible. Our analysis highlighted the importance of anticipating such issues for supply chain management given the strong impact on transportation cost, and that additional costs are reduced by the length of the navigation period.

Finally, compared to the SCR and the railroad, the NSR can offer a shorter mean transit time, but this result is highly dependent on the ice conditions. From an economic point of view, the cost of transportation is clearly less expensive along the NSR than via railroad. Furthermore, compared to the SCR, the NSR is able to be cost effective in some cases.

Our analysis is aimed to provide another point of view of the NSR integrating the impact of risk management policy and the use of a hub in accordance with investments made by the Russian government at the Murmansk Transport Hub to reach a capacity of 1 million TEU per year. Yet, given the aforementioned limitations, numerous opportunities for future research remain to further investigate the profitability of the NSR, such as through analysis of the elasticity of the freight rate.

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