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Abstract

If the use of the Northeast Passage (NEP) is considered being profitable for bulk, the point of view regarding container transportation differs according to the parameters analyzed and the point of view of the authors. Yet, as far as we know, none of them assessed the limit of the number of containers that can be managed by the NEP between Asia and Northern Europe and hence the maximum market share the NEP could, in theory, take from the Suez Canal Route (SCR).

The objective of this article is to assess the capacity of the NEP to manage a defined number of containers integrating current technical, legal and climate constraints in a safe environment.

Based on changing ice conditions, different ice class vessels with a loading capacity limited by the beam of the new generation of nuclear icebreakers and the draft of the Sannikov Strait, we shall estimate the number of containers that can be shipped on a yearly basis when vessels sail in convoy.

To do so, we will define the existing and ordered fleet of ice and polar class container vessel, their loading capacity, the number of vessels able to sail in convoy with a nuclear icebreaker considering that only nuclear icebreakers are able to assist vessels in convoy. The length of navigation will be computed via the POLARIS system according to three ice condition scenarios and different vessel ice classes. Ice data (thickness and concentration) are extracted on a daily basis over 25 years all over the Arctic ocean at a 12.5 km size grid scale.

Our results stress that the NEP is clearly not a competitor for both railroad and SCR and that the best solution depends on the strategy implemented by the company.

1. Introduction

The navigation along the Russian shore, because of its potential shortcut and ice melting raised the interest of numerous scholars. Yet, if the ice melt, the drifting ice and the unpredictable sailing conditions complexify the navigation and the respect of schedule (Lasserre et Pelletier, 2011; Cariou et al, 2019).

Considering the potential shortcut represented by the North East Passage (NEP hereafter), its economic attractivity has been mainly assessed versus the Suez Canal Route ("SCR" hereafter). However, results are highly depending on integrated economic, climate, geographical and technical parameters, which represents the highest bias of analysis as assumed by authors (Theocharis et al, 2018).

Considering the NEP as a challenger to the SCR has been considered not only by academics. For instance, Russian authorities invested in new ports and icebreakers to ease the transportation and render safer the navigation (Alix and Faury, 2019).

Yet as explained by Fedi et al (2018a), sailing in the Arctic implies to manage a higher number of hazards including ice. The icebreakers are considered as the backbone of the NEP. They are the only vessels able to sail on a yearly basis, help ships stuck or facing a claim and, open navigation channels to ships sailing on convoy.

Our analysis will develop a model assessing the ability of the NEP to posit as a SCR challenger and a game changer in the existing container flows between Asian and European countries.

After this introduction, the remainder of this article is organised as follows: Section 2 is the Literature review, Section 3 focuses on the methodology used. Section 4 discusses our assumptions and results while Sections 5 and 6 are dealing with the results and the conclusion.

2. Literature Review

During formers years, numerous articles dealing with the economic attractiveness of the NSR have been published (Theocharis et al, 2018; Lasserre, 2014; Cariou et al, 2019; Zeng et al, 2020). However, results change according to assumptions considered.

The questions related to the NSR in these analyses were to define the economic attractiveness of the NSR versus the SCR and/or the railroad (Cariou et al, 2019).

To do so, academics integrated various economic (Lasserre, 2014; Verny and Grigentin, 2009; Theocharis et al, 2019; Zhang et al, 2016; Schøyen and Bråthen, 2011), climate (Stephenson et al, 2014) and sustainable parameters (Cariou et al 2019).

Part of the economic conditions, most of them considered icebreaking fees, fuel cost, OPEX, CAPEX, voyage cost, freight rate and Time charter.

Regarding climate conditions, exception for few articles, if authors agreed on their impact on the navigation, few of them focused on it (Stephenson et al, 2014, Liu and Konbrack, 2010). They defined an average speed of the vessel (Verny and Grigentin, 2009;)

The sustainable approach has been considered by Cariou et Faury (2015), Cariou et al (2019) and Raza and Schøyen (2014).

Yet, if most the parameters have been taken into consideration, according to the assumptions and the degree of detail, as expressed by Theocharis et al (2018), result may change. Some considered that the NSR is unattractive because of cost such as fuel (Lasserre, 2014), icebreakers (Liu and Konbrack, 2010). Others conclude that if it may provide some profits, the incapacity of the NSR to provide a reliable schedule is the main break to its development as a transit line that may compete with the SCR (Lasserre and Pelletier, 2011).

However, if they may disagree on the economic potential of the NSR to compete with the SCR they all agree on the importance of the icebreaker as a backbone for the NSR development (Moe and Brigham, 2017). Icebreaker have numerous tasks. They assist vessel when stuck in the ice (Marchenko, 2014a), maintain the sovereignty of the Russian federation via a continuous presence in the Arctic Ocean and seas and convoy vessels when sailing in the Russian Economic Exclusive Zone (EEZ) to provide a safer navigation against the fast-changing weather conditions (Marchenko, 2014b). The formers years saw numerous articles dealing with Russian icebreakers fleet (Moe and Brigham, 2017; Gritsenko and Kiiski, 2016; Bukharin, 2006) providing information such as the age, the size, the power of the engine and the energy used by the IB and the beam of each IB and the way they are managed (Moe and Brigham, 2017).

Yet, if their presence is not made mandatory by the Russian administration (NSRA, 2013), underwriters require vessels to be assisted while sailing in the Arctic (Fedi et al, 2018a). As explained by Fedi et al. (2018a), underwriters may ask to shipowner to announce areas of the NSR they plan to cross.

Navigation in Arctic imply to manage numerous risks related to climate and geographic conditions in a highly sensitive ecosystem with a low resiliency capacity. Hence to protect both seafarers, vessels and ecosystem, a Polar Code (PC) entered into force in early 2017. This code draws its prophylaxis via three tools: the Polar Ship Certificate (PSC), Polar Water Operational Manual (PWOM) and the Polar Operational Limit Assessment Risk Indexing System (POLARIS) (Fedi, 2018b).

As explained by Fedi et al. (2018b), POLARIS suggests, the safest vessel speed depending on the ice class of the vessel and sailing conditions (ice thickness, concentration and temperature). The speed is that importance that as explained by Marchenko (2014a), unsuitable speed is among the root causes of claims in Arctic. This tool informs deck officer on the capacity or inability of their vessel to sail in coming conditions and the level of risk they may face.

Finally, Solakivi et al. (2018) stressed the impact of the ice class on the loading capacity of vessels and highlighted that the use of ice class had strong technical influence on the attractivity of the Arctic navigation.

Hence as explained, the attractivity of the NSR has been analysed from numerous points of view with changing result according to assumptions. The Russian IB fleet has been the topic of various articles providing a global vision of its state. The use of POLARIS as a decision-making tool has been demonstrated since 2017. Yet, to the best of the authors' knowledge, no articles combine these three themes in order to assess the number of containers the NSR is able to manage during a defined season.

3. Methodology

To define the number of containers the NEP can manage we have to consider the existing global fleet of containerships up to 5,089 TEU, including the ice-class vessels among these, the available IB fleet, the pathway defined with underwriters, the speed of the vessels and the ice conditions.

3.1. Definition of the global ice-class fleet

Vessels sailing through the NEP may have to deal with specific constraints such as the draft of the Sannikov strait (13m) and the maximum beam of IB (34 m). Due to the aging of the current IB fleet, we will assume for our assessments an IB fleet composed of next generation vessels.

Based on these assumptions, we found that 3,408 vessels with a capacity oscillating between 100 and 5,089 TEUs compose the container vessels world fleet (Clarkson, 2020). Among these there are 322 ice class 1A and 17 ice class 1AS. Regarding the loading capacity, the non-ice class vessels can load up to 5,089 TEUs, the 1A vessels up to 2,808 TEUs and the 1AS vessels up to 1,638 TEUs.

3.2. IB fleet

The current aging fleet of IB is about to be renewed (Moe and Brigham, 2017). Therefore, we decided to ground our analysis on the next generation of icebreakers with a beam extended to 34 m (Clarkson, 2020).

3.3. Ice conditions

3.3.1. POLARIS RIO

POLARIS aims at providing information to deck officers about the capacity of their vessels to sail in different types of ice conditions that may be encountered. Vessels ability to sail within an area depends on different parameters that should be gathered to define a Risk Index Outcome (RIO). The RIO is a combination of the Risk Index Values (RIV), ice thickness, concentration and typology. The RIV is a value varying between 3 and -8 (Table 1) with regard to the ice or polar class of the vessel and the type of ice.

Table 1 : Risk Index Values (RIV) per typology of vessel and ice.

		Ice free	New ice	Grey ice	Grey White ice	Thin First Year 1st Stage	Thin First Year 2nd Stage	Medium first year	Thick first year	Second year	Multi year	Heavy Multi-year
Polar Class	PC1	3	3	3	3	2	2	2	2	2	1	1
	PC2	3	3	3	3	2	2	2	2	1	1	0
	PC3	3	3	3	3	2	2	2	2	1	0	-1
	PC4	3	3	3	3	2	2	2	1	0	-1	-2
	PC5	3	3	3	3	2	2	1	1	-1	-2	-3
	PC6	3	2	2	2	2	1	1	0	-2	-3	-3
	PC7	3	2	2	2	1	1	0	-1	-3	-3	-4
Ice Class	1AS	3	2	2	2	2	1	0	-2	-3	-4	-5
	1A	3	2	2	2	1	0	-1	-3	-4	-5	-6
	1B	3	2	2	1	0	-1	-2	-4	-5	-6	-7
	1C	3	2	1	0	-1	-2	-3	-5	-6	-7	-8
Catregory II	Not Ice Class	3	1	0	-1	-2	-3	-4	-6	-7	-8	-8

Source: Authors based IMO (2016)

Based on Table 1 and on Equation (1), one is able to define the RIO of a vessel in the different conditions that may be faced and thus the ability of the vessel to sail within these conditions.

$$RIO = RIV_1 * Ice_1 + RIV_2 * Ice_{21} + \cdots + RIV_n * Ice_n \qquad (1)$$

where Ice_i, $i = 1, \dots, n$, is the concentration of ice thickness i.

3.3.2. Ice conditions statistics

Ice conditions constantly change in the Arctic and highly depend on space and time. The European Copernicus database hosts a dataset named ARCTIC_REANALYSIS_PHYS_002_003 (von Schuckmann et al., 2016). This dataset covers the full Arctic and contains daily data cells gridded at 12.5 km resolution since 1991. From this dataset, the daily sea ice concentration and sea ice thickness are extracted. Ice thickness is converted into an ice type from Table 1 as detailed in the conversion scheme of Table 2 that is inspired from WMO Sea Ice Nomenclature (1970).

Table 2 : POLARIS Sea Ice thickness conversion table.

Ice Type	**Ice-Free**	**New Ice**	**Grey Ice**	**Grey White Ice**	**Thin First Year ice 1st Stage**	**Thin First Year Ice 2nd Stage**	**Medium First Year Ice less than 1 m**	**Medium First Year Ice**	**Thick First Year Ice**	**Second Year Ice**	**Light Multi Year Ice, less than 2.5 m**	**Heavy Multi Year Ice**
WMO Sea Ice Nomenclature (cm)	**0**	**<10**	**10 - 15**	**15 - 30**	**30 - 50**	**50 - 70**	**70 - 120**		**>120**	**≤250**	**≥300**	
Model minimum thickness (cm)	0	0	10	15	30	50	70	100	120	200	225	250
Model maximum thickness (cm)	0	10	15	30	50	70	100	120	200	225	250	+∞

Source: Authors (2020)

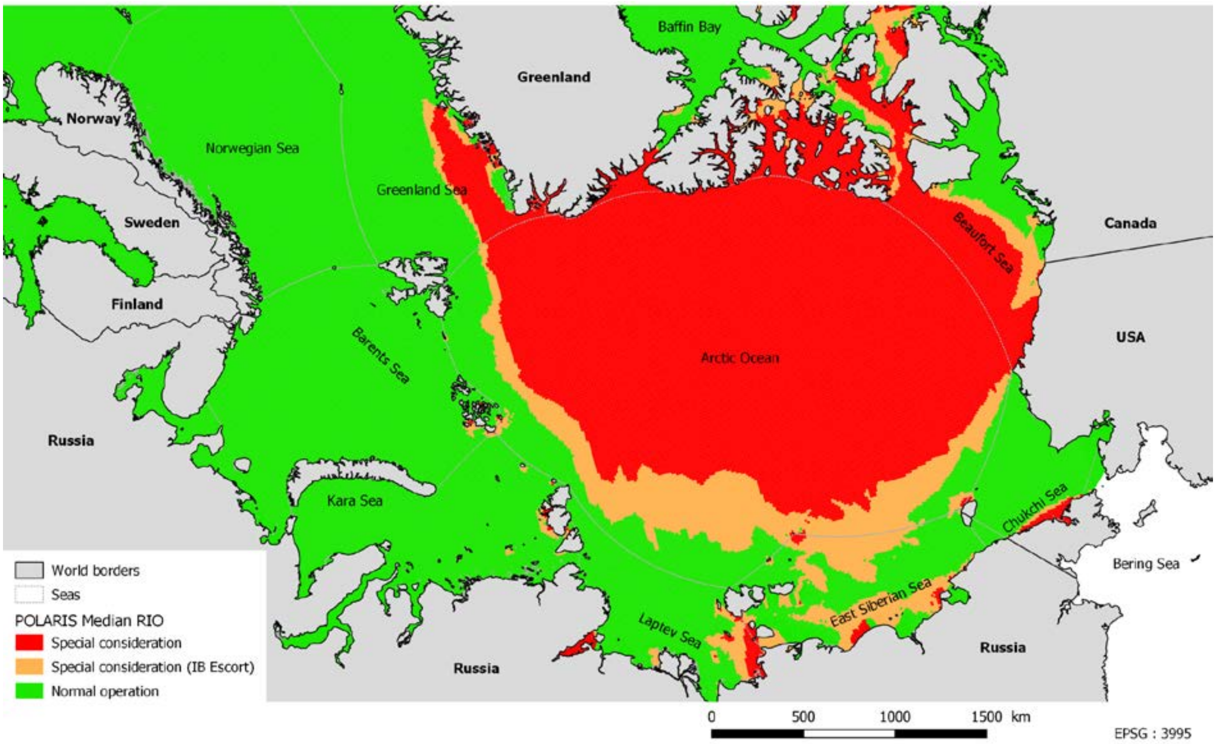
The POLARIS RIO is computed for each grid cell and every ship ice class using Equation (1) and Table 1 and Table 2. All these POLARIS values are grouped by grid cell (space aggregation), ship ice class and day of year (time aggregation). The median POLARIS value is deducted from these grouped values. Depending on this median POLARIS RIO value, three different operational risk levels are listed in Table 3. When the POLARIS RIO is positive, the ship has the ability to operate normally (Green area in Figure 1). If the POLARIS RIO is between 0 and -10, the ship should slow down and/or require an icebreaker escort (Orange area in Figure 1). Below -10, the planning of the operation should be avoided (Red area in Figure 1).

Table 3: Risk Index Outcome criteria

RIO_{SHIP}	***Ice classes PC1-PC7***	***Ice classes below PC 7 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)

Figure 1 : POLARIS Median RIO for a IA Super vessel navigating on January 1st (day of year 1)

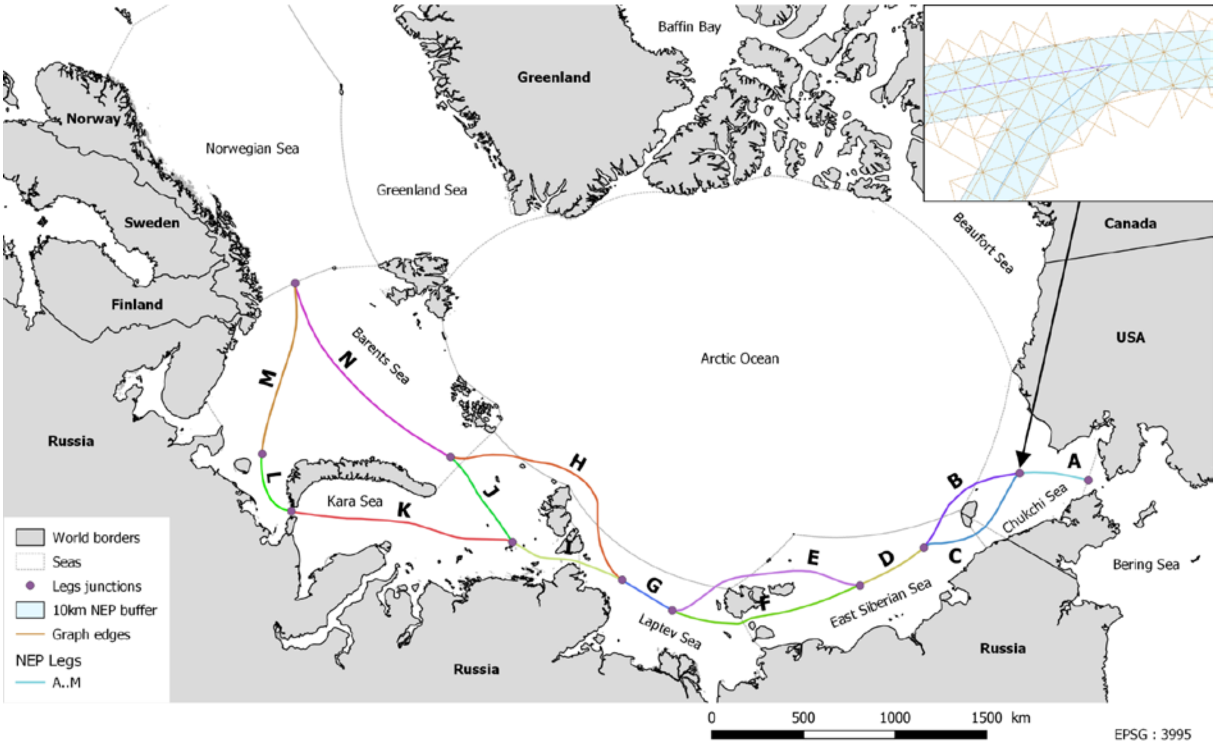


Source: Authors (2020)

3.4. Definition of the Pathway

The NEP is an area with numerous pathway possibilities. In our model we considered the fastest pathway. These legs of the studied paths are defined according to AMSA report (2009) and aligned with the ARCTIC_REANALYSIS_PHYS_002_003 grid cells resolution (12.5km). Grid cells intersecting with a 10km buffer around the AMSA NEP routes were selected. A graph network was created by connecting every grid cells to its neighbors. Nodes of the graph are the center of each grid cells and edges of the graph connects theses nodes to theirs nearest neighbors as illustrated in Figure 2.

Figure 2: NEP pathway legs graph



Source: Authors (2020)

3.5. Computation of vessels speed

As an unsuitable speed is one of the main causes of claims, we computed vessel speed according to the RIO of the vessel. As explained by Table 3, the RIO defines the level of navigability of the vessel based on ice conditions.

Based on the RIO obtained previously and Table 2, we are able to define when, where and for how long an icebreaker is needed.

This result has to be put into perspective with the speed of the vessel that changes depending on ice conditions.

However, as explained in Table 1, each ice class does not behave the same way in equivalent ice conditions. Hence, considering that with a positive RIO, vessel speed changes between optimal speed and 8 kts when icebreaker assistance becomes necessary and then from 8 kts to 3 kts when it reaches its limits in terms of ice resistance (Kitigawa, 2000).

Hence, the speed of vessels can be calculated using Equation (2) with *x* being the POLARIS RIO varying between +30 and -10.

$$S = \frac{-1}{300}x^2 + \frac{7}{15}x + 8 \quad (2)$$

3.6. Number of handled containers

The number of transported containers on a yearly basis depends on the number of trips done per convoy, the number of vessels composing the convoy, the number of containers each vessel can load and the number of icebreakers on duty.

4. Business case

Our analysis relies on several assumptions. First, we considered that vessels must always sail in convoy assisted by a nuclear icebreaker, even in summer months. We made this assumption for safety reasons and in order to increase the capacity of vessels to arrive on time and avoid the risk of being stuck. As explained by Fedi et al. (2018a), underwriters may render compulsory the use of icebreakers for safety reasons, a vision shared by Marchenko et al. (2015). Secondly, looking at the case of the *Inger*, even if the RIO is positive some drifting ice may exist, hence being assisted by an icebreaker is mandatory.

Third, we considered that the convoy begins in the Russian EEZ (Russo-Norwegian boarder) in the western part and ends when the vessels leave the Bering strait.

Fourth, we assumed that a convoy is made of three vessels, all of them having the same ice class. Hence, we composed seven different scenarios. The uniform convoys are made of one type ocean class exclusively, a full Not-Ice Strengthen ("Not-IS" here after), 1A and 1AS. The mix convoy organization significates that the IB escort, the highest ice class of the convoy, and the vessel composition change due to the change in ice conditions between the case where these conditions allow the use of a lower ice class till they impose the use of the highest ice class again.

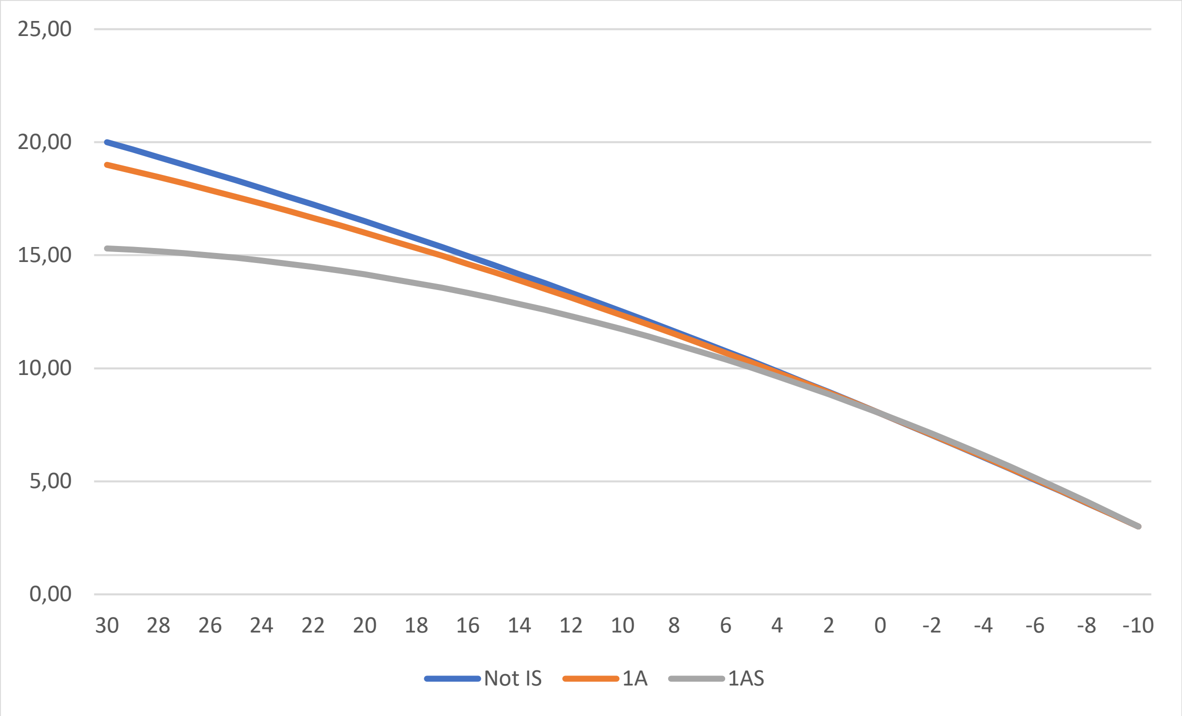
Regarding the speed values, as stressed in Figure 1, each vessel has its own speed curve, the optimal speed being computed based on example coming from Clarkson (2020).

Table 4 : Different convoy organisation

Type of convoy	Ice classes composing the convoy
Uniform	Not-IS
	1A
	1AS
Mixed	Not-IS + 1A
	Not-IS + 1AS
	1A + 1AS
	Not-IS + 1A + 1AS

Source : Authors (2020)

Figure 3 : vessels speed according to the RIO and their ice class.



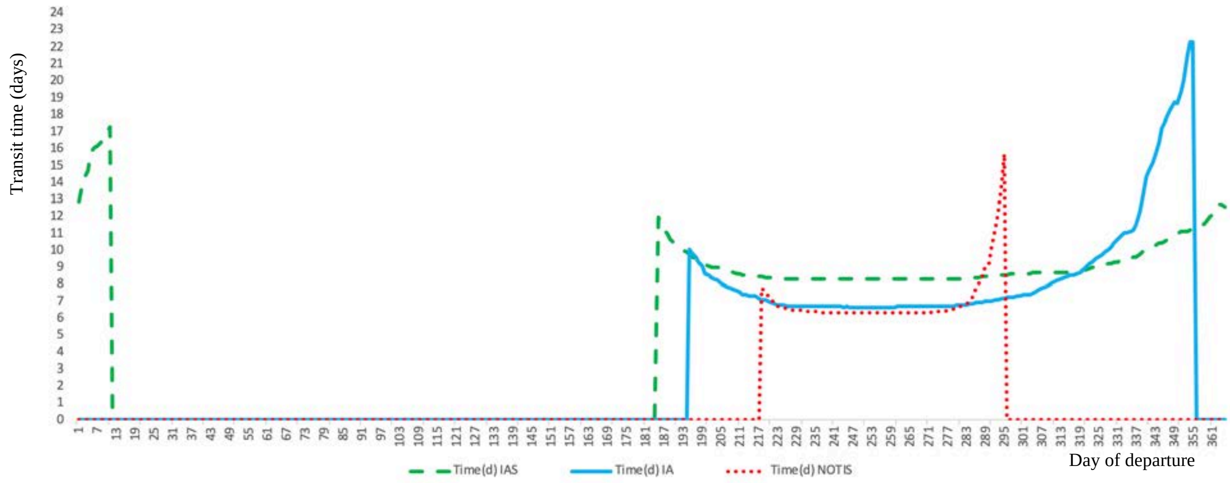
Source: Authors (2020)

Concerning the loading capacity, we consider the largest vessels available with a loading capacity of 5089 TEUs, 2,408 TEUs and 1,638 TEUs for the Not-IS, 1A and 1AS respectively. The number of vessels sailing in convoy is defined by Sakhuja (2013) who considered that a convoy is made of three vessels. To define the maximum loading capacity of the NEP, we would calculate the annual capacity of one IB, then multiply our result by the number of nuclear IB able to convoy such vessels.

As the ice conditions have a direct impact on the navigability of the NSR, we consider a median climate scenario based in the extraction of the ice conditions over 28 years on a daily basis all over the Arctic Ocean as indicated in Section 3.3.2.

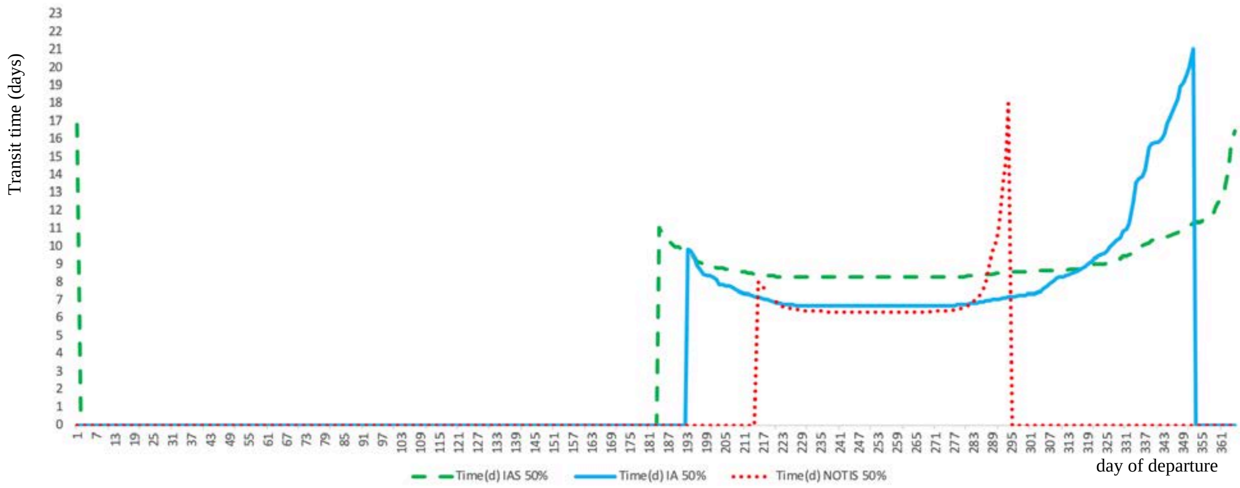
This approach related to the numerous possible pathways as explained by AMSA (2009), enabled us to define the sailing period of each type of vessel when sailing from the Bering strait to the Barents Sea and vice versa. The median POLARIS RIO and speed formula 2 were used to compute the transit time for each edge of the NEP legs graph (Figure 2). The total time required to transit the NEP was computed for each departure day in the year using time dependent Dijkstra algorithm. Results of these computations are presented in Figure 4 and Figure 5.

Figure 4: Sailing period – from Bering strait to Barents Sea.



Source: Authors (2020)

Figure 5 : Sailing period – from Barents Sea to Bering strait



Source: Authors (2020)

5. Results

Our results stress the highest number of containers that can be loaded on a yearly basis along the NEP in compliance of safety rules implemented with the Polar Code. To do so, we calculate the number of trips an IB can carry out per year for each convoy organization and compare the annual loading capacity of each convoy organization.

5.1. Loading capacity

Looking at table 4 with the different convoy organizations, the best option is when all types of ice classes are used with 214,878 TEUs shipped. This result can be explained by the length of navigation provided. On the other side, the worst option is when the convoy is made exclusively of 1AS. In fact, looking at the loading capacity the option with mixed convoy provides a better result than those with a single ice class (Table 5).

Notwithstanding, even if all the convoys are organized as the "Not-IS -1A-1AS", we remain far away from the number of containers that can be loaded using the the SCR. Although the results of the NEP are close to the railroad by one million TEUs, the lack of reliability clearly stresses that the NEP has currently no capacity to challenge any of them, but offers an additional way to link both Asian and European markets.

Another point stressed by Table 5 is the fact that, despite a navigation period longer by 120 days compared to the full Not-IS convoy, the use of both 1A and 1AS only adds 9,678 containers. Knowing that ice class vessels are more expensive than Not-IS ones, this result raises the question of the utility of investing in vessels dedicated to the Arctic navigation from a purely economic point of view.

Table 5 : loading capacity of each organisation (yearly)

Organisation	Number of TEUs	Number of trips	Length of navigation (days)	Distance sailed by the IB (nm)	Fuel cons.	Fuel cons. per containers
Not IS -1A-1AS	214,878	23	203	70,233	25,741	0.120
Not IS -1AS	204,132	24	210	73,275	25,194	0.123
Not IS -1A	197,850	20	167	61,057	25,138	0.127
1A-1AS	175,428	25	205	76,337	26,279	0,150
Full Not IS	165,750	13	85	39,634	21,149	0,128
Full 1A	165,600	23	181	70,212	25,512	0,154
Full 1AS	113,022	23	204	70,213	15,009	0,133

Source: Authors (2020)

5.2. Length of navigation and reliability issue

Figures 4 and 5 highlight the combined impact of ice and ice-class on the length of navigation. As an example, the not Ice-Strength vessel can sail between days 218 and 310. In other words, early August till early November in both directions. The other extreme case corresponds to the 1AS which can provide services during 6 months.

However, this increase of the number of navigation days has an impact on the loading capacity of the vessel. Reinforcing the hull of a vessel has direct negative impact on the loading capacity (Mulherin et al, 1996).

Yet, as explained by Lasserre et Pelletier (2011), one of the main challenges faced by the NEP in terms of attractiveness compared to the SCR or the railroad lays in its capacity to offer and sustain a steady schedule.

Table 6 : Transit Time (TT) of the NEP according to the convoy organization (in days)

Organisation	Min TT	Average TT	Max TT	Standard deviation
Not IS-1A-1AS	6,4	8,8	17,3	2,8
Not IS -1AS	6,4	8,8	16,5	2,5
Not IS -1A	6,4	8,2	17,3	2,6
1A-1AS	6,7	8,7	22,3	3,6

Full Not IS	6,4	7,0	12,1	1,5
Full 1A	6,7	8,4	22,3	3,6
Full 1AS	8,3	9,3	12,9	1,4

Source: Authors (2020)

Table 6 sheds a light on the capacity of the NEP to provide a service respectful of the schedule. In this case, the best option seems to be the use of a convoy made exclusively of 1AS. In this case, the 1AS convoy provides and transit time of 9.3 days to cross the Arctic, yet if it is not the fastest option, this one being a convoy with Not-IS and 1A vessel, it is the one with the lowest standard deviation (1.4 days). Yet, if we include in our analysis the transit time, hence the use of a convoy made of “Not-IS” is a better option with a possibility to save 2.3 days in average.

Based on the fuel consumption, the use of Not-IS is, once again, the organization that shows the lowest level of fuel consumption compared to the others (Table 5). However, looking at the fuel consumption per container shipped (Table 5), the convoy made of 1AS has the lowest level of fuel consumption. This result can be explained by its design speed of 15.3 kts versus the 19 kts and 20 kts for the 1A and Not IS respectively.

Hence our analysis highlighted the following points:

- If the strategy of the maritime company is to ship as many containers as possible, hence the use of a mixed convoy is mandatory;
- The 1A may not be a solution when compared to the Not-IS but it could be interesting when analyzed versus the 1AS;
- The 1AS is the best option if a maritime company wants to offer a reliable service during half of the year.

6. Conclusion

Looking at our result, we are in line with numerous articles (Lasserre and Pelletier, 2011; Cariou et al, 2019) affirming that the Arctic shipping lane cannot compete with the SCR for container shipping. The main reason is due to its low loading capacity compared to the SCR and to the difficulty to maintain a steady schedule.

As explained, the convoy can only manage 214,878 containers per year. This result does not take into consideration the cost for such a transportation as Icebreakers, CAPEX, OPEX and voyage cost.

Secondly, if the Not-IS is more interesting than the 1A, this is only because it is able to load more containers. However, here again, integrating economic parameters would be the next stage of this analysis. Besides, the 1A appears as more profitable than the 1AS. With a shorter period of navigation, it is able to ship more containers.

Thirdly, the 1AS is the option that provides a service with the lowest variation of transit time despite its limited capacity.

If our analysis provides another point of view regarding the navigation along the NEP, some assumptions shall be added. First the integration of a number of vessels in the convoy varying from one to four according to the ice class of the vessel and ice conditions.

Finally, the GHG emissions impact with the new SOx rules shall be more deeply analyzed in order to find out whether, despite the low number of shipped containers, the use of this lane may allow some GHG savings.

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