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The impact of adding the Northern sea route to the Belt and Road Initiative for Europe: A chain cost approach

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ABSTRACT

In this paper, the possibility of adding the North Sea Route (NSR) route to the Belt and Road Initiative (BRI) is researched whereby the main aim is to determine if it is possible to set up a container service via the NSR route that could attract cargo from the existing maritime routes via Suez and the land route. In order to make the analysis, a model which is able to calculate the total generalised chain cost for a supply chain is used and updated.

This analysis shows that it is possible to set up such a competitive service compared to the land bridge and the Suez Canal Route (SCR) for cargo that has a high value of time. For these specific cargo types, it is possible to attract cargo for the NSR from the SCR at equal costs, but with an average time saving of 10%. Comparing the BRI or land bridge to the SCR, there is a cost increase of 20% and a time decrease of almost 65%. Considering the rather strict limitation in capacity, it should be noted that a single NSR service of eight 5,400 TEU vessels already offers around half the capacity of the land bridge. The uncertainty in arrival times, however, would remain an issue in the NSR service, but with ice diminishing, this risk will decrease as well.

Introduction

The Northern Sea Route (NSR) or the North East Passage (NEP) is the shipping lane connecting Europe and Asia via the North of Russia. Together with the Northwest Passage along the northside of Canada and Alaska, it is located in the Arctic and would offer significant reductions in travel distance for ships. These routes have already been explored with varying degrees of success for over five centuries. However, with the continuing decline in sea ice (Hagen and Jones, 1996; Brigham, 2000; Rodrigues, 2008; Comiso, 2012; Shepherd et al., 2012, Rogers et al., 2015, Melia et al., 2016, Khon et al., 2017), a new rise in interest can be observed both in commerce and research since the 1990 s. The potential duration and resulting cost and time reductions of these shipping lanes motivate this.

Since 2005, China has started to show interest in the arctic as well (Huang et al., 2015). With the achievement of observer status at the Arctic Council in 2013 (Hossain et al., 2019), the interest of China in the arctic was made official. Although there is an interest in the minerals, in June 2017, China added the Northern Sea Route (NSR) to its Belt and Road Initiative (BRI) (Song, 2018), launching a Polar Silk Road (PSR) in early 2018 (Sun, 2018) with the release of a white paper.

Despite the intentions of both Russia and China to make the NSR into a successful shipping lane, there have not yet been any large investments in the required infrastructure. The increased risk of the Arctic route due to the combination of the presence of a large amount of sea ice and the lack of land and sea-based infrastructure (refuge ports, communication, sea lanes, etc.) is a major drawback of the route. Another drawback is the fact that the suitable ship size is much smaller than allowed for the Suez Canal Route (SCR). It would, therefore, be crucial to investigate the potential gains before these investments are made.

This paper investigates the impact of adding the NSR in the existing BRI on the trade flows between Asia and Europe. As transport chains do not start or end in the seaports, the analysis considers the hinterland part as well, ensuring that any switch in trade flows will also be accounted for. The main aim of this paper is to determine if it is possible to set up a container service via the NSR that could attract cargo from the existing maritime routes via Suez and the land route. This leads to the following research question: How competitive is the NSR as an alternative for the SCR and the land bridge route between China and Europe?

To be able to answer this question an extensive review of arctic shipping has been executed, discovering several flaws in the assumptions used so far and combining insights, that until now have only been

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studied independent. This increases the validity of the results compared to earlier research with similar focus. Furthermore, an in depth investigation of large vessels on the NSR was executed to cover also the potential further into the future. By using a proven model forregion-to-regionn transport, the results of this research will create additional insights into the effectiveness of the alternative route between Asia and Europe, other than the land bridge. The effectives of the land bridge could be jeopardised by potential (political) conflicts. Therefore the NSR could also be seen as an alternative for the land bridge routes in case of disruptions.

This paper is structured as follows. Section 2 discusses the literature on the NSR, as well as the link to the BRI. Section 3 describes the model and the input parameters for the model, leading to the discussion of the results in Section 4. Section 5 presents the conclusions.

Literature review

The amount of literature studying the potential of the Belt and Road Initiative's (BRI) railway link in comparison to the Suez Canal Route (SCR) is quite significant. This paper extends the work of Meersman et al. (2020). As demonstrated there, the potential of the BRI is existing, especially for higher-value goods. However, the capacity is very limited, and there is a significant risk of a delay along the way. With the addition of the Northern Sea Route to the BRI, the capacity issues may be alleviated through this extra corridor. This literature study is, therefore, primarily focussed on the research into the NSR.

Both Lasserre (2014) and Pruyn (2016) offer extensive NSR literature categorisations in their papers, which served as the basis for this literature study, extending these insights with more recent papers. It should be mentioned that the sheer increase in the number of papers on the NSR in the period between 2015 and 2020 makes it difficult to ensure a complete overview. With over 80 sources identified on the NSR alone, we are confident that not many have been overlooked.

The International Northern Sea Route Programme (INSROP) is still the largest international research effort into the use of the NSR as a shipping lane. It also seems to be the starting point of research into the NSR. It led to several economic evaluations of the NSR (BUCHAN, B., 1995, Heimdal and Wergeland, 1995, RAMSLAND, 1999, Ramsland and Hedels, 1996, Takamasa et al., 1996, Mulherin et al., 1999). Moreover, the data and knowledge on the route itself provided by these studies still form the basis of many of the later studies. These studies are extended with more details, or they took into account changes in the world.

Thereafter, the research into the economic benefits can be split into two approaches, macroeconomic and microeconomic. The number of macroeconomic papers is limited (Francois et al., 2013, Ha and Seo, 2014, Bekkers et al., 2018, Liu et al., 2019, Zeng et al., 2020), and a major drawback of these papers is the fact that crucial aspects of the NSR do not seem to be accounted for. A very good point of these models is the incorporation of the link between trade volumes and prices. The NSR does offer shorter distances, and this could result in extra trade between Asia and Europe. However, the time advantages are already uncertain for many routes, and due to the many variables that influence the costs, these are even harder to determine. Finally, the draft and width limitations on the NSR route (BUCHAN, B., 1995, Liu and Kronbak, 2010, NSRA, 2020, NSRA, 2014, Pruyn, 2016), also limit the constant effects of economies of scale. This means that some of the assumptions behind the macroeconomic models do not hold, making the results susceptible.

The microeconomic or ship and transport cost focussed models can be further split into two groups. The first is considering the NSR in isolation to determine if transporting along this route is feasible. The second group compares the NSR with the alternative being the Suez Canal Route (SCR). All INSROP papers (BUCHAN, B., 1995, Heimdal and Wergeland, 1995, RAMSLAND, 1999, Ramsland and Hedels, 1996, Takamasa et al., 1996, Mulherin et al., 1999) belong to the first group, but also later research such as that of Lasserre and Pelletier (2011), Huang et al. (2015), Lasserre et al. (2016), Otsuka et al. (2016), Zhao et al. (2016), Lin and Chang (2018), Xu et al (2018), Furuichi & Otsuka (2018) and Kiiski et al. (2018) is studying the feasibility of the NSR in this way. The earlier papers show a positive outcome, while the later papers show a mixed outcome. The paper of Kiiski et al. (2018) includes the availability of suitable ice breakers to support the transits, while Zhao et al. (2016) show that the NSR should be considered as a supplementary line of existing liner networks. The ongoing decline in icebreaker capacity will delay the use of the NSR effectively for quite some time. Lasserre (Lasserre and Pelletier, 2011, Lasserre et al., 2016, Xu et al, 2018) investigate the interest of the market in the NSR, rather than modelling the feasibility. Both studies confirm a tendency to stick with the known trades and a lack of triggers to explore the arctic option.

For the studies comparing the freight rates between SCR and NSR (Verny and Grigentin, 2009, Schøyen and Bråthen, 2011, Xu et al., 2011, Furuichi and Otsuka, 2013, Lasserre, 2014, Faury and Cariou, 2016, Pruyn, 2016, Zhang et al., 2016, Wan et al., 2018, Wang et al., 2018, Zhu et al., 2018, Cariou et al., 2019, Theocharis et al., 2019, Faury et al., 2020, Wang et al., 2020) the approaches and results are very mixed. Some identify already a potential but see it declining in the future. Others see no potential now but more potential in the future. In comparison, again, others see no potential at all. The majority is focussed on container trade, while others focus on wet and/or dry bulk cargo (Schøyen and Bråthen, 2011, Furuichi and Otsuka, 2013, Faury and Cariou, 2016, Pruyn, 2016, Wang et al., 2018, Theocharis et al., 2019, Faury et al., 2020, Wang et al., 2020). It is clear that the choices for comparison ships have a large influence. Furthermore, the more recent increase in size on the SCR route from 8,000 TEU in the early 2000 s to 20,000 TEU in the 2020 s has significantly reduced the costs of the SCR over time. For the arctic, the common agreement seems to be that a 4,000–5,000 TEU ship is the largest possible vessel. The sailing speed, in combination with the fuel costs, is another factor impacting the potential significantly. With the banning of sulphur and further required CO_2 reductions (IMO, 2018), green fuels will most likely become the norm. These are significantly more expensive and may compensate for the inefficiency of the smaller ships in the arctic. However, their full-scale introduction is expected after 2030, if not 2050, based on the current regulation implementation plans.

Besides the economic benefits, several authors have also focussed on assessing the impact of shipping via the NSR (Dalsøren et al., 2007, Corbett et al., 2010, Paxian et al., 2010, Yumashev et al., 2017, Hauser et al., 2018, Zhu et al., 2018, Wang et al., 2020). These studies either focus on the potential benefit of global CO_2-emission reductions or the impact of local exhaust emissions. The use of the NSR route may reduce the fuel required per TEU, but most studies identify this as a marginal impact due to the smaller vessels used. The before mentioned green fuels may reduce the number of harmful substances emitted and reduce CO_2 accumulation globally. For instance, Xu & Yang (2020) researched the use of LNG as an alternative for vessels passing on the NSR. Many, such as biofuels or alcohol-based methanol and ethanol, will not reduce the actual CO_2 emissions from the ship, so local emissions should be expected and could be banned in a future scenario. This is, however, beyond the scope of this paper.

The mentioned legislative and political uncertainty about the arctic and the NSR has enticed a large number of researchers to discuss this situation in various forms (Peters, 1993, Hagen and Jones, 1996, Østreng, 2006, Borgerson, 2008, Brigham, 2008, Global, 2008, PAME, 2009, Lammer, 2010, Lárusson, 2010, Bunik and Mikhaylichenko, 2013, Huang et al., 2015, Chircop, 2017,Sørensen, 2017, Alexeeva and Lasserre, 2018, Sun, 2018, ABE and OTSUKA, 2019, Hossain et al., 2019, Gao and Erokhin, 2019). The main themes are the ownership of arctic waters beyond the 200-mile economic exclusive zone, the governance of one of the most pristine environments in general, and the (un)willingness of nations to cooperate in dealing with both these issues as well as the preparations required for the commercialisation of the arctic sea routes. These issues could be reason enough by themselves to never see successful shipping along the NSR. However, for this paper, we assume that these issues are solvable or even solved and that shipping along the NSR is possible and controlled from a legal perspective.

With the mixed outcomes on economic benefits, it makes sense to examine containerised goods first. These higher-value goods do benefit most from a short time to market (ABE and OTSUKA, 2019). This is an aspect that is not studied explicitly by the identified models. Following this reasoning, many higher-value goods are also lighter than the average weight of goods transported in containers. This would open up an opportunity to challenge the limit of 4,000 TEU on the NSR, a larger ship with lighter containers might still be able to fit within the draft and width limitations for the NSR and turn out to be able to do so at lower costs, but for limited types of cargo only.

Methodology and modelling approach

In order to research the effect of using the NSR and to compare it with the existing transport chains, an existing model that has been developed earlier is adjusted with new functionalities and extra data so that the required analysis can be made.

Base version of the model

The main objective of the model is to calculate the total generalised chain cost from any origin to any destination. The first version of this model was developed by van Hassel et al. (2016). In this model, the total supply chain, including maritime transport, the port process, and hinterland transport, is taken into account. The main reason to emphasise the supply chain is that the container liners, seaports, and land transport modes compete along supply chains. This is illustrated in Fig. 1, where the chain with the lowest overall generalised cost will be the most attractive transport chain.

This approach by van Hassel et al. (2016) was chosen as it not only allows calculating the generalised cost for a total logistics chain, in which ports play a vital role. Additionally, it allows comparing different scenarios, with different modes, port and hinterland origins and destinations. Other methods, mentioned in the literature review in van Hassel et al. (2016), do not have this ability, and therefore this model is used to address the proposed research question.

The model by van Hassel et al. (2016) allows calculating the generalised chain cost from a selected point of origin, via a predefined container loop to a destination point.[1] Fig. 2 gives a general overview of the developed model.

From each terminal in a port, the distances towards the hinterland via each available modality are incorporated in the model. This allows calculating the cost per mode from a terminal to a hinterland destination.

A chain is a path that connects one area of one aggregated hinterland to another area of another aggregated hinterland. As a result, a chain has a beginning and an end. The model incorporates the cost of transporting a container from a hinterland area to a port on both chain sides, the cost of a container in the port phase (port dues, pilotage, container handling, etc.) on both chain sides, and the cost of transporting a container via sea from the port of loading to the port of unloading in order to calculate the chain cost from the point of origin to the destination.

The hinterland model can be used to calculate the cost of hinterland transport from specific container terminals in certain ports in Europe, the United States, and China. The costs of three various modes of transportation (road, rail, and inland waterways) are estimated. As a result, this model may also be used to determine the cost of exclusively land-based movements, such as rail.

[1] The model was coded in C# and uses Microsoft Excel (data) and JMP11 (maps) as output formats.

The transit time is an important component of the generalised cost. As a result, the model includes the transport time for the complete transport chain. This means that the transit time from a hinterland region to a port is taken into account, as well as the dwell time of a container at a deep-sea port, maritime transport, and port and land transport times at the destination hinterland.

The main explanation of the base model, including the used formulas, can be found in van Hassel et al (2016) for the maritime chain cost calculations and in Meersman et al (2020) for the addition of the land bridge. All cost data are updated to 2020 cost values.

The model has been continuously developed and updated over the past years by making more applications with different companies and organisations in different projects. In these projects, the model has been validated to give orders of magnitude of fluctuations in impacts and the role of specific factors in supply chain changes (van Hassel et al., 2022; Aronietis et al.,2021).

Additions to the base model

In order to take the new routes via the Northern Sea Route into account in the model, a few additions to the base model have been made. Firstly, the characteristics of container vessels that could sail through the artic are determined. These new vessels are added to the model. Secondly, also the tolls charged for sailing via the NSR are determined. Thirdly, the sailing distances via the NSR are determined and added to the model. These additions are explained in more detail in the next subsections.

NSR vessel characteristics

The first step to determine the characteristics of the NSR vessel is to investigate the limitations posed on the ship's main dimensions. Advisory (2014) has published an overview of the NSR routes and all width and draft limitations occurring along the route. On both the east and west sides of the route, channels limit the draft to a maximum of 13 m (Yugorskiy Shar (West) and Sannikova (East)). On the western side, a second straight, the Kara gate has a much larger draft and is, therefore, more frequently used. On the eastern side, the alternative straight in between the New Siberian Islands is even shallower, only 8–9 m. However, when investigating the transit routes followed in 2018 and 2019 (CHNL, 2020), it should be noted that especially the New Siberian Islands and Nova Zembla are often passed on the northside in late summer eliminating these bottlenecks. As a result, the limiting draft would be increased to 20 m. However, currently, this route is not guaranteed to be open and vessels should be able to adapt to any of the other routings to not be stuck until the route clears enough to proceed. Therefore, the draft limit of 13 m will be used, although, in summer, deeper channels are regularly available.

Besides draft limits, there is a second limit to the dimensions of the vessel. This is the width of the ice breaker. When a vessel is following an ice breaker, the width of the channel created is equal to the width of the ice breaker. Therefore, the width of the vessel cannot exceed that of the icebreaker. Since 2018, this width has increased from 30 m to around 32 m with the delivery of the new nuclear ice breakers (Erikstad and Ehlers, 2012). This limit is especially relevant for vessels with lower ice classes that are not able to sail the NSR independently, and that are also not allowed to do so. According to the Northern Sea Route Administration (NSRA, 2020), a vessel with regular ice-class (ICE 1- ICE 3 see also (IACS, 2006) is only allowed to transit the NSR independently in summer in light ice conditions. However, a vessel with an arctic ice-class ARC 4 is able to travel independently year-round in light ice and even in medium ice conditions in the summer along a part of the NSR. Furthermore, starting with ARC 7 the vessel can sail independently in all conditions in the summer and winter. Only the occurrence is limited to a small number of zones in the winter. To investigate the benefits of sailing without ice breaker assistance, and thus without paying the ice breaker

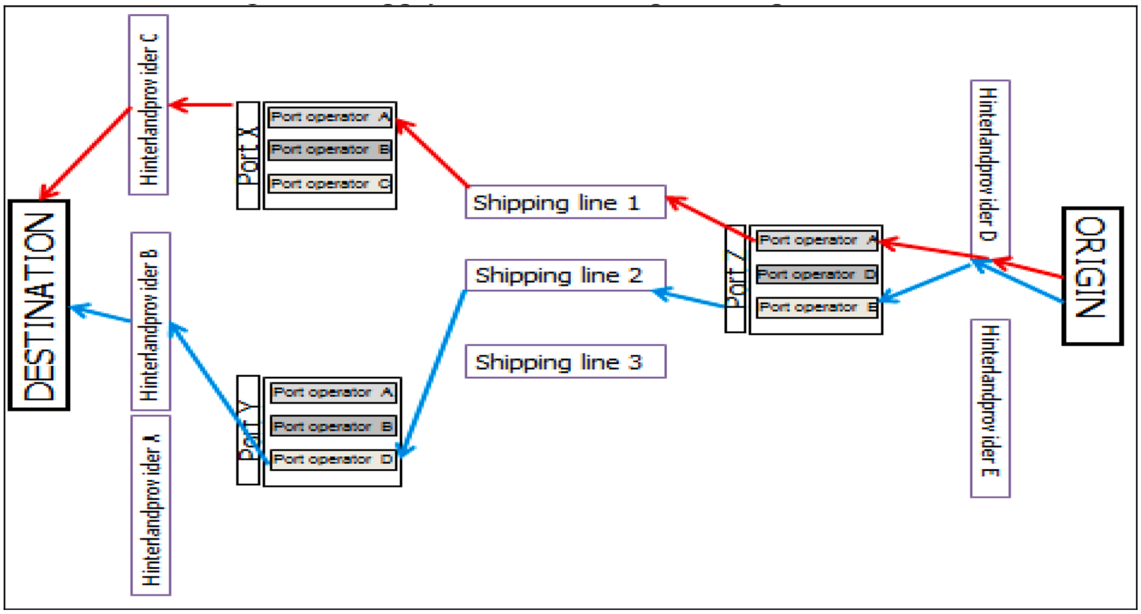

Fig. 1. Supply chain view on port competition. Source: Meersman and Van de Voorde (2012).

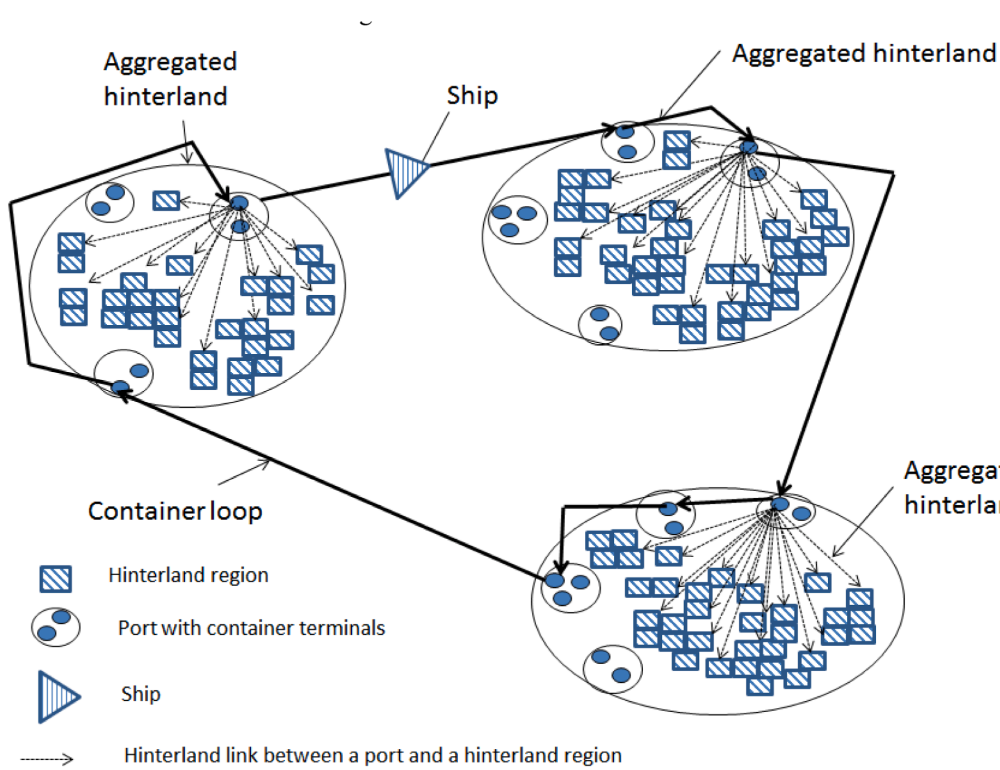

Fig. 2. Structure of the chain cost model.
Source: van Hassel et al. (2020).

fee, the investigated ships will be of ice-class ARC 4 and ARC 7.

With the limitations known, the design of the desired ships and situations to investigate can be established. In line with the NSRA, three arctic conditions will be investigated, being light, medium, and heavy. Also, the option will be available to go around the most limiting straights. In addition, the width limitation will be lifted if no icebreaker is required. Based on the limitations provided by the NSRA, it is assumed that an ARC 4 vessel will not require an icebreaker in a light situation to limit the number of situations. In the medium situation, an ARC 4 vessel can travel with an icebreaker (for four out of seven zones), while an ARC 7 vessel can still travel independently. Finally, in the heavy situation, only an ARC 7 is allowed to travel, but with an icebreaker (for four out of seven zones).

Using Clarkson (2019), the current fleet of container vessels over 4,000 TEU was investigated. Two important observations were made. First, the draft restriction is far less relevant than the width restriction of the icebreaker. The largest container vessel only has a draft of 16.5 m, fully loaded. With lighter containers, 13 m is not too difficult to reach. In comparison, the limit of 32 m will restrict the size of the container vessel to 5,000–5,500 TEU. These vessels have a draft of 13–13.5 m only. On the other hand, this means that only two sizes of vessels will need to be investigated; The largest vessel with a width of 32 m and the largest vessel without any restrictions (24,000 TEU). These large vessels offer the benefit of not requiring a year-round service, as in the winter months these could competitively be used on the SCR instead of the NSR. The smaller vessels will most likely be idle in winter, as these are not competitive on the SCR route in winter, or will need to use the NSR also in winter. Something that is not yet common. At this stage, seasonality is not yet considered, despite complicating the situation of the smaller vessel. Furthermore, for each size, an ARC 4 and an ARC 7 vessel will be considered.

In literature, there is significant uncertainty about the impact of ice-class on the vessel's new building price (Lasserre, 2014). Choices made regarding this aspect seem to impact the outcome of the resulting calculations to a significant extent. Therefore, as a starting point, the new build vessels between the years 2000–2018 were used, as about 15–20 % of the vessels between 3,000 and 8,000 TEU already have some form of regular or even arctic ice-class (4 %). This allowed the price differences to be studied on actual ships. The most important conclusions for container vessels up to ARC 4 ice-class from this investigation are represented in Fig. 3. There is no new building price difference identified (Fig. 3, right). The term LBT is the volume created by the draft (T), the width (B), and length (L) of the vessel and is often used to estimate building costs. Inflation could influence this, but with the Ice class and ARC 4 vessels being among the younger vessels, this would only favour vessels without ice class. As the number of ships for which a new building price is available is much smaller, all ice-class ships are grouped. For the GT (Gross Tonnage) graph, this group is split into ARC 4–9 (Arc class) and ICE 1–3 (Ice class). The main variation in variables is the Depth, the distance from the bottom to the top of the hold. This is caused by a larger required freeboard for ice-class ships. The impact can be seen when considering the Gross Tonnage of the vessel (GT) (Fig. 3 left). The average increase of Gross Tonnage (GT) for Arc class ships is expected to bring a very small increase (2–3 %) in ship construction weight in line with the work of Dvorak (2009).

These new insights are important as, until now, all literature has been approaching the price of the vessel from the cost side. Costs are determined by internal yard factors. However, with the international newbuilding market, the price of a ship is determined by the global supply and demand for ships. The large spread on the right side of Fig. 3 clearly supports this. Pruyn and Yan (2020) came to a similar conclusion for dry bulk vessels in a building cost investigation. While this holds for the new building price, it is also expected to hold for other cost factors.

As demonstrated by Dvorak (2009), the increase in steel weight and engine power based on the polar code is limited till the level of ARC 4. For ARC 7, an increase in installed power of about 40 % is required, with the additional steel weight for strengthening. This adds up to an increase of about 10 % in the lightweight (empty weight) of the ship. Assuming that the block coefficient and draft will remain about the same to ensure that the open water speed is not affected, this will result in a loss of DWT and therewith cargo weight. Although, a loss of cargo space is not expected, with the impact limited to the outside plating of the vessel.

The significant increase in installed power will lead to suboptimal operations of the engine during regular sailings. It is primarily there to deal with the ice. The ideal operating point of an engine is mostly between 70 and 85 % load. Outside this area, fuel consumption can increase significantly (Cariou et al., 2019, Faury and Cariou, 2016, Faury et al., 2020). With slower speeds due to ice presence on the NSR, the ARC 7 vessels will often operate in such conditions. Therefore, the option of installing two engines of half the power is also investigated. This will add costs to the vessel as not only are two engines of half the capacity more expensive than one large engine but also a gearbox is required to allow the engines to independently and jointly power the single ship's screw. On the engine configuration level, these costs are significant (40–60 % increase).

The discussion of the impact of the ice-class on the vessels and the resulting data is summarised in Table 1. Ships 1–2* are the largest ice-classed container ships, ships 3–4* are the ice-classed restricted ships, and ships 5 and 6 are the normal ships without ice class. All ship particulars are taken from Clarkson (2019).

With the suitable vessel designs available, the next element to discuss is the situation in each of the scenarios. Based on the earlier description, Table 2 shows an overview of four possible ice sailing conditions at the NSR. The medium condition is investigated twice, once with an ARC 4 ice-class and once with an ARC 7 ice class. The sources for each contribution are mentioned in the last row of Table 2. The vessel ice class will determine the requirement for the use of an icebreaker. This, in turn, restricts the movements of the vessel. The transit times are based on research on AIS data of NSR transits. The majority takes between 6 and 9 days to cross the NSR, though the extremes amount to 15–17 days (ABE and OTSUKA, 2019). Therefore, light and medium conditions are considered normal operations, whereas heavy conditions will lead to extreme delays. Based on the distance and duration, the average speed can be calculated. The speed on the part outside the NSR is assumed to be 95 % of the design speed as this relates to an 80–85 % engine load. The NSR fees are obtained from the NSRA. For the medium situation, the summer and winter tariff are averaged, whereas, for the heavy condition, the winter tariff is assumed. As a regular service is assumed, pilotage is assumed not to be required, though especially for the first couple of transits, this may be necessary. As both Lasserre (2014) and Pruyn (2016) point out, the insurance premium for the arctic transit is difficult to estimate. It depends on the perceived risk of the individual transit at this moment. Based on an average fee for the combination Hull and Machinery (H&M) and Protection and Indemnity (P&I) of 10 USD/GT/year (Pruyn, 2016), a premium for the days in the NSR will be calculated. The values are an assumption by the authors, as even a 100 % increase will only result in an additional 45 USD cents per GT per transit, which is very small compared to the icebreaker tariffs or even the Suez Canal tariffs. The last two rows establish an average ice thickness based on the average speed. To do this, the formulas on the relation between speed and ice thickness provided by Faury and Cariou (2016) are reversed, using the speed as input and the ice thickness as output.

The approach to determine the ice thickness and the ice speed is a simplification. The resulting fuel consumption could be easily 10 % lower than in reality. The reason for this is that a mixture of higher and lower speeds will result in higher fuel consumption. Moreover, low speeds will coincide with thick ice and higher speeds with less or no ice. A detailed approach, such as used by Faury and Cariou (2016), however, also requires more data and further assumptions. Therefore, this simplification is maintained here, but the outcomes will be checked for the impact this may have. This simplification allows the Admiralty Constant to be easily applied to both the speed reduction and potential draft reductions (Pruyn, 2016). Many of the discussed NSR papers do not consider the impact of a draft reduction on fuel consumption (BUCHAN, B., 1995, Furuichi and Otsuka, 2013, Ha and Seo, 2014, Lasserre, 2014, Liu and Kronbak, 2010, Mulherin et al., 1999, Otsuka et al., 2016, Schøyen and Bråthen, 2011, Theocharis et al., 2019, Wan et al., 2018, Xu et al., 2011, Zeng et al., 2020, Zhang et al., 2016). However, the impact is significant, especially as a smaller weight per container is assumed here. The simplification and resulting ice thickness also allow the calculation of an added resistance due to ice, which is quite significant (Hu and Zhou, 2015, Lee et al., 2018). The method of Riska (1997) was selected as it offers a relatively simple approach with a rather reliable outcome. With the ice resistance and the non-ice power required, an engine load factor (EF) can be calculated. This serves as an input for the specific fuel consumption formula provided by Cariou et al., (2019). The results of these calculations for each ship and situation combination are presented in Appendix A. The benefit of having two engines instead of one for the ARC 7 ships should be clear. Whether it is enough to compensate for the extra costs will be investigated next.

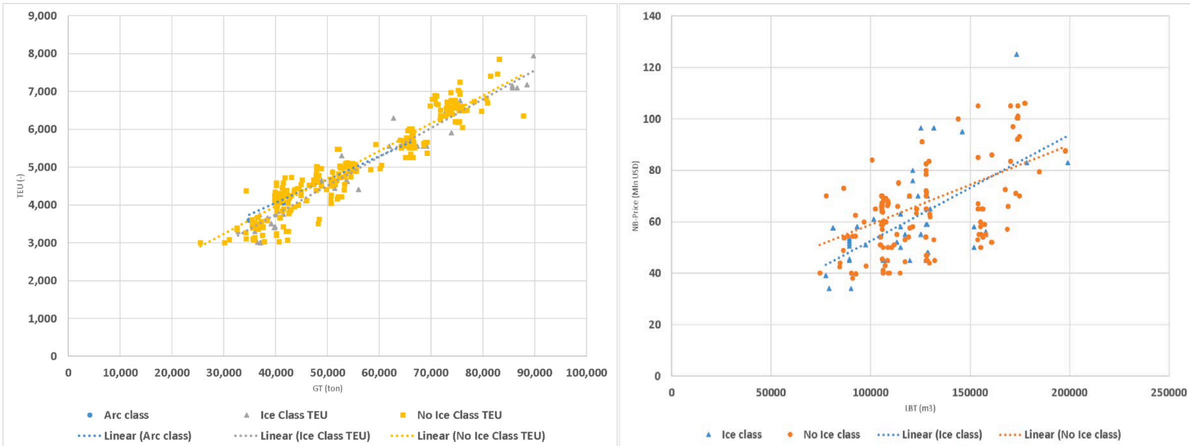

Fig. 3. Increase in GT (left), indifference in price (right).

Table 1
Selected ship designs and particulars. * indicates a dual-engine version.

	Ship 1	Ship 2	Ship 2*	Ship 3	Ship 4	Ship 4*	Ship 5	Ship 6
TEU	24,000	24,000	24,000	5300	5300	5300	24,000	5300
Ice Class	Arc 4	Arc 7	Arc 7	Arc 4	Arc 7	Arc 7	None	None
GT	239,400	239,400	239,400	55,335	55,335	55,335	228,000	52,700
Dwt	233,000	233,000	233,000	65,700	65,700	65,700	233,000	65,700
Speed (knots)	20	20	20	24.6	24.6	24.6	20	24.6
LOA (m)	400	400	400	295	295	295	400	295
Beam (m)	61	61	61	32.2	32.2	32.2	61	32.2
Draught (m)	16.5	16.5	16.5	13.5	13.5	13.5	16.5	13.5
Depth Moulded (m)	33	33	33	17.5	17.5	17.5	33	17.5
# of Engines	1	1	2	1	1	2	1	1
Engine power (kW)	75,000	105,000	105,000	40,000	56,000	56,000	75,000	40,000
Estimated Cargo (tonne)	217,000	203,500	203,500	59,100	56,800	56,800	217,000	59,100
Avg load per TEU (tonne)	9	8	8	11	11	11	9	11
Cargo at 13 m (tonne)	217,000	117,000	117,000	52,500	50,100	50,100	Not limited	Not limited
TEU @10	21,700	11,700	11,700	5250	5190	5190	21,700	5300

Source: Authors based on Clarkson (2019).

Table 2
Ice sailing conditions NSR.

	Light conditions	Medium Conditions	Medium Conditions	Heavy Conditions	Sources
Ice Class	Arc4	Arc4	Arc7	Arc7	
Ice Breaker	No	4 zones	No	4 zones	NSRA (2020)
Draft (m)	20	13	20	13	Lammer, (2010), CHNL, (2020)
Width (m)	unrestricted	32	unrestricted	32	Pruyn (2016), Erikstad and Ehlers (2012)
Length NSR (nm)	2550	2550	2550	2550	CHNL (2020)
Duration NSR (days)	6	9	9	16	CHNL (2020)
Speed NSR (kn)	18	12	12	7	CHNL (2020)
Speed Outside	95 % Design	95 % Design	95 % Design	95 % Design	Clarkson (2019)
Fuels to be used at the artic	HFO + Scrub	HFO + Scrub	HFO + Scrub	MDO	Lasserre (2014)
Ice Speed Relation	$S = 2.7818*(IC/100)^{-0.7171}$	$S = 2.533*(IC/100)^{-0.7577}$	$S = 2.533*(IC/100)^{-0.7577}$	$S = 2.533*(IC/100)^{-0.7577}$	Faury and Cariou (2016)
Ice Thickness (cm)	7	13	13	26	Faury and Cariou (2016)

Source: Based on cited sources.

NSR toll

The passage of the NSR will also involve the payment of a toll. The tolling tariffs for the NSR are given in Table 3. This toll tariff is implemented as a function in the model. This function is based on the GT and the ARC class of the vessel that is selected. The costs are based on the average 2020 exchange rate (USD-Rouble) and could vary by 20 % due to the exchange rate. This extra risk was not taken into account further in this investigation.

NSR maritime distances

In order to implement the NSR passages in the model, also the maritime distances between Chinese ports and the major European ports are updated. The total sailing distance is taken from SeaRoutes (2020). The NSR routes between the Chinese ports and the ports within the Hamburg – Le Havre (HLH) range are split into two parts:

Table 3
NSR tolls and Ice sailing conditions NSR.

	Light conditions	Medium Conditions	Medium Conditions	Heavy Conditions	Sources
Ice Class	Arc4	Arc4	Arc7	Arc7	
NSR Fee < 100,000 GT (USD/GT)	0	9.4	0	13.1	NSRA (2020)
NSR Fee >=100,000 GT (USD/GT)	0	5.6	0	7.9	NSRA (2020)
Pilotage	No fee	No fee	No fee	No Fee	Lasserre (2014)
Insurance	25 %	50 %	25 %	100 %	Pruyn (2016), Lasserre (2014)

Source: based on cited sources.

The total distance between the two ports

The distance sailed in ice conditions (2,550 nm, taken from Table 3)

By applying this split, it becomes possible to determine the sailing time and distance of the vessel in ice conditions. Based on the sailing time and distance, the total maritime sailing time from Asia to Europe, as well as the fuel cost in the ice conditions can be calculated. The Emission Control Areas (ECA) in Europe were already included in the model.

Discussion of methodology

The choice was made to use a well-established supply chain model, allowing for a greater detail and complexity of the supply chain to be studied. This is a benefit compared to most earlier studies using simplified models for the shipping lane only, sometimes not even comparing the NSR with other routes like the SCR. In this case also the rail option of the BRI is included in the comparison. Furthermore, the multiple ship types identified bridge a gap between on the one hand detailed single ship-based studies into arctic transits and on the other hand the very high level, purely economic ship approaches seen in other studies. Finally, a new approach to the costs of ice-class is presented, looking at the market price of ice classed vessel and not accounting from a cost perspective. The fact that there is no price difference for many ice-classed vessels is a key aspect often overestimated in earlier papers.

Results

With the developed model, it is now possible to calculate the generalised chain cost from any origin in China to any destination in Europe. In order to demonstrate this, one specific chain is further analysed. This transport chain has an origin in Chongqing (China), and the destination is Duisburg (Germany). Both the origin and destination, along with the three different transport chain options, are displayed in Fig. 4.

For the NSR option, no existing transport services are available yet. Therefore, a service via the NSR has to be designed first. This will be done in the next sub-section.

Developing an NSR route application

For the NSR route, the following ports are called: Shanghai, Ningbo, Rotterdam, Le Havre and Hamburg. These five ports are the main

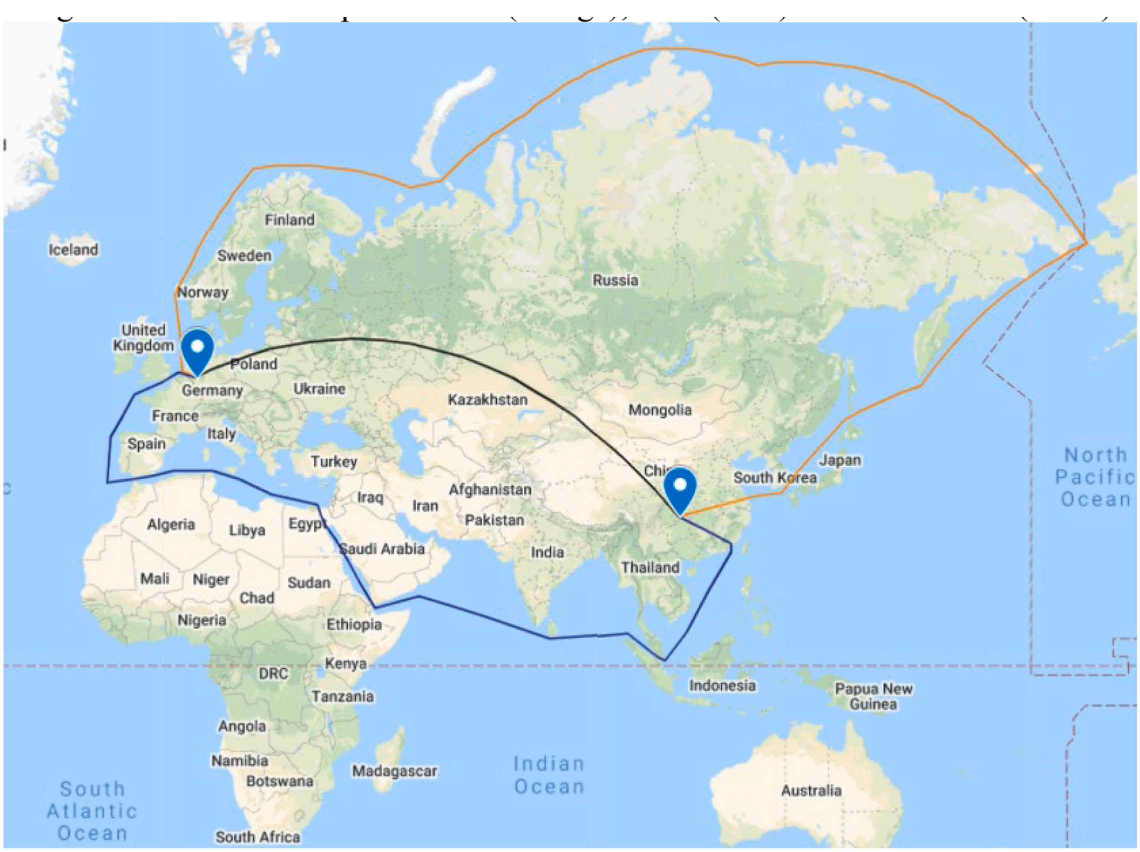

Fig. 4. Three route options NSR (orange), SCR (blue) and the rail line (black).

gateway ports of both North-Western Europe and China. For this route, the deployment of two different vessel sizes is researched. This first vessel is a 5,300 TEU vessel with an arc 4 class. The design draft of the vessel is able to sail the complete NSR, and the ice-class allows the vessel to sail the arctic region with medium ice conditions. The second vessel size is a hypothetical 24,000 TEU arc 4 vessel (see also Table 1). Due to its design draft, this vessel can only be loaded with 48 % of its design payload in order to comply with the maximum allowable draft of the artic route. For both vessels, a service is set up with a weekly departure frequency. If this weekly interval has to be researched, it is possible to determine what the optimal operational speed (lowest cost per container) of the vessel should be. The results of the calculations can be found in Fig. 5. For this case, both artic vessels will comply with the emission regulation by using MDO sailing in the artic and ECA region.[2]

From Fig. 5 can be concluded that the average cost per TEU is the lowest for a 5,300 TEU vessel with 480 euro per TEU at a speed of 15 knots. While the lowest cost of the 24,000 TEU vessel is 510 euro per TEU at a speed of 16 knots. The higher optimal speed for the larger vessel can be explained by the fact that the fixed costs are higher, which forces the rotation of the vessel to increase to reduce the average cost. Based on the analysis, it is concluded that it is better to use a smaller ship (5,300 TEU) that can be loaded to full capacity, than using a very large ship that can only be partially loaded. From the same figure, it can also be observed that with a higher operational speed, the average cost per TEU will increase. The increase in the average cost can be attributed to the fact that the fuel cost increases much more than fixed cost decreases. Moreover, with a higher operational speed, the lead time for the transported cargo will be less. This effect will be further investigated in section 4.2.

Now that the optimal speed is determined, the impact of equipping the vessel with a scrubber instead of using MDO is also investigated. The investment cost of the scrubber is set at €2.500.000 (Mohseni et al., 2019), and the MDO fuel cost at €494/ton, while the HFO cost is €400/ton. The results of these two options can be seen in Fig. 6.

From Fig. 6 can be concluded that the difference in total cost for the shipowner is very small. This small difference can be attributed to the "typical" cost structure. This means that for the voyage-related cost, the biggest part will consist of NSR passage dues. This means that the biggest cost component is not affected by a shift from MDO to scrubbers. Next to that is that the largest part of sailing at the NSR route, the sailing speed is 7 knots. This results in relatively low fuel consumption of the vessel, and consequently, the cost savings of using HFO instead of MDO are small. In addition, the scrubber itself has an investment cost of €2.500.000 which also, slightly increases the fixed costs. Therefore, we can conclude that it is best to use the MDO option for the artic vessel to sail on the NSR.

Comparing SCR, NSR, and railway chains

In order to analyse the effectiveness of the designed NSR route relative to the land bridge and the SCR route in terms of generalised cost and time, the generalised chain cost is calculated. This is done for a transport chain to transport a container from Chongqing in China to Duisburg in Germany.[3] The result can be found in Fig. 7. The cost and time of the land-based option are taken from Meersman et al. (2020). For the calculations of the Value of Time (VoT, the cargo value of €30,000 per TEU with a depreciation rate of 10 % per year is used.[4]

If we compare the generalised chain cost of the three different options, it can be concluded that the generalised chain cost is the highest for the rail option. However, the total transit time is much smaller than for both maritime options. The generalised cost for the SCR option is the lowest for all considered options. The cost for the NSR options is slightly higher and at this point does not include a factor related to the uncertainty in the schedule or costs (ice-breaker fees). For the schedule risk, the relatively low average speed is a benefit and would allow for compensation of delays on other parts than the NSR. There is an increase of 1.9 % for the NSR option in which the vessel sails at 22 knots, 0.3 % for the optimal speed with scrubbers, and 0.1 % for the optimal speed with MDO. The higher chain cost for the NSR is caused by the higher maritime cost compared to the maritime cost for the SCR. This higher cost is caused by the deployment of a smaller vessel on the NSR,[5] and the low sailing speed on the artic section of the NSR. It can also be concluded that if the operational speed of the artic vessel is increased from 15 to 22 knots, the generalised chain cost increases by 1.6 %, but the transit time for the cargo owner is reduced from 48,24 days to 45,48 days (decrease of 6.1 %). This means that if the cargo owners are willing to pay more for the NSR service, the vessel owner could opt for a faster operational speed. If the cargo owner requires a very fast transit time, the railway option is an option to choose, but the chain cost is twice as high as one of the maritime options. For very time-sensitive cargo, such as high-tech products (cargo with a high value of time), the railway option, along with the NSR option, becomes a competitive option. The results of the chain cost comparison for high-value cargo can be seen in Fig. 8.

From Fig. 8 can be concluded that the total generalised chain cost will increase due to an increase in the value of time. The increase is higher for the SCR option than for the NSR option. The main reason for this is the longer maritime transit time for the SCR option. In this case, both the railway and the NSR options become interesting alternatives. The competitiveness of the NSR will increase if the arctic vessel can sail at a larger speed through the ice. The speed of the vessel in ice conditions depends on the thickness of the ice. So, if the ice thickness is reduced from 26 cm to 13 cm, the vessel's speed in ice conditions could increase from 7 to 12 knots[6] (see also Table 2). In this case, the generalised chain cost will reduce by 11 % compared to the SCR option. This reduction is due to the strong reduction in sailing time (39,01 days for the medium ice conditions compared to 45,08 days in the thick ice conditions). In this case, the NSR option becomes very competitive. Discussion of results.

Based on the initial cost evaluation the larger vessels will not be able to operate profitably on the NSR. The lower loaded capacity is a clear deal breaker in this case and a fully loaded smaller 5,300 TEU vessel is more flexible and favourable for use on the NSR. On the other hand, the difference in lowest cost is only around 5 %, which could still be in the error margins of our assumptions. We have discarded it for now, but a more detailed schedule and loading study could reveal further benefits or draw backs. Furthermore, the key costs of the NSR remain the ice breaker fees, in combination with the current political uncertainty, these form the highest risks to address for a fruitful NSR operation. Policy makers have therefore two options to make the NSR more attractive:

Reduce the transit tolls set by the russian Federation. As was shown in Fig. 6, the transit cost makes up a large part of the total cost for the vessel owner to operate vessels on the NSR.

To take away the draft limitations so that larger Ice class container vessels can be deployed. It also needs to be mentioned here that it is more difficult to develop a service with larger vessels that are loaded with high-tech and high-value products.

To what extent these measures will be able to increase the traffic volume on the NSR is currently beyond the scope, but would be a

[2] Which has to be considered for the ECA zone at the North sea.

[3] For the SCR an existing loop of CMA-CGM is taken. On this loop, 18,000 TEU vessels are deployed.

[4] Based on these values it is possible to calculate the VoT of 0.456 €/h (40.000 * 10%/(365*24)).

[5] Which is caused by the draft limitations on the NSR.

[6] The fuel consumption of the vessel sailing at 12 knots is determined by applying the admiralty constant formula to scale the fuel consumption at 7 knots.

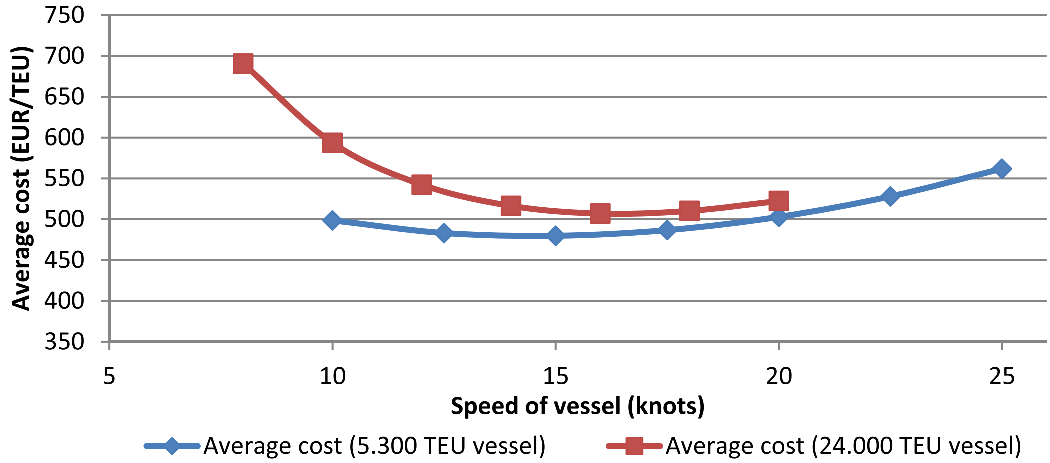

Fig. 5. Speed impact on the average maritime transport cost for two different vessel sizes.

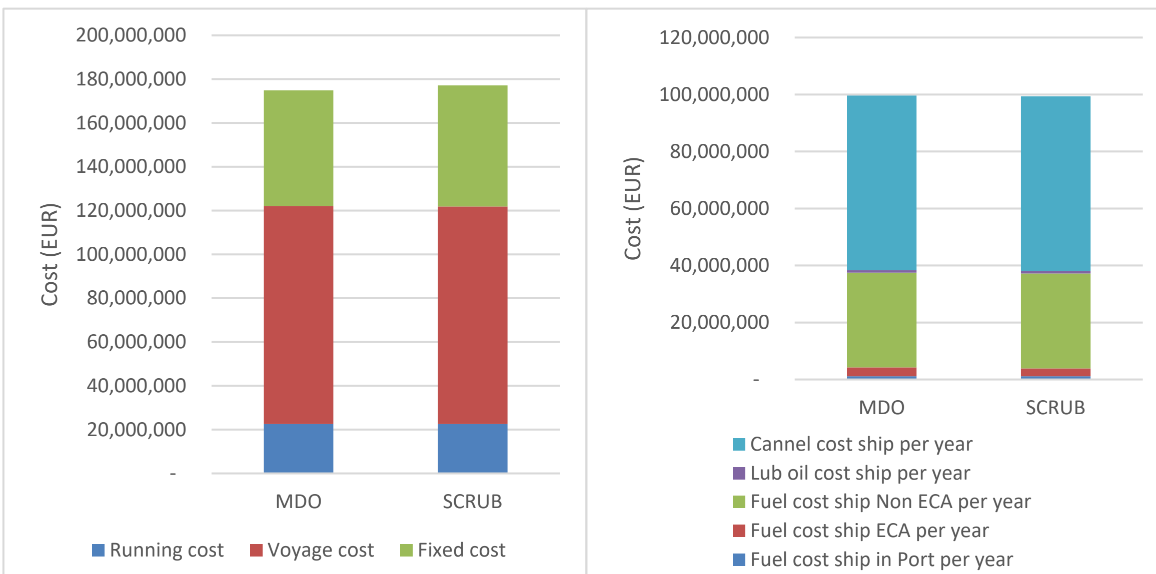

Fig. 6. Total cost for a fleet with MDO or scrubber option (left), details on voyage cost (right) (5,300 TEU).

valuable aspect to consider for follow up research. Approaching the NSR from the state perspective instead of from the ships' perspective. To see if any investments in the operability can be earned back by the increase in traffic.

Conclusions

In this paper, the possibility of setting up a service via the NSR route that could attract cargo from the existing maritime routes via Suez and the land route is researched. Compared to previous studies on the potential of the NSR (which go back 25–30 years), this study extensively models the potential vessels extending the studied range to include the newer Ultra Large Container vessels (25.000 TUE) to sail a more northern route now that ice levels continue to decrease. Also, the lower container weight, as well as the technical details of the vessel, exceed the previous studies. Finally, on the data side, the use of vessel prices and not vessel costs has brought to light that the cost bases ice-class approach overestimates the expenses, as in practice there is no significant difference between the two prices. An important finding, putting many earlier conclusions to the question, as significant cost increases for ice-class construction were applied there.

From the analysis, it is determined that a 5,300 TEU vessel with arc class 4 which will call at the ports of Shanghai, Ningbo, Rotterdam, Le Havre and Hamburg could be set up as such a service. Although an ARC4 and ARC7 vessel of 24,000 TEU were also considered, these proved uncompetitive on the NSR route and were thus not further investigated. These vessels will sail at a speed of 15 knots and a total of eight vessels are needed to ensure a weekly departure interval. Furthermore, the vessels will be fuelled with MDO in order to comply with the current emission regulations. With this service, a total transport capacity of 237,440 TEU can be offered. To put this in perspective, the land bridge had a total volume of 557,000 TEU in 2020 (Eurasian Rail Alliance Index, 2020) for which a total of 1,946 trains are required. So, these eight vessels would already count for 42 % of the total land bridge volume. This means that with only a few ships, the same amount of volume can be transported via the land bridge. However, the total transit time via the NSR will be higher (between 150 % and 200 %, depending on the ice thickness on the NSR route). Moreover, the costs are slightly higher (~2%) than the currently offered SCR services, while a time reduction of about 10 % is achieved on the NSR.

Within this research no yearly service with varying ice conditions is considered, only two relevant ice conditions for the use of ARC4 and

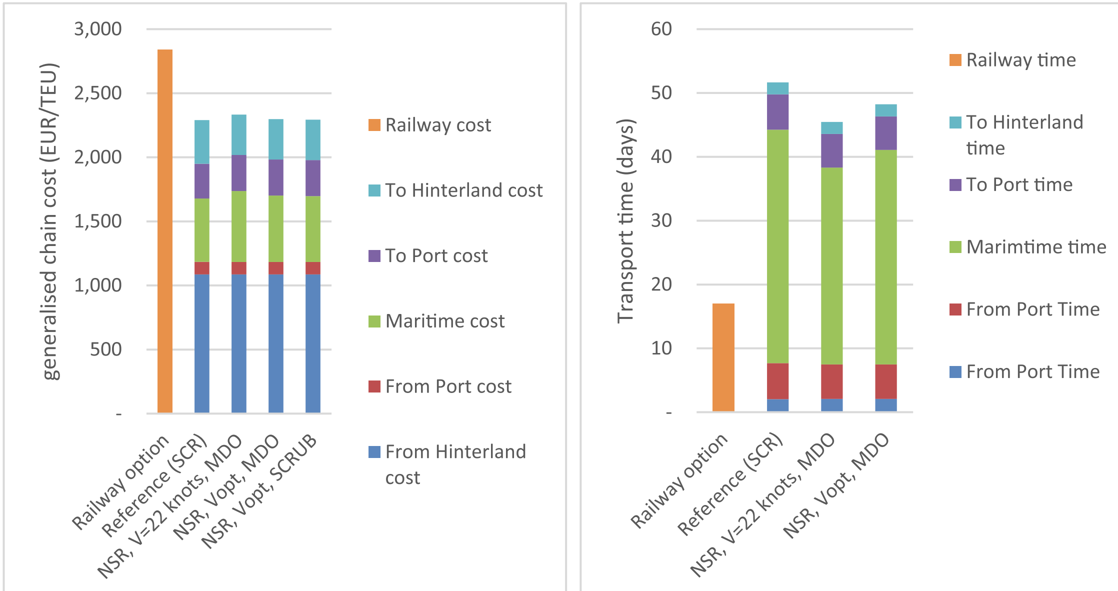

Fig. 7. Generalised chain cost comparison (left) and total transport time (right).

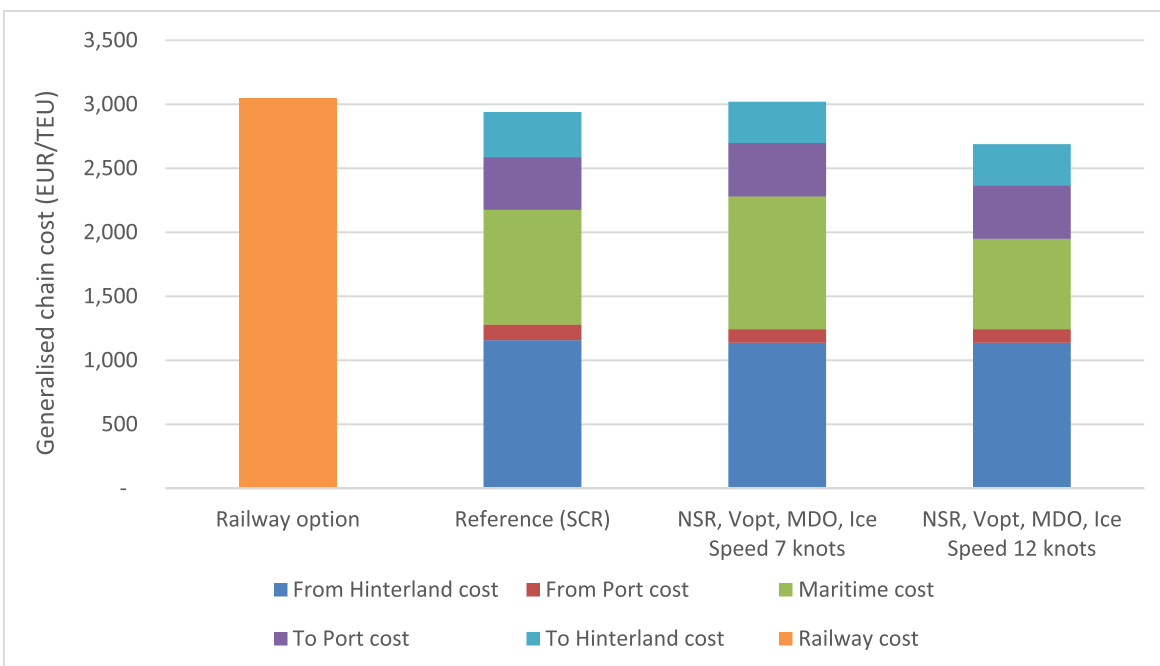

Fig. 8. Generalised chain cost comparison for time-sensitive cargo (high-tech cargo).

ARC7 ice-class vessels have been investigated. It should however be noted that it is not economical for the 5,300 TEU vessel to offer a winter service on the SCR. For the before mentioned 24,000 TEU vessel this would be an option. In addition, the uncertainty in scheduling was not addressed as well as the uncertainty in tariffs due to exchange rates. All these aspects could change the situation in favour of the SCR, requiring further improvements to the NSR case to make it a viable alternative.

The most prominent options to improve the competitiveness of the NSR are a further reduction of the ice thickness and a reduction in the toll tariffs. Then it becomes, for certain niche markets such as the high-tech and time-sensitive products, possible to set up a competitive NSR service. These niche markets are also the markets that are transport via the land bridge. For such an NSR service, the total generalised chain cost for the transport chain Chongqing – Duisburg, will be 20 % lower compared to the land bridge.

Finally, as the land bridge as well as the NSR will compete for a specific type of cargo, namely cargo with a high value of time (for instance high-tech cargo), they will only be able to support marginal trade volumes. At the moment, there is no sufficient benefit or volume for the NSR to take over the role of the land bridge. However, with the diminishing ice thickness, and disruption on the land bridge due to conflicts, the competitive position of the NSR will improve, which will increase the potential market share for this service in the future. Therefore the NSR could also be seen as a backup option to ensure a reliable transport service between Asia and Europe.

The findings of this research have implications, for policymakers who must decide on which transport connection between China and Europe to invest. The policymakers it can be concluded that the NSR can be seen as an alternative if there are disruptions on the land bridge. Having a reliable and stable transport system, including different transport corridors and modes, is of the utmost importance. Therefore, a holistic approach is advised in where both existing maritime connection via the SCR, the land bridge as well as the NSR need to be considered. The Evergiven recently demonstrated that also the SCR is vulnerable and that trade flow cannot be rerouted to the rail connection. The NSR once developed could provide some alleviation at shorter times and comparable costs. With respect to the NSR it is advised to further research potential new port investments to accommodate artic class vessels in the region north of the Hamburg – Le Havre range.

CRediT authorship contribution statement

J.F.J. Pruyn: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **E. van Hassel:** Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Ship specific fuel consumption for each ice situation.

Conditions	Ship	Speed (knots)	Propulsion (kW)	Ice Addition (kW)	Engine load Factor	SFC (g/kWh)
HEAVY	Ship 1	7	3216	4950	10.90 %	223
	Ship 2	7	3216	4950	7.80 %	227
	Ship 2*	7	3216	4950	15.60 %	218
	Ship 3	7	899	1800	6.70 %	228
	Ship 4	7	899	1800	4.80 %	231
	Ship 4*	7	899	1800	9.60 %	225
MEDIUM	Ship 1	12	16,200	5100	28.40 %	206
	Ship 2	12	16,200	5100	20.30 %	214
	Ship 2*	12	16,200	5100	40.60 %	197
	Ship 3	12	4528	1850	15.90 %	218
	Ship 4	12	4528	1850	11.40 %	223
	Ship 4*	12	4528	1850	22.80 %	211
LIGHT	Ship 1	18	54,675	4900	79.40 %	186
	Ship 2	18	54,675	4900	56.70 %	189
	Ship 2*	18	54,675	4900	56.70 %	189
	Ship 3	18	15,281	1800	42.70 %	196
	Ship 4	18	15,281	1800	30.50 %	205
	Ship 4*	18	15,281	1800	61.00 %	188
OPEN WATER	Ship 1	19	64,303	0	85.70 %	186
	Ship 2	19	64,303	0	61.20 %	188
	Ship 2*	19	64,303	0	61.20 %	188
	Ship 3	23.4	33,443	0	83.70 %	186
	Ship 4	23.4	33,443	0	59.80 %	188
	Ship 4*	23.4	33,443	0	59.80 %	188
	Ship 5	19	64,303	0	85.70 %	186
	Ship 6	23.4	33,443	0	83.70 %	186

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