Decision Support Framework for Exploiting Northern Sea Route Transport Opportunities

By Stein Ove Erikstad[1,*] & Sören Ehlers[1]

ABSTRACT

This paper presents a decision-support model identifying the most viable ice class for a liner vessel transiting along the Northern Sea Route. As input, this model requires parameters, some of which are uncertain. These include the time-dependent length of the Northern Sea Route sailing season and corresponding roundtrip times, the additional capital expenditure and operational expenditure for ice class capabilities for the vessel, as well as fuel price. Furthermore, the sensitivity of the model is discussed on the perspective ice extent, respectively the ice class allowed to enter the Northern Sea Route and possible delays, on the basis of current trend predictions.

Key words: Economics, Risk Analysis, Seaway

1 Introduction

The Russian Federation opened up the Northern Sea Route (NSR) for foreign traffic in *2009* and thereby a new transport route connecting Europe in the East and Asia in the West. Therefore, the economic viability of this route compared to the current Suez Canal Route (SCR) is of increasing interest for the commercial shipping sector. This interest can be further affiliated with the melting icecap and the correspondingly diminishing ice areas during the summer months along the NSR, thus allowing for high latitude routes with increased draft.

The implications of the diminishing Arctic icecap for maritime transport are unclear yet. On the one hand, a possible opening of the Northern or Trans-Arctic Sea route represents about *50%* reduction of the sailing distance for several trading routes. Those, being able to exploit this opportunity, are likely to improve their competitive position significantly. On the other hand, the operational challenges in these waters, and the corresponding risks and uncertainties involved, are considered very severe. This includes political factors (Russian territorial waters), environmental concerns (possible oil spills), operational conditions (harsh environment, distance to nearest base etc.), ice navigation (possibility of drifting ice), contractual issues (increased probability of delays) and the length of the season that is sufficiently ice free. As a result, arctic transit is not even considered by

[1] Norwegian University of Science and Technology, Trondheim, Norway

[*] *Corresponding author*. Present address: stein.ove.erikstad@ntnu.no

most shipowners. However, *DNV* (2010) expects *480* container transit voyages across the Arctic Sea in *2030*, primarily using the Northern Sea route (NSR).

The NSR is defining the different fairways going from Novaya Zemlya in the west to the Bering Strait in the east with a current draught limitation of *13* m and a width limitation of *30* m. The latter is subjected to increase to *32* m with the new nuclear ice breaker due in *2018*. The length of the route depends on the ice conditions and the choice of different stretches of the route, but is generally considered as *2100* to *2900* nautical miles. The Russian Federation has made claims to the ownership of the route and controls the traffic with their icebreaker fleet as well as the transit tariffs.

In *2009*, two vessels from Beluga Shipping Group sailed on the NSR as a part of a small convoy escorted by a Russian nuclear-powered icebreaker. In *2010*, the transit traffic increased to *8* vessels, and in *2011*, *34* vessels transited through the NSR, due to the extended ice-free sailing period among other reasons. The shortest transit time was *6.5* days with an average speed of *14* knots. The total amount of cargo transported along the route was *820000* t in *2011*, consisting primarily of liquid cargo (*83*%) and bulk (*13*%), *Omre et al.* (2012).

The current NSR transits benefit from the availability of the shorter route and the resulting fuel savings. The insurance cost for similar vessels has so far been equal to the SCR insurance including piracy addition for the Gulf of Aden. However, these savings became possible because the tariff to be paid to the Russian Federation, respectively Rosatomflot, have been fairly low when compared to the actual operational cost of the nuclear ice breakers. The current tariff per ton of cargo transported can be as low as *5* USD, which is similar to the Suez Canal, *Mahony* (2011). However, the additional hurdle of a fairly non-transparent process needs to be taken to enter the NSR. This process includes the local inspection of the vessel in question by a Rosatomflot representative in order to comply with the Russian ice class requirements. This inspection is mandatory even though the vessel fulfills the ice class requirements of its classification society for the class in question, currently at least 1A or equivalent. This inspection process as well as the actual tariff negotiations require at present two months of planning ahead, with a potential reduction for the subsequent journeys to one month. Once this phase is passed, the Russian authorities will schedule a date and route based on the capabilities of the ship and the availability of icebreakers. Compared to the *48* h notice and the eventual waiting day at the Suez Canal this represents a significant hurdle, which needs to be improved in the future. Additionally, the Suez Canal fee can easily be calculated based on the tonnage of the vessel.

Furthermore, there is basically no land-based infrastructure, such as rescue centres or repair yards, along the NSR, especially when considering draft limitations of larger vessels. Therefore, insurance companies are more or less requiring the Rosatomflot ice breaker escorting as well as the possible towage of a damaged vessel to a port outside the NSR. Hence, if accident happens, towage would cause a significant delay and financial penalty to the voyage. In view of these facts, the Russian Federation is currently intending to invest *910* billion rubles (*21.8* million Euro) in the development of ten centres for search and rescue along the NSR as an attempt to reduce the rescue response time. Additionally, the overall shipping of cargo at sea is increasing at the rate of about *6*% per year. This may lead to a capacity problem in the Suez Canal, which is already one of the busiest shipping lanes in the world. Then the NSR could serve as a route for the overcapacity of the SCR.

This paper presents a decision model to identify the feasibility of Arctic transport in comparison to the conventional Suez and Cape based routes. Especially the slow-steaming potential of the NSR will be exploited, under the assumption of equal round trips per year for both routes, i.e. that NSR vessels benefit from the shorter route. The latter also accounts for a higher reliability in the transport along the NSR as a result of the additional buffer days and the vessels potential to increase its speed, however, under the assumption of reliable metocean data predictions. The application area of the decision model is not necessarily restricted to the study of the NSR. It is valid also for other routing problems where there is a significant cost effect of time-variant seasonal conditions and stochastic events. A recent example is the alternative routing between Suez and Cape, where, in addition to the more traditional cost elements of fuel, time and tariffs, the probability of pirate attacks and both the direct and indirect cost effects of this need to be taken into consideration. However, in the NSR case, the strategic level aspects are less important than the investment-time decision of ice class notation.

2 Model Development

The main purpose of the model presented in this paper is to serve as a basis for discussing what considerations should be taken into account for a ship owner, considering if and when to secure the option to use the NSR for parts of a liner operation. Thus, the question is not addressed whether this is a viable alternative today per se.

For a line operation, the decision to exploit the NSR is a decision that can be postponed to immediately before leaving port. Therefore, practical issues such as polar environment preparedness and lead time for booking NSR assistance are not considered. Thus, the NSR opportunity can be considered a real option that can be called if the benefits outweigh the cost.

The benefits can be exploited in two different ways. One is to increase the number of roundtrips that can be made annually, thus increasing the freight income of the vessel. Alternatively, the benefit can be taken by slow-steaming on the shorter distance, which will result in considerable fuel savings, as well as having the additional benefit of reduced emissions of CO_2. Which of these alternatives is preferable, will depend on the type of the shipping operation considered.

For a liner operation, there are several arguments for the slow-steaming alternative. First, the market for these vessels requires a high degree of operational regularity, which will be incompatible with the seasonal variations experienced if NSR operations are used to maximise annual roundtrips. Second, slow-steaming also provides a buffer towards maintaining the schedule even if unforeseen delays are experienced during the transit in ice infested waters. Third, the typically high service speed of these vessels, and correspondingly high fuel consumptions per tonne mile, provide a larger potential for considerable fuel cost savings than for slower bulk carriers.

In the model, a finite set of different vessel alternatives will be considered. These vessels have similar performance with respect to service speed and cargo carrying capacity, but different levels of ice class, ranging from no ice class to the 1AS ice class. With the same cargo capacity and schedule, the revenue side of the operation can be considered as similar, thus only the cost side needs to be considered. Thus, in the base case model, the decision problem for the ship owner is to select the optimal level of the ice class, taking into considerations his expectations about the future availability of the NSR. The ice class level is assumed to influence the cost and operational factors of the vessel in the following way:

1. The NSR sailing window. The annual savings using the NSR option will be more or less proportional to the number of trips per year using this route. The sailing window is assumed to correspond to the season when an average required speed can be maintained to maintain the schedule. For a given ice class, the number of NSR trips will to some extent depend on the risk level accepted towards being delayed or not being able to pass.
2. The initial investment cost of the vessel. Higher ice class leads to a higher cost due to several factors. One is the increased construction cost resulting from the ice strengthening of the hull including appendages. This will typically be in the range of *6%* to *12%* for 1C to 1AS ice classes, respectively. Another is the increased size of the required propulsion plant, given the assumption of similar open water service speed of the alternative vessels considered. In addition to this comes the cost related to the winterisation of the vessels, such as deck heating, deck machinery coverings etc.
3. Operational cost. The operational cost of an ice-classed vessel will increase as a result of the higher resistance in ice as well as in open water; the latter due to increased weight and altered bow shape. For a vessel sailing at about *21* knots, this increase can be assumed to be in the range of *5%* to *15%*. In addition, for having the opportunity to go the NSR, the crew should be specifically briefed to comply with the demands of the high north, which is however not adding to cost notably.
4. Voyage cost. The dominant part of the voyage cost will be savings due to the reduced fuel consumption resulting from slow-steaming through the NSR. Depending on the actual service considered, the sailing distance can be close to *50%* of the Suez alternative. The corresponding fuel savings can then be significant. The tariffs for the NSR transit act in the opposite direction.

What the long-term level of these will be, is presently highly uncertain; currently, it is negotiable down to *5* USD/t. Still, in the short-term, these can be expected to be slightly above the Suez transit fee. In the medium to long term, the level of these tariffs will be dependent on total traffic volumes, the development rate of critical infrastructure (including icebreakers) and political factors. It is also relevant to include the insurance cost as a voyage-related cost. Today, a medium sized vessel can be expected to pay an insurance fee in the range of *40000* USD for a single transit, which is comparable to the southern route due to the piracy problems experienced in the last decade, but there is a considerable uncertainty with respect to the further development of this cost.

5. Lost opportunity cost. For weight constrained vessels, the additional steel weight resulting from the ice strengthening will reduce the cargo carrying capacity of the vessel. This represents a lost opportunity cost corresponding to reduced freight income. For the type of vessels considered here – liner vessels such as RO/RO or container ships – this cost is likely to be small, and will thus not be considered in the development of the model.

3 Reference Model Formulation – NSR

Here, the model is described, denoted as the Basic Trans Arctic Shipping Opportunity Model. The following notation is used:

Sets:

V	set of ice class levels for the relevant vessel type, indexed by v
T	set of time periods within the planning horizon, indexed by t

Parameters:

w_{st}	available NSR sailing window for vessel v in time period t, in number of periods of S days
S	one way sailing time between loading and unloading port
ΔC_v^C	additional capital cost of vessel with ice class v compared to base case
ΔC_{vt}^O]	additional operating cost for vessel v in time period t compared to base case (increased fuel cost in open water at service speed)
ΔC_{vt}^V	saved voyage cost for vessel v in time period t compared to base case, equal to saved fuel cost less tariff rate difference
r	discount rate

Variables:

x_v	binary variable equal to *1* if a vessel with ice class level v is chosen, *0* otherwise

The problem can be formulated as a simple selection model:

$$\min \sum_{v\in V} x_v \left[\Delta C_v^C + \sum_{t\in T} \left(\Delta C_{vt}^O + w_{vt}\Delta C_{vt}^V\right)/(1+r)^t\right] \tag{1}$$

subject to

$$\sum_{v\in V} x_v = 1 \tag{2}$$

$$x_v \in [0,1], \quad v \in V \tag{3}$$

Objective function (1) calculates the minimum cost difference between the base case and the NSR option. Constraints (2) ensure that only one vessel is selected. Binary requirements for the vessels ice class level variables are imposed by constraints (3). By solving the problem (1)-(3), the optimal ice class level of the vessel to acquire will be determined.

4 Case Study

A simple case study is shown which illustrates the decision problem as seen from a ship owner's perspective. First, the operating context for a particular trade is developed, in terms of ice conditions, corresponding NSR availability and cost consequences. These context parameters will then be taken into the decision model for finding preferable fleet renewal strategies.

4.1 Ice Conditions, NSR Availability and Cost Consequences

The main obstacle for safe transport along the NSR is the ice covering the passages and the severity of the ice in terms of thickness, ridges and compression. Therefore, the vessels need to be ice strengthened to withstand those loads, and it needs to be known when ice can be encountered along the route and to which extent, in order to select the appropriate ice class. A prediction of the future sea ice extent based on historic measurements is carried out to visualise the potential operational days per year along the NSR in the future. At first, the summer and winter average of the sea ice anomaly for the northern hemisphere from *1980* to *2012*, *N.N.* (2008), is used to obtain the general anomaly trend, Fig. 1. Therein a fairly linear behaviour can be seen, however, with a fairly large SSE resulting in a wide standard deviation band to cover most values. In other words, this indicates a high uncertainty with respect to the absolute numbers, yet the trend is clearly visible, with no contradiction with the record summer low in *2007* with *4.3* million square kilometres resulting in a completely ice-free NSR. Consequently, this trend of decreasing ice extents is mapped to the latest ice extent measurements in *2010* until the beginning of *2012* according to *N.N.* (2012) for the northern hemisphere, Fig. 2 (Measurements). Using a sinusoidal fit through those measurements and the average sea ice anomaly trend from Fig. 1 results in the prediction of sea ice extent for the summer and winter season as shown until *2050*. Figure 2 includes the current limit value for NSR transit in accordance with the time window of actual 1A ship transits made in *2009*, *2010* and *2011*, *Omre et al.* (2012). The resulting sea ice extent threshold value of *4.8* million square kilometres assumes that the areas of diminishing ice will follow the past trends, which also indicates diminishing multi-year ice along the NSR. Furthermore, the September *2007* low resulted in a completely ice free NSR and is thus assumed to be the limit value for ice-free navigation along the NSR. Consequently, the future summer sea ice extents below these threshold values will allow for NSR transits, respectively operational days along this route.

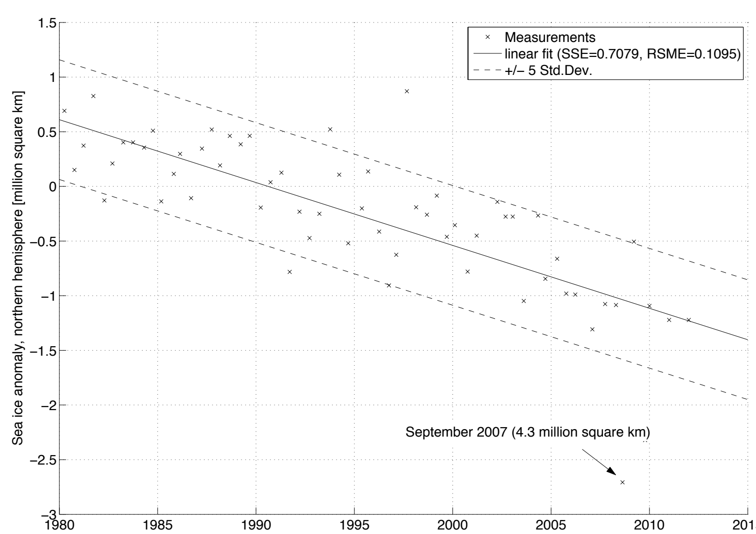


Fig. 1: Mean sea ice anomaly measurements and trend for the northern hemisphere.

The resulting trend of operational days along the NSR is presented in Fig. 3. Therein, ice class 1A in *2011/12* corresponds to current limit ice class for ships transiting the NSR. However, as ice is not predicted for a substantial amount of days per year along the route in the future, an ice-classed vessel would not be needed. Further, the potential operational days for the lower ice classes 1A and 1B are given in Fig. 3 together with an operational extension to 1AS, following the difference in potential ice encounters along those routes according to the allowed 1A for each ice class.

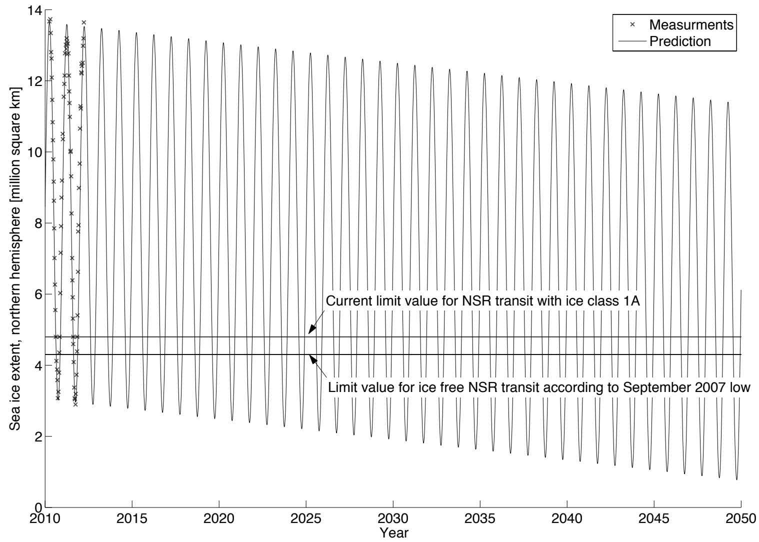


Fig. 2: Summer and Winter Sea ice extent measurements and predictions.

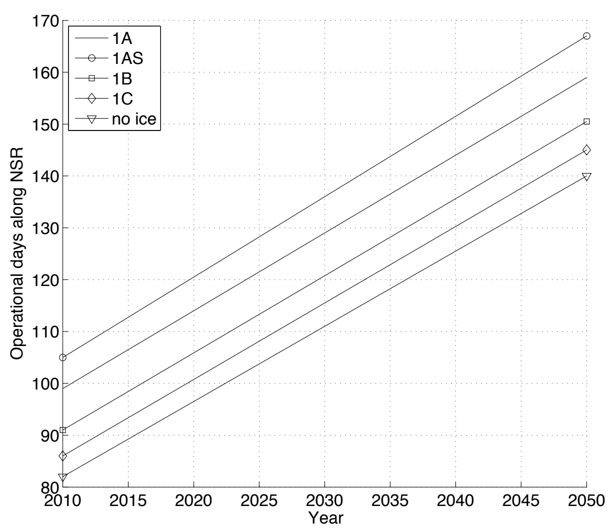


Fig. 3: Current and predicted operational days along the NSR for different ice classes.

The additional capital cost ΔC_v^C of the vessel v with ice class compared to the base case is assessed in line with a typical increase of hull structural cost due to the increased scantlings, including hull appendages as well as the increased machinery cost, *Polach et al.* (2012). The increased fuel cost in open water at service speed as a result of the increased weight, ice class complying bow shape and hull appendages is estimated based on the increased frictional resistance for increased wetted surface due to the potential draft increase. The resulting cost differences for the different ice class vessels are summarised in Table 1.

4.2 Implications for the Fleet Renewal Strategy

Consider a car carrier liner operation between Europe and South-East Asia. The sailing distance from typical destinations will be *11500* nm along SCR and *6900* nm using the NSR. The base case vessel considered is a *6000* pure car carrier (PCC) with a newbuilding price of *65* million USD, a service speed of *20* knots and a *13.5* MW propulsion plant operating at *85*% of MCR. Further, the specific fuel consumption is assumed as *190* g/kWh, and the fuel price as *750* USD/t, increasing by

Tab. 1: Percentage difference for the considered cost components.

Ice class	ΔC_v^C	ΔC_{vt}^O
1C	6.5%	2.5%
1B	7.5%	3.4%
1A	9.5%	5.1%
1AS	12%	6.3%

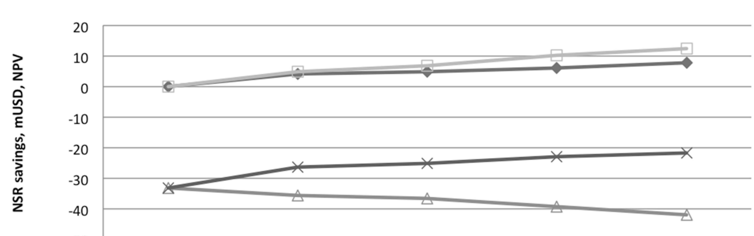
3% per annum. The discount rate used in the net present value calculation is *7%*. Initially, the tariffs using the SCR and the NSR are considered to be the same, based on the discussion in Section 2.

Thus, capital expenditure (CAPEX) and operational expenditure (OPEX) consequences of using the NSR can be calculated using the percentage differences found in Table 1. For voyage costs, the change in powering requirements following from slow-steaming the NSR needs to be estimated. This can be found by

$$kw_{NSR} = kw_{SCR} \left(D_{NSR} / D_{SCR} \right)^{\beta} \tag{4}$$

D_{NSR} and D_{SCR} are the distance along the NSR and SCR, respectively. For these vessels, $\beta = 2.5$ can be assumed. This gives a speed along the NSR of *12.0* knots, and a corresponding powering requirement of *3.2* MW in the slow-steaming NSR condition.

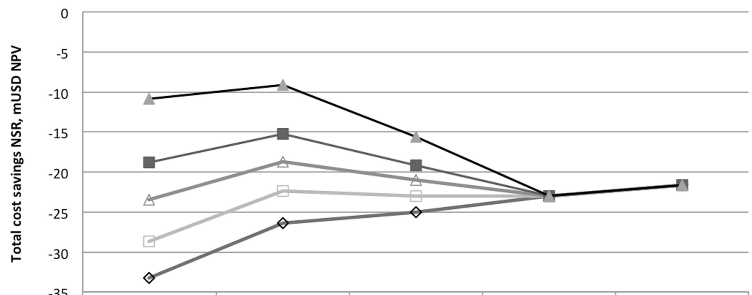
In the base case, it was assumed that the NSR is available for all ice class categories from period *1*, as follows from Figures 2 and 3. Since the differences in NSR availability are relatively small between the different ice class categories investigated, the 'No ice class' will have the highest cost savings as expected. However, this assumption is not realistic when the existing regulatory regime is taken into account. Currently, Russian authorities require the vessels to have at least an ice class 1A to be allowed to enter. Whether and when other ice classes will be allowed is at the moment unclear, even though the operational window without ice encounters continuously increases, Fig. 2. One possible scenario could be a stepwise opening of the passage, allowing one additional class of vessel at a time with a given interval while gathering operational experience. Figure 5 illustrates this assumption implemented in the model, comparing different phase-in schemes, each with an interval of *N* years. This means allowing NSR passage for 1B after *N* years, 1C after *2N* years, and finally all vessels after *3N* years. The highest cost savings for phase-in schemes with *N* larger than *0* will be with a 1A ice class vessel. The relative savings will increase towards lower ice classes as the phase-in intervals increase.



	No ice class	1C	1B	1A	1AS
CAPEX	0	4.225	4.875	6.175	7.8
OPEX	0	4.973	6.763	10.145	12.532
VOYEX	-33.243	-35.56	-36.667	-39.297	-41.97
TOTAL	-33.243	-26.362	-25.028	-22.977	-21.638

Fig. 4: Net present value of cost savings for alternative ice class options over 25 years, assuming that the NSR will be available for all vessel categories as given in Fig. 3.

Furthermore, the bunker price, currently almost *750* USD/t, may change. Its influence on the cost of the different ice class categories is presented in Fig. 6. For bunker prices above *450* USD/t, the ice class 1A becomes most favourable, whereas the lowest ice class 1C results in the lowest savings.



	No ice class	1C	1B	1A	1AS
0YR	-33.243	-26.362	-25.028	-22.977	-21.638
1YR	-28.697	-22.37	-22.994	-22.977	-21.638
2YR	-23.454	-18.671	-21.036	-22.977	-21.638
3YR	-18.778	-15.243	-19.151	-22.977	-21.638
5YR	-10.887	-9.123	-15.59	-22.977	-21.638

Fig. 5: Net present value of savings for phasing in of different ice class categories with varying intervals.

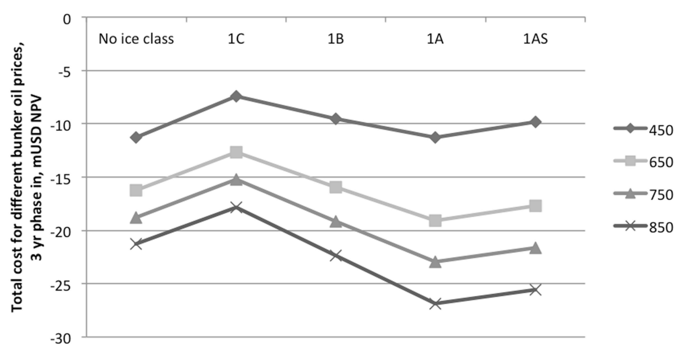


Fig. 6: Sensitivity of the ice class to the bunker price in USD/t.

5 Considering Risk and Reliability

As with all strategic-level decisions in the shipping industry, the fleet renewal decision involves a considerable degree of risk. Uncertainty related to the future availability of the NSR is one more risk factor that needs to be taken into consideration. This risk is presently independent of the investment decision made. If the 'no ice class' alternative is selected, and the NSR turns out to be an available option for a large part of the year in the near future, competitive position will weaken. On the other hand, if investment is made in ice class, and neither the ice conditions nor the political, commercial or regulatory development of this sailing route is developing as expected, the vessel will be uncompetitive for the open water route via Suez.

Another perspective on this risk is the insurance policy, where the premium is currently comparable to the SCR. However, this is due to the fact of missing accidents or major insurance claims along the NSR. The insurance companies take the wait-and-see position here, thus they may respond to possible accidents in the future with an increased premium, e.g. *Haahjem* (2012). Furthermore, the most common ice damages, e.g. damage to the propeller, thruster, rudder, shell plating or ice wear, are typically below the deductible limit and thus not claimed and registered. Nonetheless, the biggest concerns of insurance companies lay with the challenges concerning salvage, rough conditions, lack of infrastructure, repair facilities and communication. As a result, they typically insist on ice breaker escorting services during the transit to avoid a situation where a small incident can develop into a major claim. In other words, insurance companies make individual risk and hazard identification for NSR transits and adjust the premium accordingly. However, they do not share the residual risk in the event that the precaution measures fail and a major claim develops. The re-insurance companies, on the other hand, seem to have a wider view on arctic transport, because they are looking into the sustainability of the entire transport system to identify not only the current risk, but also the perceived risk and thereby the reputation of the transport system and its perspective development, *Schneider* (2012). Thereby, they are much more concerned with the future developments, which will hopefully lead to a more transparent treatment of the Arctic transport risk with a better distribution among the stakeholders.

In addition to the risk related to the availability of the NSR and the safety aspects of people and property, there is also an operational risk related to the maintenance of maritime logistics operation with a sufficient degree of reliability. Most approaches to exploiting the NSR foresee a reduction in total roundtrip time, increasing the number of annual roundtrips, and thus the revenue potential of a given vessel. For liner trades, operating on a predetermined schedule, any delay due to unforeseen ice conditions or accidents will compromise the reliability and regularity of the operation. This is not unique to the NSR – there are a number of similar risk factors for the SCR as well. However, in the current situation with small transit volumes and limited experience with the NSR option, this is likely to be a serious inhibitor to increased NSR usage.

With the approach to NSR exploitation assumed here, the consequence in terms of reliability may rather be opposite to the common consensus. By designing a vessel for the SCR open-water service speed and exploiting the NSR by fuel-cost savings that follow from slow-steaming rather than reduced sailing time, at the same time, an option is acquired for a speed increase. This option can be called, of course at a price corresponding to the increased fuel cost, if unforeseen delays occur during the NSR transit. This option is not necessarily available on a tightly scheduled Suez route, and is likely to contribute to an increased reliability of typical liner trades rather than decreasing it.

6 Conclusion

A decision-support model is presented, identifying the most viable ice class for a liner vessel transiting along the NSR. Its sensitivity is discussed with respect to the perspective ice extent, respectively the ice class allowed to enter the NSR and possible delays, on the basis of current-trend predictions. The presented ice extent prediction and the resulting operational days for the individual ice classes are highly uncertain and may change because of future observations and better prediction models. Nonetheless, the potential is discussed of increased transport reliability of the NSR as a result of slow-steaming and the possibility to increase the vessel speed whenever needed as a result of the shorter overall distance. As a result, it is shown that with longer time intervals, allowing the NSR to be transited with lower ice classes, the choice of ice class 1A becomes most prominent, while the additional investment in 1AS is too high to be reimbursed and the gain due to 1C compared to no ice class is insignificant to justify its expenditure. The latter is also identified in view of possible bunker price developments, indicating the same trend, however, with increasing bunker prices. The presented decision support methodology can be updated to reflect new findings and developments.

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