Simulations of shipping along Arctic routes: comparison, analysis and economic perspectives

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ABSTRACT. Arctic sea routes have for long been of interest for shipping because of much shorter distances between the Atlantic and the Pacific. Sea ice prevented real development of significant traffic, but did not prevent research from trying to assess their economic viability. With the melting of sea ice in the Arctic, this effort at modeling the profitability of Arctic shipping routes has received a new impetus. However, the conclusions of these studies vary widely, depending on the parameters chosen and their value. What can be said of these models, from 1991 until 2013, and to what extent can a model be drawn, capitalising on twenty years of simulations?

Introduction

In the framework of climate change and the melting of Arctic sea ice, now well documented, scenarios of developing Arctic shipping emerged anew, echoing the European projects of the 16th–19th centuries to discover a shorter route to Asia, or more recently the *Manhattan* project to develop a commercially viable tanker route across the northwest passage, all ill-fated. Only in the USSR, by dint of huge investment in Arctic ports and heavy icebreakers in the framework of a planned economy, did Arctic shipping develop before the effects of climate change. Now, every summer when the official statistics about the decline of the sea ice are published, the media repeat the oncoming age of Arctic shipping, an idea resting, often without any deeper analysis (Lasserre 2010), on the fact that Arctic routes are much shorter than through Suez or Panama between northern Europe and northern Asia, and that, therefore, they would automatically attract shipping firms. The melting of sea ice did not merely reactivate ancient ambitions about transportation in the Arctic, but immediately proved to bear a political issue, as the growth of shipping in the region underlines the question of what the status of the northwest and northeast passages will be (Byers 2009; Lasserre 2010): international straits, as claimed by the United States or the European Union? Or internal, and thus subject to their sovereignty, as claimed by Canada and Russia? Neutral, if ships navigate across the Arctic Ocean? The question of the development of Arctic shipping remains controversial as expert analyses do not converge (Howell and Yackel 2004; Gedeon 2007; Loughnane 2009; Lasserre 2011).

It is in this context of renewed interest, that models have been designed to attempt to assess the economic feasibility of commercial shipping along Arctic routes. The issue proves not to be technical: with powerful icebreakers and, more recently, the advent of double-acting ships (DAS), navigation across ice that becomes thinner and thinner and sees multiyear ice melt, is no longer an engineering difficulty, but rather a business case problem (Niini and others 2007; Lasserre, 2010b). Several models tried to address the following question: to what extent would shipping in these waters be profitable?

These models, published between 1991 and 2012, are analysed in this paper. They reveal the difficulty of defining credible parameters to build up a model that could assess the profitability of Arctic shipping. The author has also attempted to construct his own so as to feed the discussion. The objective of this article is to discuss the strengths and weaknesses of these models and the reliability of their assessments on the profitability of Arctic shipping, and to capitalise on their teachings to set up a new model that would take into account market issues.

Throughout the paper the following abbreviations are employed: NWP - northwest passage, NEP - northeast passage, P&I – protection and indemnity insurance, H&M – hull and machinery insurance, TEU – twenty foot equivalent unit (this is the unit used to count containers), PC – polar class, NYK Nippon Yusen Kaisha (Japanese shipping line), DNV – Det Norske Veritas (a ship classification society), UNCTAD – United Nations Conference on Trade and Development. All currencies are US$. Volumes where cited as 'gal' are US gallons.

Several models describe the economics of Arctic shipping

Even before climate change effects were widely discussed, studies had been undertaken to assess the feasibility of developing shipping along the northern sea route (NSR). Echoing Soviet attempts at revitalising the seaway, following President Mikhail Gorbachev's Murmansk initiative of 1 October 1987, several research projects tried to evaluate the technical and economic feasibility of developing international commercial shipping. The idea was all the more rational as, in contrast with the northwest passage where traffic was next to nil, the USSR had developed an series of active commercial ports and a busy seaway along the Siberian coast that rested on the escort of many powerful nuclear and diesel icebreakers. The western part of the route, between Murmansk and Dickson, was even open to year-round navigation after 1980 (Mulherin 1996). In particular, the INSROP (International Northern Sea Route Programme) was a six year (June 1993–March 1999) international research programme designed to assess the economics of the NSR, a project that, besides Russia, interested Japan and Norway very much. Wergeland's studies (1991, 1992) were also early attempts at assessing the business potential of the NSR. But the collapse of the Soviet Union in 1991 led to the rapid decline of economic activity along the NSR, and no follow-up of these early research models. Some of the models analysed are indeed reflections of research programmes that were carried on since the early 1990s to assess the feasibility and profitability of shipping in the Arctic. These research programmes include INSROP (1993–1999, mainly funded by Japan, Norway and Russia, studying the NSR); Ice Routes - The Application of Advanced Technologies to the Routing of Ships through Sea Ice (1997–1998, European Union); ARCDEV – Arctic Demonstration and Exploratory Voyages (1997–1999, European Union, studying the western Russian Arctic seas); ARCOP – Arctic Operational Platform (2002–2006, European Union, studying the NSR); Northern Maritime Corridor (2002–2005, European Union, Norway and Russia, studying the North, Barents and Kara Seas); JANSROP (2002–2005, Japan, studying the NSR); Canadian Arctic Shipping Assessment (2005–2007, Canada, studying the Canadian Arctic waters); AMSA - Arctic Marine Shipping Assessment (2006–2008, initiated by the Arctic Council, considering the whole Arctic). Research thus largely emphasised the NSR as a potential transit route and gateway to Russian resources.

General portrait of the models considered

Climate change renewed interest in modeling Arctic shipping. 23 simulations have been identified and analysed: 9 articles from journals; 8 technical reports; 1 book chapter; 2 communications and 3 master's theses. They were published between 1991 and 2012, but 18 were published in or after 2006, attesting to the renewed interest in Arctic shipping in the climate change context. Two tackle destinational traffic (that is shipping going to/from the Arctic for the exploitation of natural resources: Juurmaa 2006 and Falck 2012), while the 21 others are interested in transit shipping. The majority display the study of container traffic (15); seven address bulk shipping (LNG, tanker, dry bulk), and four are interested in general cargo. Four studies did not consider ice-class vessels; five simulated an ice-class vessel without specifying which class. One considered a 1B ice-class vessel; 5 either a 1A (PC7) or a 1AS (PC6) ice-class; one seemed to consider a PC5 vessel, and 8 envisaged a PC4 vessel or higher. 3 models considered DAS ships. These are in the Baltic ice-class system; for equivalences, see Annex 1.

Reflecting both the early development of traffic along the NSR and the presence of infrastructure to facilitate present shipping (ports, numerous icebreakers), most tackle the profitability of shipping in the NSR (18); 7 consider the northwest passage (NWP), three the transpolar route across the heart of the Arctic Ocean, and one does not specify any Arctic route. When they establish comparisons, the articles compare these Arctic sea lanes with the Suez route (16), Panama (5) and the Trans-Siberian rail link (1) (Table 1).

Main parameters used in the models: discrepancies and similarities

It is interesting to stress that the parameters used by the authors of the models differ widely, and not only for the type and ice-class of the ships considered.

For instance, fuel costs are the largest single cost factor according to all simulations. Probably for simplification reasons, the fuel consumption rate, in 14 models, is considered the same for Arctic and southern routes, whereas 7 models underline that rates are different, either because a limited speed entails a lower consumption rate, or because progressing across ice calls for more power and thus consumes more. These two parameters (type of fuel used and consumption rate) are very important, as fuel costs are the largest single operational cost, among direct costs (thus excluding general management costs but including operational and depreciation costs), they range from 36.7% (Verny and Grigentin 2009) to 54.2% (Schøyen and Bråthen 2011), 54.3% (Chernova and Volkov 2010), 56% (Dvorak 2009) and 61% (Srinath 2010). Models are thus very sensitive to the two parameters of bunker cost (independent from the author) and the average speed and consumption rate, which the author must determine, a sensitivity that several authors recognise (Guy 2006; Somanathan 2009; Chernova and Volkov 2010; Wergeland 2013).

All models depicting year-round Arctic navigation consider that the same type of fuel will be used in summer as in winter, usually IFO 380. In fact, IFO 380 may be widely used but it is not well-suited for very cold temperatures that will keep prevailing in winter in the Arctic. The Canadian Coast Guard requests naval distillate fuel (NATO code F75) for all its Arctic operations; in winter the CCG uses P50 as its freezing point is much lower. At Eureka Base, the fuel used for the generators is P60 with an even lower freezing point. It is therefore unlikely that shipping companies could use ships with classical IFO 380 during winter navigation (Ouellet 2011; MacLeod 2012). This element is important as prices reflect the specialisation of the fuel: in early October 2012, IFO 380 was worth 2.43$/gallon; naval distillate 3.267$/gal; and P50 3.322$/gal (+36,7% over IFO380). Simulations implying shipping in winter usually using the same fuel as in winter therefore underestimate the cost of fuel by a large margin.

The average cruise speed of a commercial ship differs also widely depending on the model. For year-round navigation, three models suggest an average speed between 7 and 11 kts; six consider the average speed will be between

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Table 1. Models of Arctic shipping considered for the review

Year	Lead author	Title	Objective	Route	Type of ship	Origin-destination	Time window of navigation considered
1991	Wergeland	NSR. Project	Compare transportation costs per tonne	NSR; Suez; Panama	General cargo/heavy lift ship, 20 000 dwt conventional and ice-class 1AS = PC6	Two routes: - Hamburg-Dutch Harbor via Panama - Yokohama - Hamburg via Suez	Year-round
1992	Wergeland	NSR - Rosy prospects for commercial shipping	Compare transportation costs per tonne	NSR; Suez; Panama	General cargo ship, 20 000 dwt conventional and ice-class (unspecified)	Two routes: - Hamburg-Dutch Harbor via Panama - Yokohama - Hamburg via Suez	Year-round
1996	Mulherin	Develoment and Results of an NSR Transit Model	Evaluate direct costs (single trip) of exploiting ice-class ships in the NSR	NSR	Three ship types considered: - Norilsk-class bulk ice-strengthened ship, ice class ULA = PC4-PC5 - Lunni-class tanker, ice class 1AS = PC6 - Strekaloovsky-class bulker, UL ice-class = PC7	Murmansk - Bering Strait	April to October
1999	Kamesaki,	Simulation of NSR Navigation Based on Year Round and Seasonal Operation Scenarios	Compare transportation costs for yearly service. Ships can ply both routes depending on ice conditions	NSR, Suez	Handy max 50900 dwt for Suez route (general cargo) Three ice-class ship types for the NSR.: - 25000 dwt with 'high ice-class' ("ULA?" = PC4-PC5) (general cargo) - 40000 dwt with 'high ice class' ("ULA?" = PC4-PC5) (general cargo) - 50000 dwt with 'medium ice class' ("UL" = PC7) (bulk)	Hamburg - Yokohama	Year-round
2001	Kitagawa, H.	NSR.The shortest sea route linking East Asia and Europe	Same as Kamesaki 1999	NSR, Suez	Same as Kamesaki 1999	Hamburg - Yokohama	Year-round
2006	Arpiainen	Arctic shuttle container link from Alaska US to Europe	Find operation costs per TEU	NSR	750 TEU container ship DAS 5000 TEU container ship DAS LU8 or 9, PC4 to 3	Arctic shuttle service, Reykjavik-Adak (Aleutians)	Year-round

Table 1. Continue

Year	Lead author	Title	Objective	Route	Type of ship	Origin-destination	Time window of navigation considered
2006	Guy, E.	Evaluating the viability of commercial shipping in the NWP	Compare operation costs for a single trip	NWP; Suez	Panamax standard containership, about 4000 TEU	Rotterdam-Shanghai	Summer transit. 6 scenarios considered with change in three parameters : speed, hire rate and transit fees
2006	Juurmaa	Arctic operational platform: integrated transport system	Compare transportation costs for oil to Europe: destinational shipping	NSR; pipelines across Russia and north Europe	Oil tanker versus oil pipeline	Varandei - Rotterdam	Year round Several scenarios
2007	Somanathan,	Feasibility of a sea route through the Canadian Arctic	Compare operation costs per TEU for regular service	NWP ; Suez	4500 TEU Container ship CAC3/PC2	Yokohama-New-York Yokohama-St John's	Year round
2008	Borgerson	Arctic meltdown	Assess transportation costs, single trip	NWP; Panama; Suez	Large container ship; apparently, conventional	Rotterdam-YokohamaSeattle-Rotterdam	Unspecified
2009	Dvorak	Engineering and economic implications of ice-classed containerships	Find specific ship costs for year-round operation in Arctic waters	No specific route studied	Container ship, 5000 TEU. A1/1AS/PC6. A3/PC3. A5/PC1	None. Objective is to determine the cost to exploit the ship	Not specified
2009	Mejlaende	ARCON - Arctic container	Compare transportation costs for regular service	Polar and Suez	8600 TEU container ship:- conventional for Suez for Arctic navigation, three cases: ice-strenghtened (no ice class mentioned); ice-breaking hull; DAS. Analysis based on scenarios from 2010 till 2050, taking into account diminishing ice cover	Yokohama-Rotterdam	Year round
2009	Somanathan	NWP: a simulation	Assess costs of regular service on the NWP route	NWP; Panama	4500 TEU Container ship CAC3/PC2	Yokohama-New-York Yokohama-St John's	Year-round

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Table 1. Continue

Year	Lead author	Title	Objective	Route	Type of ship	Origin-destination	Time window of navigation considered
2009	Verny	Container shipping on the NSR	Compare transportation costs for the period 2015–2025	NSR; Suez: Transsiberian	4000 TEU container ship, conventional for Suez; ice-class (not specified) for NSR.	Hamburg-Shanghai	Year-round
2010	Chernova	Economic feasibility of the NSR container shipping development	Assess cost per TEU and compare with cost per TEU for Suez route	NSR; Suez	DAS container ship, 650 TEU	Rotterdam - Yokohama	July-December
2010	Srinath	Arctic shipping: commercial viability of the Arctic sea routes	Find profit margins	NWP; NSR; Polar; Suez	4000 TEU Container ship. CAC3/PC2	Shanghai-Rotterdam	Three scenarios : Year-round in the Arctic; 6 months in the Arctic; 4 months in the Arctic
2010	Det Norske Veritas (DNV)	Shipping across the Arctic Ocean	Evaluate transportation costs for a year	NSR Suez	6500 TEU standard ship. 5000 TEU PC4 DAS ice-class ship. 6500 TEU PC4 ice-class ship	Rotterdam - Tokyo, Hongkong, Singapore	S1: Year-round (DAS ship) S2: seasonal (PC4)
2010	Liu	The potential economic viability of using NSR as an alternative route between Asia and Europe	Compare operation costs for regular service	NSR; Suez	4300 TEU container ship. 4300 TEU container ship, ice-class 1B	Rotterdam - Yokohama	NSR used for 3, 6 or 9 months
2011	Paterson	Cost comparison of shipping in the Arctic	Fednav's simulation: outline cost comparison for a single trip	NWP; Panama	Conventional bulk ship	New-York - Shanghai	Summer transit
2011	Hua	The potential seasonal alternative of Asia-Europe container service via NSR under the Arctic sea ice retreat	Assess fuel costs	NSR, Suez	Conventional 10 000 TEU container ship, no ice-class No NSR fee	Several sets of origin - destinations from Atlantic Europe to Northern Asia	Summer transit

Table 1. Continue

Year	Lead author	Title	Objective	Route	Type of ship	Origin-destination	Time window of navigation considered
2011	Schøyen	NSR versus Suez Canal: cases from bulk shipping	Optimize fuel consumption efficiency and fuel costs to assess transit costs	NSR, Suez	Conventional bulker vs ice-strengthened (not specified) bulker Insurance cost based on E3 = 1A = PC7	Two scenarios: - LNG: Porsgrunn (southern Norway) to Shekou - Bulk: Narvik - Qingdao	Summer transit
2012	Falck	Shipping in Arctic waters: the NSR	Tschudi Shipping's simulation: compare costs for a single destinational trip	NSR; Suez	Ice-class (1A) bulker and LNG tanker	Kirkenes - YokohamaMelkøya - Yokohama	Summer transit
2013	Wergeland	NEP, NWP, and Transpolar Passages in comparison	Assess cost differences between studied routes	NSR; NWP; Transpolar; Suez	Two scenarios, but no ice-class ship considered - General cargo/Heavy lift ship, Yokohama-Hamburg - Container ship 4000 TEU, Shanghai-Hamburg	Yokohama-Hamburg Shanghai-Hamburg	Year-round

11 and 13 kts; two opt for an average speed between 13 and 15 kts, and one estimates on an average speed of 17 kts (Verny and Grigentin 2009). For summer shipping, one study has a speed slower than 10 kts; two consider the speed between 11 and 13 kts; one between 13 and 15 kts, and 3 above 15 kts (up to 25.8 kts with Hua and others 2011). The difference between these models is striking, as authors modeling a summer transit do not present us with an average speed much higher than for year-round traffic, whereas it is difficult to envisage rapid transits across Arctic passages in the winter time given the prevalence of thick one-year ice, if not multiannual. As for summer navigation, it is debatable that commercial ships can achieve average speeds greater than 15 kts, not merely because of drifting ice, but also because of increasingly prevalent fog and, for the NWP, the increasing density of icebergs in Baffin Bay and lack of accuracy of charts within the Canadian archipelago (Lasserre 2010a, 2010c).

The estimates for the increased capital cost for the construction of an ice-class ship vary widely. For Arctic shipping, Laulajainen (2009) estimates increased capital costs at 70 to 100%, a figure that seems high when compared with the models considered. In Table 2 are displayed the spectrum of values for capital cost premium for an ice-class commercial ship, with a similar capacity as the benchmark vessel, set forth among the models.

One study (Hua and others 2011) considers there will be no NSR fees, a daring assumption given Russian intent to use the NSR toll precisely to finance the maintenance of its Arctic icebreaker fleet. Eight models rest on the same cost structure for the crew, assuming wages and advantages are similar as crews operating along classic routes, whereas six mention there definitely is a need for a well-trained crew for Arctic shipping, and thus either imply or explicitly mention that crew costs are higher: experienced crews command a higher salary if the employer wants to make sure the firm will retain their services.

Insurance premiums are also the object of a wide range of estimates. Three models rely on no insurance premiums. One mentions a cargo insurance premium of 50% over standard tariffs. Three models suggest global insurance costs may be between 75% and more than 100% higher than regular fees. For P&I, insurance that covers third party liabilities encountered in the commercial operation of vessels, premiums vary from 16.7%, 25% (two), 43% 50% (three) and 100%; for H&M, (insurance protection for damage done to the ship itself or the equipment which forms part of it) premiums display a range between 25% (two), 50% (three) and 100% (three). Arpiainen and Kiili (2006) quote 800$/day as the average insurance cost for a ship plying Arctic waters year-round, whereas Somanathan (2009) sets this cost at 1746 $/day, Wergeland (2013) at 1150 $/day for a containership along the NSR, and Verny and Grigentin (2009) at 3344 $/day. Clearly, such a wide range of cost estimates underline the degree of uncertainty of these models.

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Table 2. Estimates of capital cost premium for a commercial ice-class ship depending on the class, from the selected simulations.

Lead author	Ice class category considered	Capital cost premium
Mejlaender-Larsen 2009; Wergeland 2013	'Ice class'	+10 to 35%
Liu 2010	1B	+20%
Mulherin 1996; Kamesaki, 1999; Kitagawa, 2001	PC7	+20 to 36%
Mulherin 1996; Schøyen 2011	PC7 to PC4	+20%
Mulherin 1996; Dvorak 2009	PC6	+1 to 20%
DNV 2010	PC4	+30%
DNV 2010	PC4 and DAS	+120%
Dvorak 2009	PC3	+6%
Somanathan 2007, 2009	PC2	+30%
Srinath 2010	PC2	+40%
Chernova 2010	DAS/'high ice class'	+30 to 40%

We contacted several insurance companies and among the factors considered for the risk assessment and thus the rate, is the experience of the crew in Arctic shipping; the availability of rescue units (icebreakers or else); the distance to a port in case of damage; the ice class of the ship and the prevalence of fog and ice along the route considered. These factors indicate higher premiums along the NWP as the NSR boasts intermediate ports (Varandei, Amderma, Dickson, Tiksi, Pevek, Provideniya), more icebreakers, less drifting ice and fewer icebergs and growlers, because land glaciers that calve icebergs when entering the sea on Novaya Zemlya, Severnaya Zemlya and Zemlya Frantsa-Iosifa are much smaller than those of Greenland and Ellesmere Island (Dowdeswell and Hambrey 2002: 95–96).

A diversity of models and conclusions

The models are of diverse quality and purpose. Borgerson (2008) uses his very synthetic simulation to illustrate his idea that the NWP will witness a traffic explosion, but he does not disclose his sources and his reasoning rests on a debatable hypothesis that ships will navigate the NWP with the same speed as along southern sea lanes. Paterson (2011) and Falck (2012) displayed simplified simulations in the frame of more general presentations. Juurmaa (2006), Mejlaender-Larsen (2006) and DNV (2010) do not disclose many details. But simulations from authors like Kitagawa (2001), Verny and Grigentin (2009), Somanathan (2009), Srinath (2010), Liu and Kronbak (2010) and Wergeland (2013) offer detailed and accounted for hypotheses with several parameters.

Given all the parameters involved, 13 models conclude that Arctic routes can be profitable for commercial shipping in the short term; five are more ambivalent or do not take a position, and five conclude that conditions are difficult for a profitable exploitation of these routes (Tables 3, 4).

However, as for any model, the conclusions must be handled with care. Arpiainen and Kiili, who conducted the simulation for Aker Arctic (2006), reach an overall direct cost of 354$/container on the route Iceland-Aleutians through the NSR. Combining this cost with the two transhipments Europe-Iceland and Aleutians-Asia (figures not provided), they conclude that the three segment route between Europe and Asia is profitable, but they do reckon many variables are not accounted for in the model (Arpiainen and Kiili 2006: 28).

Guy studies the NWP under several scenarios, based on the charter cost of the ship, transit duration and possible transit fees. His calculations show that the transit through the NWP may be potentially profitable, but he underlines optimal conditions must be met: rapid transit speed; low transit fees (it is free now but this goes with the scarcity of services along the NWP); and limited premiums for Arctic shipping (ice-class ship; crew; insurance; maintenance) (Guy 2006: 13).

The general conclusion that seems to emerge from these models is that direct costs are lower for transit shipping using Arctic routes. However, as hinted to by a few authors, the models are by definition simplifications of the reality and do not take into account all variables, and sometimes oversimplify them. They rest on simplifications of the cost structure (structural limitation) and, for most, on the choice to focus on cost issues. For instance, they never consider general cost issues like the twice yearly redesign of schedules a seasonal use of Arctic routes implies for container shipping; they rarely consider marketing issues like the load factor, and never the risk-aversion that characterises liner shipping regarding the risk of delays because of unpredictable drifting ice, especially at the beginning and the end of potential Arctic shipping seasons, as repeated delays would entail significant financial penalties (cost dimension) and damaged credibility (marketing dimension) (see Lasserre and Pelletier 2011 on these perception issues). One simulation, for instance, posits the same speed for summer transit across the NSR; the absence of NSR tariffs; and does not consider other costs. No surprise it then concludes the NSR is profitable – but what did it test? (see Hua and others 2011)

Some of these factors, especially the potential costs of commercial risks such as delays, are difficult to factor in in quantitative models. However, the author considered

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Table 3. Conclusions of the simulations that conclude Arctic routes are profitable

Year	Lead author	Results
1991	Wergeland	Panama scenario: 10.98$/t via NSR; 27.56$/t via Panama Suez scenario : 22.2 $/t via NSR; 34.16 $/t via Suez All costs before depreciation
1992	Wergeland	Same as Wergeland 1991.
2006	Arpiainen	With 5000 TEU ship, TEU unit cost is between 354$ and 526$ With 750 TEU ship, TEU unit cost is between 1244$ and 1887$
2006	Guy	Savings with the NWP over Suez vary from 33% (most optimistic case) to 14.2%; 8% or 4%, or even a loss of 1.05% in one intermediate scenario
2006	Juurmaa	Transport of oil by seaway : 12 euros/ton By pipeline: 20 euros/ton
2008	Borgerson	Savings up to 20% - from 17,5 M$ per trip to 14M$.
2010	Srinath	Polar routes display better profit margins for all three scenarios. Costs are inferior and revenues more important because of a higher turnover (more round trips).
2010	Liu	With an 85% rebate on official NSR fees, NSR is almost always more profitable than Suez, by 24% for a 9 month Arctic navigation and low bunker fuel cost. If bunker fuel costs increase, NSR can turn a profit for a 9 month Arctic shipping season, whereas shipping through Suez incurs a loss.
2011	Hua	NSR route saves between 3 to 5% of fuel cost
2011	Schøyen	NSR cheaper by 1.5%. NSR very fuel efficient in this scenario
2012	Falck	NSR route saves. Bulk ship: 839 000 $ LNG : 8 264 000 $
2013	Wergeland	At bunker cost of 500$/t, cost is cheaper with Arctic routes between 14.87$/t and 19.87$/t (general cargo); 16.13 $/t and 19.95$/t for container ship

Table 4. Conclusions of the simulations that conclude Arctic routes are not or may not be profitable.

Year	Lead author	Results
1996	Mulherin	Cost per trip: April. Norilsk class 528 850$; Lunni class 559 439$; Strekalovsky class 409 677 $ August. Norilsk class 347 945$; Lunni class 369 642 $; Strekalovsky class 275 470 $
1999	Kamesaki	Cargo volume is higher with NSR route, thus generates higher income costs, including high capital cost, are higher with NSR (comparison for 50000 dwt/Handymax). Overall: NSR 21,11$/ton, Suez (Handymax): 18,1$/ton
2001	Kitagawa	Same as Kamesaki1999
2007	Somanathan	On NY route, Panama is 8% cheaper. On St John's route, NWP is 10% cheaper.
2009	Verny	Cost per TEU: Suez : 1400–1800 $. NSR: 2500–2800 $. Trans-Siberian: 1800–2200$
2009	Dvorak	Total cost differential for Arctic shipping (fuel and capital) : A1 : +0,25%. A3 : +26,5%. A5: +152%
2009	Mejlaender-Larsen	Savings of Polar route appear: - in 2020 for ice-strengthened vessel but remain marginal (less than 3%) - around 2022 for the DAS ship, and reach 10% in 2050 - not before 2037 for the icebreaking option, and remain below 5% in 2050,
2009	Somanathan	NWP cheaper by 13$ per TEU(2,3%) for St-John's route. NWP more expensive by 84$ per TEU (15,5%) for NY route
2010	Chernova	Cost per TEU, NSR: between 1416 and 1133 $/TEU Suez: 979 $/TEU based on Liu and Kronbak for 4500 TEU
2010	DNV	2030. S1: Not competitive. S2: competitive for Northern Asian hubs (Tokyo) 2050. S1: Not competitive unless fuel costs above 900$/t S2: competitive for Tokyo; could be competitive for HK if high fuel cost and very long Arctic shipping season, low probability.
2011	Paterson	More costly by 75 000 to 175000 $ per trip to use NWP.

that it was possible to tailor another simulation that would capitalise on the knowledge accumulated through two decades of Arctic transit shipping modeling, and that would also try and take into account marketing constraints like the location of intermediate markets, reflected in the load factor, constraints repeatedly underlined by shipping firms (Lasserre and Pelletier 2011).

Designing a simulation drafting on past models

So as to capitalise on these scenarios, it is proposed to establish another simulation. As all models, it is prone to simplifications and works with estimates. I designed a scenario modelling a 4500 TEU containership based in Rotterdam and servicing Shanghai or Yokohama through the NSR or the NWP, competing with a similar ship going

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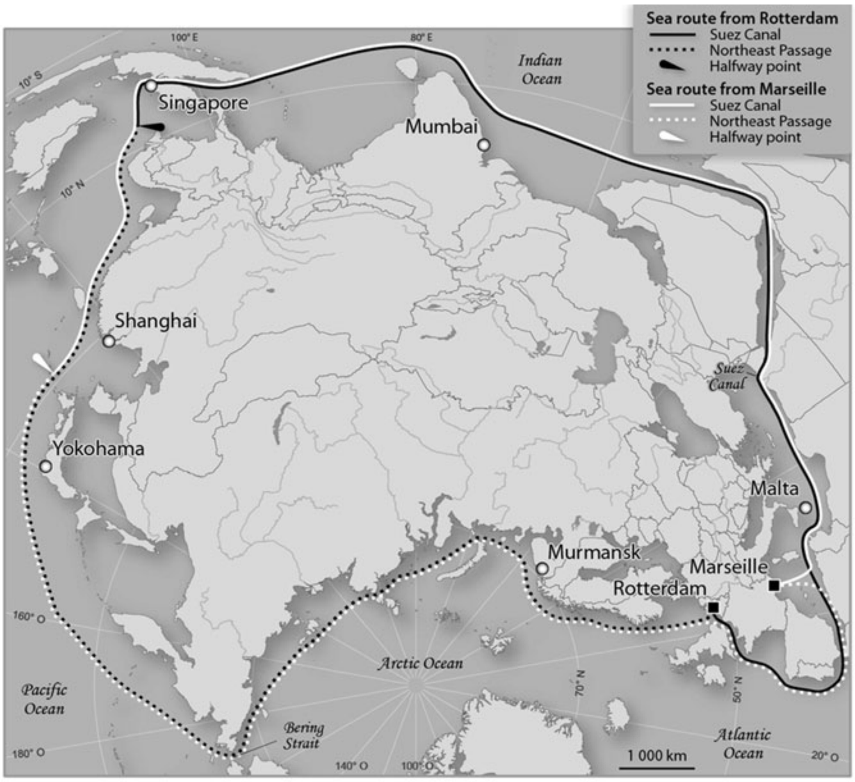

Fig. 1. Halfway point for sea routes along the NEP and across the Suez Canal, from Rotterdam and Marseille.

through Suez and stopping over at three intermediate ports, Malta, Mumbai and Singapore. Choosing a more southern destination is irrelevant, for then the distance across Arctic routes tends to surpass distances along the Suez route, depending on the origin point (see Fig. 1).

The first scenario considers summer shipping for a 6-month shipping season (an optimistic scenario given the present state of sea ice in spring and autumn), and a regular ship compared with an ice strengthened 1AS-class ship (Baltic classification system) plying the NSR. The second scenario is similar but the northern ship crosses the NWP. The third scenario displays year-round shipping across the NWP, with a heavy northern ship Polar Class 4 (IACS classification system; see Annex 1), similar in ice strengthening as the bulk ships used by Fednav to service Canadian mines in Labrador and northern Quebec, the MV *Arctic* and the MV *Umiak 1* (*Nunatsiaq Online* 2012). The goal of the simulation is to sketch an approximate cost of operation per transported TEU. The fourth scenario displays a 1AS ship crossing the NSR year-round: this is technically possible given the escort service provided by the Russian icebreakers.

I opted for an approach based not on the calculation of costs on a single leg: given the shorter distance, it is quite possible that these are lower than for the Suez route, although that must be checked. Such an approach emphasises a direct cost analysis per trip (as used by authors like Wergeland or Mulherin and others) but neglects the revenue issue: to what extent can a ship plying Arctic passages convert shorter distances into more revenue and/or, with lower costs, a higher profit? As a proxy for this question, I decided to study the direct costs compared with revenue-generating cargo over a whole season, or a complete year. Several authors already opted for such a methodology (Verny and Grigentin 2009; Somanathan 2009; Srinath 2010; Chernova and Volkov 2010, Arpiainen and Kiili 2006).

First scenario: Rotterdam-Asia across the NSR, summer navigation

Origin-destination

We first considered the couple Rotterdam-Shanghai, especially with regard to growing debate about China's interest in Arctic shipping. With the hypothesis of an average summer transit speed of 14 kts in the NSR, the distance Rotterdam-Shanghai is traveled in 20.6 days against 22.6 days via Suez with an average speed of 20 kts. We also considered Yokohama as a final destination, a more northerly port that favours the NSR over the Suez route. I also applied the model to the NWP.

NSR tariff

Obviously official tariffs are very restrictive for the NSR, especially for container cargo as the official rate (1048 Rb/ton, or 34$/t), is very high. Tschudi Shipping (Falck 2012) claims it used the NSR with a tariff of 5 $/t for iron ore, but such a low tariff (170 Rb/t) is

Table 5. First scenario, benchmark simulation. Summer transit with official NSR tariffs, Rotterdam-Shanghai. Period: 1 May – 1 November = 180 days

	NSR	Suez	
Distance, km	15 793	19 550	Calculated on GIS Mapinfo.
Load factor, eastbound	50%	75%	After Damas 2012
Load factor, westbound	70%	85%	
TEU transported per trip, eastbound	2250	3375	
TEU transported per trip, westbound	3150	3825	
Maintenance, days per 6 months	5	2	Somanathan, 2009 indicates 14 d/yr for PC4 in winter ice. Here, navigation conditions are much easier.
Suez canal delay		2	
Ports called at	1	4	Days in port: 2
Stop days at port, per leg	2	8	
Stop days, total	2	10	
Average sailing speed	17.71	20	NSR segment (south Novaya Zemlya, north New Siberian Is): 5635 km; Not NSR segment: 9787 km Average speed inside NSR: 14 kts; outside: 20 kts
Loop time			
Sailing time (days)	20.6	22.6	Of which in the NSR: 9.32
Total segment time	22.6	32.2	Sailing time + stop days on 180 days less maintenance days
Total possible segments during summer	7.73 Rounded at 8	5.46 Rounded at 6	
Total TEUs transported	21 600	21 600	
Cost analysis			(for 6 months)
Crew	858,000	780,000	Suez: Verny 2009 quote 100 000$ for a crew of 19. We worked with 23 people for the crew, www.fairship.com.ph; monthly cost about 130 000$ for 2012. NSR: +10%
Insurance: H&M, P&I	1,200,500	700,000	Somanathan 2009: 425,000$/yr for standard ship; Wergeland 2012: 339 450$/yr; Srinath 2010: 1,400,000$/yr. Conversely, Verny 2009 suggest 1,204,000$/yr for the NSR according to insurance sources. We therefore opted for a conservative 700,000$/yr value and a 50% premium (Srinath, DNV, Somanathan)
Capital cost	5,645,970	4,516,800	Suez: conventional 4500 TEU ship. At 90 M$ with 8% over 20 yrs, straight line depreciation method: 752 800$/month. NSR: 1AS 4500 TEU, with 20% construction premium (108M$), same depreciation, 940 995$/month.
Maintenance	360,000	300,000	Schøyen: +20%; Wegerland: +23%. Somanathan 2009 indicates 320 000$/yr. In 1992, Wegerland considered 1100$/d = 401 500$/y. We opted for 600 000$/y for 2012. Premium considered for NSR: +20%
Transit fees	11,016,000	1,440,000	NSR: 1048 Rb/t = 34$/t. Average loaded TEU weigth: 15t/TEU Suez: 240 000$/transit, Suez Canal Authority, www.suezcanal.gov.eg
Average transit fee per trip	1,377,000	240,000	

Table 5. Continued

	NSR	Suez	
Fuel consumption rate, tons/day	78.76	100	Guy 170 t/d; Verny & Grigentin 125 t/d for a 4000 TEU ship; Somanathan 83 t/d; Notteboom 90 t/d. We opted for 100 t/d. Consumption rate in the NSR: adjusted for speed. Wegerland (2012) uses formula as a function of cube of speed, but Notteboom & Vernimmen (2009) underline consumption rate stabilises at low speeds and stops decreasing. From their calculation, at 14 kts, 40 t/d. Besides, consumption increased by 8% because of ice-class. No overconsumption for friction with loose ice considered
Sailing days per segment	20.6	22.6	
Fuel consumed	1625.88	2262.73	
Bunker price, IFO 380, $/t	600	600	Average price in October 2012, according to Bunker Index, www.bunkerindex.com
Fuel cost per leg	975,525	1,357,639	
Fuel cost, total $	7,804,200	8,145,833	
Total cost, 6 months	26,884,670	15,882,633	
Cost per TEU	1,244.66	735.31	

Table 6. First scenario, benchmark simulation. Summer transit with official NSR tariffs, Rotterdam-Yokohama. Period: 1 May - 1 November = 180 days

	NSR	Suez	
Distance, km	13,400	21,200	Calculated on GIS Mapinfo.
Average sailing speed	16.95	20	NSR segment (south Novaya Zemlya, north New Siberian Is): 5635 km; Not NSR segment: 7765 km Speed inside NSR: 14 kts; outside: 20 kts
Loop time			
Sailing time (days)	18.3	24.5	Of which in the NSR: 9.32
Total segment time	20.3	34.5	Sailing time + stop days
Total possible segments during summer	8,62 Rounded at 9	5,15 Rounded at 5	
Total TEUs transported	24,750	17,775	
Cost analysis			
Crew	858,000	780,000	
Insurance: H&M, P&I	1,200,500	700,000	
Capital cost	5,645,970	4,516,800	
Maintenance	360,000	300,000	
Transit fees	12,622,500	1,200,000	
Average transit fee per trip	1,377,000	240,000	
Fuel consumption rate, tons/day	75.02	100	
Sailing days per segment	18.3	24.5	
Fuel consumed	1373.13	2453.70	
Bunker price, IFO 380, $/t	600	600	
Fuel cost per leg	823,875	1,472,222	
Fuel cost, total	7,414,875	7,361,111	
Total cost, 6 months	28,101,845	14,857,911	
Cost per TEU	1,135.43	835.89	

Table 7. First scenario, summer transit with discounted NSR tariffs, Rotterdam-Shanghai. Period: 1 May – 1 November = 180 days

	NSR	Suez	
Distance, km	15,793	19,550	Calculated on GIS Mapinfo.
Load factor, eastbound	50%	75%	
Load factor, westbound	70%	85%	
TEU transported per trip, eastbound	2250	3375	
TEU transported per trip, westbound	3150	3825	
Maintenance, days per 6 months	5	2	
Suez canal delay		2	
Ports called at	1	4	Days in port: 2
Stop days at port, per leg	2	8	
Stop days, total	2	10	
Average sailing speed	17.71	20	
Loop time			
Sailing time (days)	20.6	22.6	Of which in the NSR: 9,32
Total segment time	22.6	32.2	Sailing time + stop days on 180 days less maintenance days
Total possible segments during summer	7.73 Rounded at 8	5.46 Rounded at 6	
Total TEUs transported	21,600	21,600	
Cost analysis			
Crew	858,000	780,000	
Insurance: H&M, P&I	1,200,500	700,000	
Capital cost	5,645,970	4,516,800	
Maintenance	360,000	300,000	
Transit fees	2,656,800	1,440,000	NSR: 252 Rb/t = 8,2$/t. About 15t/TEU Suez: 240 000$/transit, www.suezcanal.gov.eg
Average transit fee per trip	1,377,000	240,000	
Fuel consumption rate, tons/day	78.76	100	
Sailing days per segment	20.6	22.6	
Fuel consumed	1625.88	2262.73	
Bunker price, IFO 380, $/t	600	600	
Fuel cost per leg	975,525	1,357,639	
Fuel cost, total	7,804,200	8,145,833	
Total cost, 6 months	18,525,470	15,882,633	
Cost per TEU	857.66	735.31	

nowhere to be found in updated NSR tariffs, in which bulk cargo is rather priced at 707 Rb/t (NSR Administration 2011: it is likely Russian authorities negotiate *ad hoc* tariffs so as to be competitive, a hypothesis confirmed by Tschudi Shipping itself when asked about its case (Ulf Hagen, Managing Director, Tschudi Arctic Transit, personal communication, 23 October 2012). If such a policy induces a reduction in Suez traffic, it is likely that Suez Canal Authorities will lower their own tariffs so as to remain competitive. Falck also quotes the likely Suez fees at 180 000 $, but the Suez Canal authority online toll calculator gives a tariff of 90 000 $ (Suez Canal Authority 2012). Verny and Grigentin (2009) assume NSR tariffs are likely to remain double that of Suez, but this would already be an improvement over official tariffs. This assumption would be in line with the calculation I made about the Suez tariff in the Tschudi/Falck simulation. However, so as to reflect the adaptability and marketing efforts of Russian authorities, I established a variant scenario in which NSR tariffs for container cargo represent the same reduction as that applied for Tschudi Arctic Transit with bulk cargo: 252 Rb/t, or 8,2 $/t (Falck 2012; NSR Administration 2012). Such a discounted tariff (76% discount from the official tariff) would be 38% above the official Suez rate, with a moderate hypothesis of an average container weight of 15 tons; (max. 28 t according to NYK (2012).

Load factor

Most models consider the market opportunities are the same for a ship stopping over at several busy ports along the Panama or Suez routes as for a ship loading only once: there are no intermediate ports in the Arctic. Several shipping firms mentioned this point during the

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Table 8. First scenario, summer transit with discounted NSR tariffs, Rotterdam-Yokohama. Period: 1 May – 1 November = 180 days

	NSR	Suez	
Distance, km	13,400	21,200	Calculated on GIS Mapinfo.
Average sailing speed	16.95	20	NSR segment (south Novaya Zemlya, north New Siberian Is): 5635 km; Not NSR segment: 7765 km Speed inside NSR: 14 kts ; outside: 20 kts
Loop time			
Sailing time (days)	18.3	24.5	Of which in the NSR: 9.32
Total segment time	20.3	34.5	Sailing time + stop days
Total possible segments during summer	8.62 Rounded at 9	5.15 Rounded at 5	
Total TEUs transported	24,750	17,775	
Cost analysis			
Crew	858,000	780,000	
Insurance: H&M, P&I	1,200,500	700,000	
Capital cost	5,645,970	4,516,800	
Maintenance	360,000	300,000	
Transit fees	3,044,250	1,200,000	NSR: 252 Rb/t = 8,2$/t. About 15t/TEU Suez: 240 000$/transit, www.suezcanal.gov.eg
Average transit fee per trip	1,377,000	240,000	
Fuel consumption rate, tons/day	75.02	100	
Sailing days per segment	18.3	24.5	
Fuel consumed	1373.13	2453.70	
Bunker price, IFO 380, $/t	600	600	
Fuel cost per leg	823,875	1,472,222	
Fuel cost, total	7,414,875	7,361,111	
Total cost, 6 months	18,523,595	14,857,911	
Cost per TEU	748.43	835.89	

survey we carried (Lasserre and Pelletier 2011). So as to reflect this market reality, which none of the models considered tries to depict, and the fact that container traffic is much more sustained from Asia than to Asia (UNCTAD 2012: 23–24; Damas 2012), I set the load factor at 85% (Asia to Europe) and 75% (Europe to Asia) for the Suez route, and 70% and 50% for the Arctic route.

From this benchmark scenario, based on official NSR fees, it is apparent that:

Indeed the ship plying arctic waters can make more rotations, but not necessarily a lot more TEUs given the lower load factor,

Fuel consumption is much reduced per leg along the NSR. The total fuel cost may look similar, but this is because the ship plying the NSR route can make more rotations than the ship going through Suez and Malacca.

NSR tariffs make the NSR option largely unprofitable, as already mentioned by several firms (Lasserre and Pelletier 2011) and confirmed by Hagen as already quoted (Table 5, 6).

Of course, this scenario is largely fictional as it appears that the NSR Administration is keen on offering attractive tariffs if the shipping company pledges to use the route on a regular basis, which is consistent with liner service. I therefore adapted the scenario to a situation where, as exposed above, NSR tariffs are much lower.

In this sub-scenario (Tables 7, 8), it appears that, despite a much discounted NSR tariff, the service to Shanghai is not competitive against a classical liner service through Suez; however, a service to Yokohama is, despite the lower load factor.

If the service across the NSR could manage a similar load factor as through Suez and Malacca, then the cost per TEU to Shanghai would drop to 674$, making it competitive against the classical route (8% cheaper), but this possibility, as discussed above, is seriously challenged by shipping firms themselves.

Fuel economies are often depicted as the main cost advantage of Arctic routes. The scenario works with the October 2012 IFO 380 cost of 600$/metric ton. If fuel cost was to increase to 1000$/t with the lower load factor constraint, then the total cost per TEU on the Shanghai route would be 1098.53$ with the NSR and 986,72$ through Suez, and thus remain uncompetitive: fuel cost is not, in itself, a factor so important as to be

Table 9. Second scenario, summer transit across the NWP, Rotterdam-Shanghai. Period: 1 May – 1 November = 180 days

	NWP	Suez	
Distance, km	16,384	19,550	Calculated on GIS Mapinfo, NWP across McClure Strait.
Load factor, eastbound	50%	75%	
Load factor, westbound	70%	85%	
TEU per trip, eastbound	2250	3375	
TEU per trip, westbound	3150	3825	
Maintenance, days per 6 months	5	2	
Suez canal delay		2	
Ports called at	1	4	Days in port: 2
Stop days at port, per leg	2	8	
Stop days, total	2	10	
Average sailing speed	16.94	20	NWP segment (from southern Greenland to Bering Strait): 5500 km; Not NWP segment: 10,884 km Average speed inside NWP: 13 kts; outside: 20 kts
Loop time			
Sailing time (days)	22.4	22.6	Of which in the NWP: 9.79
Total segment time	24.4	32.6	Sailing time + stop days on 180 days less maintenance days
Total possible segments during summer	7.17 Rounded at 7	5.46 Rounded at 6	
Total TEUs transported	18,450	21,600	
Cost analysis			
Crew	858,000	780,000	Same cost for NSR and NWP.
Insurance: H&M, P&I	1,115,000	700,000	For the NWP, the risk is higher : 65% premium
Capital cost	5,645,970	4,516,800	Same type of ship for the NSR and the NWP
Maintenance	360,000	300,000	Same as for the NSR
Transit fees		1,440,000	Suez: 240 000$/transit, www.suezcanal.gov.eg
Average transit fee per trip		240,000	
Fuel consumption rate, tons/day	79.18	100	At 13 kts, 39 t/d
Sailing days per segment	22.4	22.6	
Fuel consumed	1773	2262.73	
Bunker price, IFO 380, $/t	600	600	
Fuel cost per leg	1,063,800	1,357,639	
Fuel cost, total	7,446,800	8,145,833	
Total cost, 6 months	15,465,570	15,882,633	
Cost per TEU	838.24	735.31	

able to overcome market issues such as the load factor. This conclusion is still valid with the NWP scenario, see below.

Second scenario: Rotterdam-Asia across the NWP, summer shipping

The second scenario examines summer shipping across the NWP. Most parameters remain the same. However, the distance is a longer than with the NSR; fog, icebergs and drifting ice are more prevalent than along the NSR (Lasserre 2010) and contribute to reduce the average speed, 13 kts in this simulation in the NWP against 14 kts with the NSR, which is already optimistic for the present time given the fact the period considered lasts from May to November. There is still much ice in June; this factor as well as the absence of ports and of numerous icebreakers to assist in case of accident justify an increased insurance premium. However, I decided not to try and model the increased consumption due to friction with ice and considered that loose ice had a marginal impact on consumption rates (Tables 9, 10).

Despite the absence of tariffs (for the present time) on NWP transits, it appears a regular service between Rotterdam and Shanghai remains more costly to operate per TEU than via Suez and Malacca: more rotations are possible thanks to the route being shorter, but this advantage does not translate into more affordable costs per TEU since the load factor is lower for the Arctic route.

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Table 10. Second scenario, summer transit across the NWP, Rotterdam-Yokohama. Period: 1 May - 1 November = 180 days

	NWP	Suez	
Distance, km	14,470	21,200	Calculated on GIS Mapinfo, NWP across McClure Strait.
Load factor, eastbound	50%	75%	
Load factor, westbound	70%	85%	
TEU per trip, eastbound	2250	3375	
TEU per trip, westbound	3150	3825	
Maintenance, days per 6 months	5	2	
Suez canal delay		2	
Ports called at	1	4	Days in port: 2
Stop days at port, per leg	2	8	
Stop days, total	2	10	
Average sailing speed	16.6	20	NWP segment (from southern Greenland to Bering Strait): 5500 km; Not NWP segment: 8 970 km Average speed inside NWP: 13 kts ; outside: 20 kts
Loop time			
Sailing time (days)	20.2	24.5	Of which in the NWP: 9.79
Total segment time	22.2	34.5	Sailing time + stop days on 180 days less maintenance days
Total possible segments during summer	7.89 Rounded at 8	5.15 Rounded at 5	
Total TEUs transported	21,600	17,775	
Cost analysis			
Crew	858,000	780,000	Same cost for NSR and NWP.
Insurance: H&M, P&I	1,115,000	700,000	For the NWP, the risk is higher : 65% premium
Capital cost	5,645,970	4,516,800	Same type of ship for the NSR and the NWP
Maintenance	360,000	300,000	Same as for the NSR
Transit fees		1,440,000	Suez: 240,000$/transit, www.suezcanal.gov.eg
Average transit fee per trip		240,000	
Fuel consumption rate, tons/day	76.02	100	At 13 kts, 39 t/d
Sailing days per segment	20.2	24.5	
Fuel consumed	1,533.75	2,453.7	
Bunker price, IFO 380, $/t	600	600	
Fuel cost per leg	920,250	1,472,222	
Fuel cost, total	7,362,000	7,361,111	
Total cost, 6 months	15,380,970	14,857,911	
Cost per TEU	712.08	835.89	

If the load factor was the same as the Suez route, the cost per TEU would be 619 $/TEU, thus cheaper by 15.8% than the alternate route via Suez. The break-even point as regards the load factor could be, for instance, 61% on westbound legs (Europe to Asia) and 75% on eastbound legs (Asia to Europe), with a cost per TEU of 732.79$ compared to 735.31$.

A service to Yokohama, however, as with the NSR, displays much lower costs per TEU: it would be 14.8% cheaper despite the difference in load factor; with a load factor of 61/75%, the cost per TEU would drop to 628.31$ compared to 835.89$, thus 24.8% cheaper. However, if the average speed across the NWP dropped to 9 kts instead of 13 kts, then the cost per TEU would increase to 825.51 $, or just 1.2% cheaper than with the Suez route.

Third scenario: Rotterdam-Yokohama across the NWP, year-round shipping

I also decided to test the assumption that year-round shipping could be profitable for a liner service across the NWP (Table 11). Parameters are more difficult to simulate here, as average speed is inherently different in winter and summer. Navigating the NWP in winter is no longer technically impossible for commercial ships, and Fednav opted for year-round shipping scenarios to service mines in the Canadian Arctic: Voisey's Bay (northern Labrador), Deception Bay (northern Quebec),

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Table 11. Third scenario, year-round transit across the NWP, Rotterdam-Yokohama.

	NWP	Suez	
Distance, km	14,470	21,200	Calculated on GIS Mapinfo, NWP across McClure Strait.
Load factor, eastbound	50%	75%	
Load factor, westbound	70%	85%	
TEU tper trip, eastbound	2250	3375	
TEU tper trip, westbound	3150	3825	
Maintenance, days per year	14	4	Somanathan, 2009 indicates 14 d/yr for PC4 used in winter ice
Suez canal delay		2	
Ports called at	1	4	Days in port: 2
Stop days at port, per leg	2	8	
Stop days, total	2	10	
Average sailing speed, summer	16.6	20	NWP segment (from southern Greenland to Bering Strait): 5 500 km; Not NWP segment: 8 970 km Average speed inside NWP: 13 kts ; outside: 20 kts
Average sailing speed, winter	11.72	20	Average speed inside NWP: 7 kts ; outside: 20 kts
Loop time			
Sailing time in summer (days)	20.2	24.5	Of which in the NWP: 9,79
Total segment time, summer	22.2	34.5	Sailing time + stop days on 180 days less maintenance days
Total possible segments during summer	7.80 Rounded at 8	5.15 Rounded at 5	
Sailing time in winter (days)	28.6	24.5	Of which in the NWP: 18.19
Total segment time, winter	30.6	34.5	
Total possible segments during winter	5.66 Rounded at 6	5.15 Rounded at 5	
Total TEUs transported	37,800	36,000	
Cost analysis			(Over 12 months)
Crew	1,794,000	1,560,000	Suez: 23 people for the crew, www.fairship.com.ph. Monthly cost about 130, 000$. NWP: +15% because of winter operations
Insurance: H&M, P&I	2,520,000	1,400,000	For the NWP year-round, the risk is higher : 80% premium
Capital cost	11,743,000	9,033,552	Suez : conventional 4500 TEU ship: at 90 M with 8% over 20 yrs, straight line depreciation method: 752 796$/month NWP: PC4 4500 TEU, with 30% construction premium (117M$), same depreciation, 11 743 000 $/yr
Maintenance	1,500,000	600,000	Somanathan 2009 indicates 320 000$/yr for standard ship maintenance and 800 000$/yr for PC4. Since we opted for 600 000$/yr as the budget for a normal standard ship, we keep the same value for it and the proportion for the PC4 ship.
Transit fees		2,400,000	Suez: 240 000$/transit, www.suezcanal.gov.eg; 10 possible legs
Fuel consumption rate, summer, tons/day	80.95	100	At 13 kts, summer shipping, 39 t/d. Consumption increased by 15% because of PC4 ice-class + double shaft. No overconsumption for friction with loose ice considered

Table 11. Continue

	NWP	Suez	
Fuel consumption rate, winter, tons/day	126.26	100	Dvorak underlines consumption increases fast when using power to break ice (+46% for a PC3 at nominal power). At 7 kts when navigating in heavy ice, 120 t/d Besides, consumption increased by 12% because of PC4 ice-class + double shaft
Sailing days per segment, summer	20.2	24.5	
Fuel consumed per leg, summer	1633.16	2453.70	
Sailing days per segment, winter	28.6	24.5	
Fuel consumed per leg, winter	3607.22	2453.70	
Bunker price, IFO 380, $/t	600	600	
Bunker price, P50, $/t	822		37% premium over IFO380
Average fuel cost per ton, NWP, winter	741.33		Calculated as proportional to Arctic/non Arctic segments
Fuel cost per trip, summer	979,896	1,472,222	
Fuel cost per trip, winter	2,674,134	1,472,222	
Fuel cost, summer	7,839,167	7,361,111	
Fuel cost, winter	16,044,801	7,361,111	
Fuel cost, total	23,883,968	14,722,222	
Total cost, 12 months	42,766,462	29,715,774	
Cost per TEU	1,096.32	825.44	

and eventually Milne Inlet (Baffin Island). It however requires a higher ice class and a double shaft for more power to break ice since the scenario assumes here there is no icebreaker escort; to simulate one would probably imply tariffs as are charged for the NWP. I opted for a PC4 ship, similar to those already used by Fednav. This entails a significant increase in fuel consumption rate since breaking ice requires huge power. I tried to balance the increased fuel consumption rate due to used power and double shaft propulsion, with the reduced fuel consumption rate due to lower speed when ice is not too solid. For simplification purposes, winter was set at 1 November until 1 May. Specific fuel is mandatory in the winter season to cope with polar temperatures.

It appears that offering a liner service year-round is definitely not profitable, even across the NWP for a high ice-class container ship. The main potential advantage of the Arctic route, fuel consumption (Schøyen and Bråthen 2011) does not materialise as winter navigation requires much more power. Insurance costs are more important, a ship navigating the NWP alone in the winter without ports to stopover bears a higher risk, and potential speed is not high enough to make more rotations that could compensate for the higher general costs (insurance, crew, maintenance). If the load factor was the same as with Suez (75/85%), then the cost per TEU would be similar, 822.24 $ or 0.4% cheaper for the NWP route. If the load factor was the same but the average winter speed dropped to 5 kts instead of 7 kts, then the average TEU cost would be 918.23 $, or 11.2% more expensive than the Suez route.

Fourth scenario: Rotterdam-Yokohama across the NSR, year-round shipping

In this scenario (Table 12), because of the icebreaker service offered by the NSR administration, the same type of ship as in the summer is assumed fit for winter transit, thus reducing capital costs as well as fuel consumption, since the icebreaking is ensured by the icebreakers. Transit fees will apply however, and transit speed will remain low, for if they are powerful, the icebreakers do not necessarily progress faster than a strong PC4 commercial ship; and second, because of possible damage against huge chunks of broken ice, the 1AS ship cannot afford a much higher speed.

It turns out the winter route along the NSR, even to Yokohama which is a profitable destination in the summer, is not when compared to the Suez route: the number of rotations is too low to make up for the increased costs due to winter shipping (crew, higher fuel cost, insurance, maintenance). The break-even point is reached if the load factor reaches 61/74% for instance. But if speed across the NSR drops to 5 kts, the break-even point will increase to a load factor couple of 66/79%.

If fuel costs increased to 1000$/t for IFO380 (and 1370$/t for P50), then the cost per TEU would still be

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Table 12. Fourth scenario, year-round transit across the NSR, Rotterdam-Yokohama.

	NSR	Suez	
Distance, km	14,470	21,200	Calculated on GIS Mapinfo, NWP across McClure Strait.
Load factor, eastbound	50%	75%	
Load factor, westbound	70%	85%	
TEU per trip, eastbound	2250	3375	
TEU per trip, westbound	3150	3825	
Maintenance, days per year	10	4	10 days for a demanding navigation in winter
Suez canal delay		2	
Ports called at	1	4	Days in port: 2
Stop days at port, per leg	2	8	
Stop days, total	2	10	
Average sailing speed, summer	16.95	20	NSR segment (south Novaya Zemlya, north New Siberian Is): 5635 km; Not NSR segment: 7765 km Speed inside NSR: 14 kts; outside: 20 kts
Average sailing speed, winter	11.23	20	Average speed inside NSR: 7 kts; outside: 20 kts
Loop time			
Sailing time in summer (days)	18.3	24.5	Of which in the NSR: 9.32
Total segment time, summer	20.3	34.5	Sailing time + stop days on 180 days less maintenance days
Total possible segments during summer	8.62 Rounded at 9	5.15 Rounded at 5	
Sailing time in winter (days)	27.6	24.5	Of which in the NSR: 18,63
Total segment time, winter	29.6	34.5	
Total possible segments during winter	5.91 Rounded at 6	5.15 Rounded at 5	
Total TEUs transported	40,950	36,000	
Cost analysis			(Over 12 months)
Crew	1,794,000	1,560,000	Suez: 23 people for the crew, www.fairship.com.ph. Monthly cost about 130 000$. NSR: +15% because of winter operations
Insurance: H&M, P&I	2,310,000	1,400,000	For the NSR year-round, the risk is higher than in the summer: 65% premium
Capital cost	11,291,940	9,033,552	Suez : conventional 4500 TEU ship: at 90 M with 8% over 20 yrs, straight line depreciation method: 752 800$/month NSR: 1AS 4500 TEU, with 20% construction premium (108M$), same depreciation, 940 995 $/month
Maintenance	750,000	600,000	Premium considered: +25% for winter
Transit fees	5,036,850	2,400,000	NSR: 252 Rb/t = 8,2$/t. About 15t/TEU Suez: 240,000$/transit, www.suezcanal.gov.eg
Fuel consumption rate, summer, tons/day	75.02	100	At 14 kts, summer shipping, 40 t/d. Consumption increased by 8% because of 1AS/PC6 ice-class No overconsumption for friction with loose ice considered.
Fuel consumption rate, winter, tons/day	67.93	100	At 7 kts when navigating in heavy broken ice, 45 t/d.
Sailing days per segment, summer	18.3	24.5	
Fuel consumed per leg, summer	1373.13	2453.70	

Table 12. Continue

	NSR	Suez	
Sailing days per segment, winter	27.6	24.5	
Fuel consumed per leg, winter	1876.25	2453.70	
Bunker price, IFO 380, $/t	600	600	
Bunker price, P50, $/t	822		37% premium over IFO380
Average fuel cost per ton, NSR, winter	741.33		Calculated as proportional to Arctic/non Arctic segments
Fuel cost per trip, summer	823,875	1,472,222	
Fuel cost per trip, winter	1,406,751	1,472,222	
Fuel cost, summer	7,414,875	7,361,111	
Fuel cost, winter	8,440,507	7,361,111	
Fuel cost, total, $	15,855,382	14,722,222	
Total cost, 12 months	37,038,172	29,715,774	
Cost per TEU	904.47	825.44	

Table 13. Parameters that favour Arctic or Suez routes in the scenarios

The values of these parameters favour either Arctic or the Suez route :	
Arctic routes	Suez route
Average speed set at 14 kts for the NSR and 13 kts in the NWP for the whole summer. For now (2012), these are average speeds that can be reached only during a few weeks in August, September and early October.	Load factor, set according to the literature and reflecting the fears of the shipping industry.
Average speed set at 7 kts in the NWP and NSR for the whole winter. This is an optimistic speed for progression when breaking thick ice, even first-year.	Conservative insurance premiums for the Arctic, based on the literature
No friction effect of loose but dense ice in summer on fuel consumption rate considered.	
No indirect cost taken into account, notably the management of twice yearly change of schedules for summer Arctic navigation scenarios.	
No indirect cost and penalty linked to potential delays caused by drifting ice, icebergs, and unpredictable patterns of ice melt in spring and reformation in autumn. It is anyway very difficult to quantify such a parameter.	

greater for the NSR option, at 1162.60$ for the NSR with the lower load factor and 1098.07$ for Suez. Here again, higher fuel costs alone cannot ensure a profitable NSR option unless prices rocket up: prices per TEU are similar only when prices reach 2500$/t . . .

Criticism on the value of parameters

As a critical look on the proposed simulation, some parameters may favour the Arctic or the Suez routes. Table 13 summarises the main biases the chosen parameters introduce.

Conclusion

Many models have been published trying to assess the potential profitability of commercial shipping along Arctic routes, mostly to study transit shipping. A relative majority concluded the Arctic routes are likely to be profitable. However, the assumptions, simplifications inherent to any modelling differ widely.

I built up, using partial conclusions from the set of studied models, a new model in which I tried to take into account market considerations, something that is less prevalent in past models that usually focus of cost-analysis. This methodological approach is also justified by conclusions of a large survey conducted with the shipping industry (Lasserre and Pelletier 2011).

It appears that:

1. Official Russian tariffs for the NSR make any route prohibitively expensive; but the Russian authorities do intend to enforce a very flexible real tariff so as to attract business.
2. Summer transit to Shanghai is usually not cost-competitive for a liner service, unless fuel costs are higher and, more strategically, the load factor

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is much improved. Fuel costs in themselves are not important enough to account for the profitability of Arctic routes.

3. Transits to Yokohama, however, are more profitable with Arctic routes, along both the NSR and the NWP, despite lower load factors. However, if transit speed along the Arctic segments proved to be slower than assumed in this simulation, it would question the profitability of the service.
4. Year-round liner service is never profitable, even to Yokohama, neither along the NWP with a dedicated powerful PC4 ship, nor with a 1AS ship along the NSR with an icebreaker escort.
5. Rather than being directly dependent on the variable of fuel cost, the profitability of Arctic routes depend on average transit speed, that determine the number of possible rotations, and on the load factor, underlining the importance for shipping companies of securing a large enough market for a direct transit route to make a profit.

The simulation thus indirectly confirms fears many expressed during the survey we conducted: without a strong load factor, Arctic routes will hardly be profitable.

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Annex 1. Approximate equivalence of ice class classification systems

				Ice-breaking ships					Ice-strengthened ships			
Baltic								1AS	1A	1B	1C	II
Russian, old rules												
Commercial vessel							ULA	ULA-UL	UL	L1	L2	L3
icebreaker				LL1	LL2	LL3		LL4				
Russian, current rules												
commercial vessel					LU9	LU7/LU8	LU6	LU5	LU4	LU3	LU2	LU1
icebreaker				LL9	LL8	LL7		LL6				
Lloyd's Register	LR3	LR2		LR1.5		LR1		1AS	1A	1B	1C	1D
Canadian Arctic Shipping - CASPPR		CAC 1		CAC 2	CAC 3	CAC 4		A	B	C	D	E
IACS - International Association of Classification Societies			PC1	PC2	PC3	PC4	PC5	PC6	PC7			
American Bureau of Shipping		A5		A4	A3		A2	A1	A0	B0	C0	D0

Sources: Appolonov and others 2006; Lamb 2004, International Association of Classification Societies 2006, Bridges (2004), Lloyd's Register (London) 7 September 2004; Eyres 2001; National Research Council 2007.

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