



Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra



Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector



Frédéric Lasserre *

Department of Geography, Laval University, 2405 Terrasse St, Abitibi Price Building, Québec, QC G1V 0A6, Canada

ARTICLE INFO

Article history:

Received 15 November 2012
Received in revised form 2 May 2014
Accepted 11 May 2014
Available online 10 June 2014

Keywords:

Arctic shipping
Model
Simulation
Profitability
Northern Sea Route
Northwest Passage

ABSTRACT

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

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

In the summers of 2012 and 2013, several events attracted the interest of observers regarding Arctic navigation. Transit traffic along the Northern Sea Route (NSR) was performed by 46 ships in 2012 and 71 in 2013 (official figures, NSRA 2013). In the summer of 2012, the cruise ship *MS The World* transited the Northwest Passage (NWP) with 508 passengers, and in August 2013, the coal bunker *Nordic Orion* transited the NWP as well between Vancouver and Europe.

In the frame 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 XVIth–XIXth 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 Soviet Union, by dint of huge investments in Arctic ports and heavy icebreakers in the frame of a centrally planned economy, did Arctic shipping develop before the effects of climate change, only to collapse sharply after the demise of the Soviet Union and slowly recovering recently.

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, 2010a), 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. Arctic ice has been thinning for the past 25 years, an impact related to the warming of the Canadian north. The technology to navigate Arctic waters is available, but the critical question is whether on a commercial basis the Arctic passages are competitive with classical routes, the Panama Canal or the Suez Canal routes. The melting of sea ice did not merely reactivate ancient ambitions about transportation in the Arctic, but immediately

* Tel.: +1 418 656 2131/12435; fax: +1 418 656 3960.

E-mail address: Frederic.lasserre@ggr.ulaval.ca

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, 2010a): international straits, as claimed by the United States or the European Union? 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 experts' analyses do not converge (Howell and Yackel, 2004; Gedeon, 2007; Loughnane, 2009; Lasserre, 2011).

It is in this context of renewed interest, from the media, the governments and the business circles that models have been designed to try and assess the economic feasibility of commercial shipping along Arctic routes. Compared to the traditional routes mentioned above, shipping through the Arctic could obviously save sailing distance. The issue proved not to be technical any more: with powerful icebreakers and, more recently, the advent of double-acting ships (DAS), navigation across ice that, on the other hand, is thinner and thinner as years go by and see multiyear ice melt, is no longer an engineering difficulty, but rather a business case problem (Niini et al., 2007; Lasserre, 2010b). Several models tried to address the following question: to what extent would shipping in these waters be profitable?

Twenty-six models, published between 1991 and 2013, have been analyzed in this paper. The study underlines the difficulty of defining credible parameters to build up a model that could assess the profitability of Arctic shipping. Capitalizing on these models, the author also tried 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 capitalize on their teachings to set up a new model that would take into account operational issues.

2. 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. Echoing Soviet attempts at revitalizing the seaway, following President Mikhail Gorbachev's Murmansk Initiative of October 1st, 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, contrary to 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 Northern Sea Route (NSR), a project that, besides Russia, interested Japan and Norway very much. Tor *Wergeland's early 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 analyzed are indeed reflections of research programs that were carried on since the early 1990s so as to assess the feasibility and profitability of shipping in the Arctic. These research programs include INSROP (1993–1999, mainly funded by Japan, Norway and Russia, studying the Northern Sea Route); 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 emphasized the NSR as a potential transit route and gateway to Russian resources.

2.1. General portrait of the models: a large diversity of approaches and methods

It is climate change that renewed interest in modeling Arctic shipping. Twenty-six simulations have been identified and analyzed: 9 articles from journals; 8 technical reports; 2 book chapters; 4 conference communications and 3 Master's theses. They were published between 1991 and 2013, but 20 were published in or after 2006, attesting to the renewed interest in Arctic shipping in the climate change context. Three tackle with destination traffic (i.e., shipping going to/from the Arctic for the exploitation of natural resources: Juurmaa, 2006; Cho 2012 and Falck, 2012), while the 23 others are interested in transit shipping. The majority displays the study of container traffic (18); 8 address bulk shipping (LNG, tanker, dry bulk), and 4 are interested in general cargo. Six studies did not consider ice-class vessels; five simulated an ice-class vessel without specifying which class. One considered a 1B ice-class vessel¹; 6 either a 1A (PC7) or a 1AS (PC6) ice-class; one seemed to consider a PC5 vessel, and 8 envisioned a PC4 vessel or higher. Besides, 3 models considered DAS ships.

Reflecting both the early development of traffic along the NSR and the presence of infrastructure to facilitate present shipping (ports, numerous icebreakers), most tackle with the profitability of shipping in the NSR (20); 8 consider the Northwest Passage (NWP), 3 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 (19), Panama (5) and the Trans-Siberian rail link (1) (Table 1).

¹ In the Baltic ice-class system; for equivalences, see Annex 1.

Table 1
Models of Arctic shipping considered for the review, 1991–2013.

Year	Authors	Title	Medium	Objective	Route	Type of ship	Origin–destination	Time window of navigation considered
1991	Wergeland, T. et al.	The Northern Sea Route Project	<i>Pilot Studies Report</i> , Willy Østreng & Arnfinn Jørgensen-Dahl (ed.), Lysaker: FNI	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, T.	The Northern Sea Route - Rosy prospects for commercial shipping	<i>International Challenges</i> , 12(1): 43–57,	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, N. et al.	Development and Results of a Northern Sea Route Transit Model	<i>CRREL Report 96–5</i> , US Army corps of Engineers, Hanover, NH	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- Strekalovskiy-class bulk, UL ice-class = PC7	Murmansk - Bering Strait	April to October
1999	Kamesaki, K., Kishi, S., Yamauchi, Y.	Simulation of NSR Navigation Based on Year Round and Seasonal Operation Scenarios	<i>INSROP Working Paper 8</i> . Oslo:WP-164	Compare transportation costs for yearly service. Ships can ply both routes depending on ice conditions	NSR, Suez	Handy max 50,900 dwt for Suez route (general cargo) Three ice-class ship types for the NSR route: 25,000 dwt with “high ice-class” (“ULA?” = PC4-PC5) (general cargo) - 40,000 dwt with “high ice class” (“ULA?” = PC4-PC5) (general cargo)- 50,000 dwt with “medium ice class” (“UL” = PC7) (bulk)	Hamburg - Yokohama	Year-round
2001	Kitagawa, H.	The Northern Sea Route. The shortest sea route linking East Asia and Europe	Ship and Ocean Foundation, Tokyo	Same as Kamesaki et al. (1999)	NSR, Suez	Same as Kamesaki et al. (1999)	Hamburg – Yokohama	Year-round
2005	Griffiths, F.	New illusions of a Northwest Passage,	Nordquist, M., Moore, J. N. and Skaridov, A. S., <i>International Energy Policy, the Arctic and the Law of the Sea</i> , Report K-63, Aker Arctic Technology, Helsinki	Assess costs, risks and opportunities	NWP, Suez	2400 TEU conventional container ship	Yokohama – Rotterdam	Summer transit
2006	Arpiainen, M. and Kiili, R.	Arctic shuttle container link from Alaska US to Europe		Find operation costs per TEU	NSR	750 TEU container ship DAS5000 TEU container ship DASLU8 or 9, PC4 to 3	Arctic shuttle service, Reykjavik–Adak (Aleutians)	Year-round
2006	Guy, E.	Evaluating the viability of commercial shipping in the Northwest Passage	<i>Journal of Ocean Technology</i> , 1(1), 9–15.	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, K.	Arctic Operational Platform: Integrated Transport System	ARCOP Final Report. Helsinki: Aker Finnyards Inc	Compare transportation costs for oil to Europe: destination shipping	NSR; pipelines across Russia and northern Europe	Oil tanker versus oil pipeline	Varandei – Rotterdam	Year-round Several scenarios
2007	Somanathan, S. et al.	Feasibility of a Sea Route through the Canadian Arctic	<i>Maritime Economics & Logistics</i> , 9, 324–334.	Compare operation costs per TEU for regular service	NWP; Suez	4500 TEU Container shipCAC3/PC2	Yokohama – New-YorkYokohama – St John's	Year-round
2008	Borgerson, S.	Arctic Meltdown	<i>Foreign Affairs</i> , 87(2), p.63–77.	Assess transportation costs, single trip	NWP; Panama; Suez	Large container ship; apparently, conventional	Rotterdam – Yokohama, Seattle – Rotterdam	Unspecified
2009	Dvorak, R.	Engineering and Economic Implications of Ice-Classed Containerships	MSc Dissertation, MIT	Find specific ship costs for year-round operation in Arctic waters	No specific route studied	Container ship, 5000 TEUA1/1AS/PC6A3/PC3A5/PC1	NoneObjective is to determine the cost to exploit the ship	Not specified
2009	Mejlaender-Larsen, M.	ARCON - Arctic Container	<i>DNV Container Ship Update</i> , 2, 9–11,	Compare transportation costs for regular service	Polar and Suez	8600 TEU container ship;- conventional for Suez- for Arctic navigation, three cases: ice-strengthened (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, S. et al.	The Northwest Passage: a simulation	<i>Transportation Research Part A</i> , 43, 127–135.	Assess costs of regular service on the NWP route	NWP; Panama	4500 TEU Container shipCAC3/PC2	Yokohama – New – YorkYokohama – St John's	Year-round
2009	Verny, J. & Grigentin, C.	Container Shipping on the Northern Sea Route	<i>International Journal of Production Economics</i> , 122(1), 107–117	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, S. and A. Volkov	Economic feasibility of the Northern Sea Route container shipping development	MSc Business and Transportation, Bodø Graduate School of Business	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, B. N.	Arctic Shipping: Commercial Viability of the Arctic Sea Routes	MSc Dissertation, City Univ., London	Find profit margins	NWP; NSR; Polar; Suez	4000 TEU Container shipCAC3/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	DNV Research and Innovation, Position Paper 4	Evaluate transportation costs for a year	Northern NSR and Suez	6500 TEU standard ship5000 TEU PC4 DAS ice-class ship6500 TEU PC4 ice-class ship	Rotterdam – Tokyo, Hongkong, Singapore	S1: Year-round (DAS ship) S2: seasonal (PC4)
2010	Liu, M. and Kronbak, J.	The potential economic viability of using the Northern Sea Route (NSR) as an alternative route	<i>Journal of Transport Geography</i> 18, 434–444.	Compare operation costs for regular service	NSR; Suez	4300 TEU container ship4300 TEU container ship, ice-class 1B	Rotterdam – Yokohama	NSR used for 3, 6 or 9 months

(continued on next page)

Table 1 (continued)

Year	Authors	Title	Medium	Objective	Route	Type of ship	Origin–destination	Time window of navigation considered
2011	Paterson, T.	between Asia and Europe Cost comparison of shipping in the Arctic	<i>Arctic Shipping</i> 2011	Fednav's simulation: outline cost comparison for a single trip	NWP; Panama	Conventional bulker ship	New-York – Shanghai	Summer transit
2011	Hua, X. et al.	The potential seasonal alternative of Asia–Europe container service via Northern Sea Route under the Arctic sea ice retreat	<i>Maritime Policy & Management</i> , 38(5), 541–560.	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
2011	Schøyen, H. and Bråthen, S.	The Northern Sea Route versus the Suez Canal: cases from bulk shipping	<i>Journal of Transport Geography</i> 19, 977–983.	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	Cho, Y.	The melting Arctic changing the world: new sea route.	<i>Energy Security and Geopolitics in the Arctic: Challenges and Opportunities in the 21st Century</i> . Singapore, Jan 9–10.	Assess advantages and risks of NSR over Suez route	NSR, Suez	Not specified. Likely conventional since same ship used for comparison along both routes	Murmansk or Kirkenes–Pusan	Summer transit
2012	Carmel, S.	Commercial Shipping in the Arctic	<i>Marine Board Workshop Safe Navigation in the US Arctic</i> , Seattle, Oct. 15–16	Maersk's simulation: outline cost comparison and reliability for a single trip	NSR	Container ships compared; 2000 TEU for NSR and 6500 TEU via Suez. Ice-class 1A for NSR	Yokohama – Rotterdam	Summer transit
2012	Falck, H.	Shipping in Arctic Waters: the Northern Sea Route	<i>Marine Insurance Seminar</i> 2012, Marieham, April 26	Tschudi Shipping's simulation: compare costs for a single destination trip	NSR; Suez	Ice-class (1A) bulker and LNG tanker	Kirkenes – Yokohama Melkøya – Yokohama	Summer transit
2013	Wergeland, T.	Northeast, Northwest and Transpolar Passages in comparison	<i>Shipping in Arctic Waters. A Comparison of the Northeast, Northwest and Trans Polar Passages</i> , Willy Østreng (ed.), Berlin: Springer Verlag and Praxis: 299–352.	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

2.2. Main parameters used in the models: discrepancies and similarities

It is interesting to underline 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, fuel consumption rate, in 17 models, is considered the same for Arctic and southern routes, whereas 7 models underline the 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 post: 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), 57% (Carmel 2012) and 61% (Srinath, 2010). Models thus appear to be very sensitive to the two parameters of bunker cost (independent from the author) and the average speed and consumption rate, which the author of the simulation must determine, a sensitivity that several authors recognize (Guy, 2006; Somanathan et al., 2009; Chernova and Volkov, 2010; Wergeland, 2013).

All models depicting year-round Arctic navigation consider the same type of fuel will be used in summer as well as in the 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 specialization of the fuel: in early October 2012, IFO 380 was worth 2,43US\$/US gallon; Naval Distillate 3,267US\$/US gal; and P50 3,322US\$/US gal (+36,7% over IFO380). January 2014 prices stood at 2,72\$/gal for IFO380; 3,61\$/gal for Naval Distillate, and 3,62 \$/gal for P50 (+33,1% over IFO380). Simulations implying shipping in winter (year-round shipping), usually using the same fuel as in summer, therefore underestimate the cost of fuel by a large margin. Besides, this scenario seems barely credible for container shipping, because of the importance of just-in-time.

The average cruise speed of a commercial ship differs also widely depending on the model. For year-round navigation, 3 models suggest an average speed between 7 and 11 kts; 6 consider the average speed will be between 11 and 13 kts; two opt for an average speed between 13 and 15 kts, and one bets on an average speed of 17 kts (Verny and Grigentin, 2009). For summer shipping, two studies bank on an average speed slower than 10 kts; two consider the speed between 11 and 12,9 kts; three between 13 and 15 kts, and 4 above 15 kts (up to 25,8 kts with Hua et al. 2011 and 26 kts with Cho 2012). The similarity between these models is striking, as authors modeling a year-round transit do not present us with an average speed much lower than for summer traffic, whereas it is difficult to envision rapid transits across Arctic passages in the winter time given the prevalence of thick one-year ice, if not pluriannual (multi-year ice still present although declining). 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 nautical maps within the Canadian archipelago (Lasserre, 2010a,c; Lasserre and Pelletier 2011). One author reckons simulated high speeds are unrealistic and merely for the purpose of setting up scenarios (Griffiths 2005).

The estimates for the increased capital cost for the construction of an ice-class ship vary widely too. For Arctic shipping, Laulajainen (2009) estimates increased capital costs at 70–100%, 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 et al. 2011) considers there will be no NSR fees, a daring assumption given the Russian intent to use the NSR toll precisely to finance the maintenance of its Arctic icebreaker fleet; Cho (2012) does not compute NSR fees into the calculations. NWP transits thus appear to have an advantage since there is no (for now) transit fees in Canada. However, this advantage should not conceal the fact profitability threads on a thin margin: Nordic Bulk Carriers, the owning shipping firm

Table 2

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

Author(s)	Ice class category considered	Capital cost premium (%)
Griffiths (2005), Mejlaender-Larsen (2009), Wergeland (2013)	"Ice class"	+10–35
Liu and Kronbak (2010)	1B	+20
Mulherin et al. (1996), Kamesaki (1999), Kitagawa (2001)	PC7	+20–36
Mulherin et al. (1996), Schøyen and Bråthen (2011)	PC7 to PC4	+20
Mulherin et al. (1996); Dvorak (2009)	PC6	+1–20
DNV (2010)	PC4	+30
DNV (2010)	PC4 and DAS	+120
Dvorak (2009)	PC3	+6
Somanathan et al. (2007, 2009)	PC2	+30
Srinath (2010)	PC2	+40
Chernova and Volkov (2010)	DAS/"high ice class":	+30–40

Table 3

Conclusions of the simulations that conclude Arctic routes are profitable.

Year	Authors of the simulation	Results
1991	Wergeland, T. (Ed.)	Panama scenario: 10,98\$/t via NSR; 27,56\$/t via PanamaSuez scenario: 22,2 \$/t via NSR; 34,16 \$/t via SuezAll costs before depreciation
1992	Wergeland, T.	Same as Wergeland 1991.
2006	Arpiainen, M. and Kiili, R.	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, E.	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, K.	Transport of oil by seaway: 12 euros/tonBy pipeline: 20 euros/ton
2008	Borgerson, S.	Savings up to 20% - from 17,5 M\$ per trip to 14 M\$.
2010	Srinath, Badari Narayana	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, M. and Kronbak, J.	With an 85% rebate on official NSR fees, the 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, X. et al.	NSR route saves between 3 to 5% of fuel cost
2011	Schøyen, H. and Bråthen, S.	NSR cheaper by 1,5%NSR very fuel efficient in this scenario
2012	Falck, H.	NSR route saves: Bulk ship: 839,000 \$ LNG: 82,640,00 \$
2012	Cho, Y.	NSR route saves: Container ship: 39% fuel Bulk ship: 36% fuel
2013	Wergeland, T.	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

of the *Nordic Orion* that transited in August 2013, specifically underlined the transit was profitable because the Canadian government charged no fee; should there be a toll, the transit would not be profitable, according to the company (Wall Street Journal, 2013; National Post, 2013). Eight models rest on the same cost structure for the crew, assuming wages and advantages are similar as crews operating along classic routes, whereas 7 mention there definitely is a need for a well-trained crew for Arctic shipping, and thus either imply or explicitly mention crew costs are higher: experienced crews command a higher salary if the employer wants to make sure the firm will retain their services. Other models do not mention crew cost structure issues.

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. One mentions a price difference of about 100,000\$ per trip. Three models suggest global insurance costs may be between 75% and more than 100% higher than regular fees. For P&I (insurance protection that covers for third-party liabilities encountered in the commercial operation of vessels), premiums vary from 16.7%, 25% (2), 43%; 50% (3) 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% (2), 50% (3) and 100% (3). Arpiainen and Kiili (2006) quote 800 \$/day as the average insurance cost for a ship plying Arctic waters year-round, whereas Somanathan et al. (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 these models have to cope with.

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 factor plead for higher premiums along the NWP as the NSR boasts intermediate ports (Varandei, Amderma, Dickson, Tiksi, Pevek, Provideniya), more icebreakers, less drifting ice² and less icebergs and growlers, because land glaciers that calve icebergs when entering the sea on Novaya Zemlya, Severnaya Zemlya and Franz-Joseph Land are much smaller than Greenland's and Ellesmere's (Dowdeswell and Hambrey, 2002, pp. 95–96).

2.3. 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 the Northwest Passage is going to 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 (2009), Det Norske Veritas (DNV) (2010), Carmel (2012) or Cho (2012) do not disclose many details. But simulations from authors like Kitagawa (2001), Verny and Grigentin (2009), Somanathan et al. (2009), Srinath (2010), Liu and Kronbak (2010), Wergeland (2013) offer detailed and accounted for hypotheses with several parameters.

² Sea ice extent maps by the National Snow and Ice Data Center (NSIDC, www.nsidc.org) attest to the present trend of faster melt along Siberian coasts.

Table 4

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

Year	Authors of the simulation	Results
1996	Mulherin, N. et al.	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, K., Kishi, S., Yamauchi, Y.	Cargo volume is higher with NSR route, thus generates higher income costs, including high capital cost, are higher with NSR (comparison for 50,000 dwt/Handymax). Overall: NSR 21,11\$/ton Suez (Handymax): 18,1\$/ton
2001	Kitagawa, H.	Same as Kamesaki et al. 1999
2005	Griffiths, F.	The cost margin may be slightly in favor of NWP transit, but the margin is so small it may not cover for administrative costs and for the increased risk.
2007	Somanathan, S. et al.	On NY route, Panama is 8% cheaper. On St John's route, NWP is 10% cheaper.
2009	Verny, J. and Grigentin, C.	Cost per TEU: Suez: 1400–1800\$ NSR: 2500–2800\$ Trans-Siberian: 1800–2200\$
2009	Dvorak, R.	Total cost differential for Arctic shipping (fuel and capital): A1:+0,25% A3:+26,5% A5:+152%
2009	Mejlaender-Larsen, M.	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, S. et al.	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, S. & A. Volkov	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, T.	More costly by 75,000 to 175,000\$ per trip to use NWP.
2012	Carmel, S.	Cost per container is higher along the NSR because large ships cannot use NSR for now; besides, the reliability of the route is too low.

Given all the parameters involved, 13 models conclude Arctic routes can be profitable for commercial shipping in the short term; 6 are more ambivalent or do not take position, and 7 conclude conditions are difficult for a profitable exploitation of these routes (see [Tables 3 and 4](#)). (see [Tables 5–9](#)).

However, as for any model, the conclusions must be handled with great 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 transshipments Europe-Iceland and Aleutians-Asia (figures not provided), they conclude 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, p. 28](#)).

Guy studies the NWP with several scenarios, based on the charter cost of the ship, transit duration and possible transit fees. His calculation 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, a fact that translates into greater risk and thus probably higher insurance premiums); and limited premiums for Arctic shipping costs (ice-class ship; crew; insurance; maintenance) ([Guy, 2006, p. 13](#)).

[Carmel \(2012\)](#) underlines the fact that, beyond the transit time and the cost issues, a major issue for container shipping along the NSR lies in the reliability of the route, a fact largely reflected in the literature ([Terrassier, 1997](#); [Clarkson Research Studies, 2004](#); [Lorange, 2008](#); [Damien, 2008](#); [Lasserre and Pelletier 2011](#)). Maersk, he contends, has achieved a 99% reliability on its schedule, despite congestion and political risks like piracy. He doubts very much such a high level can be achieved with Arctic routes given the variability of ice coverage, especially during transition seasons.

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 them³. They rest on simplifications of the cost structure (structural

³ 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 et al. 2011](#)).

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 characterizes 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).

Some of these factors, especially the potential costs of commercial risks such as delays, are difficult to factor in in quantitative models. However, I felt it was possible to tailor another simulation that would capitalize 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).

3. Designing scenarios drafting on past models

So as to capitalize on these scenarios, I propose to establish another simulation. As all models, it is prone to simplifications and works with estimates. I designed a scenario modeling a 4500 TEU containership based in Rotterdam and servicing Shanghai or Yokohama through the NSR or the NWP, competing with a similar ship going through Suez and stopping over at three intermediate ports, Malta, Mumbai and Singapore. A 4500 TEU containership was chosen because larger ships tend to display larger beams than icebreakers, implying the (costly) use of two icebreakers to break a way across thick ice. Choosing a more southern destination is irrelevant, for then the distance across Arctic routes tend to surpass distances along the Suez route, depending on the origin point (see Fig. 1).

The goal of the simulation is to sketch an approximate cost of operation per transported twenty-foot equivalent unit (TEU), the unit used to count containers. 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 Fall), 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.

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 emphasizes a direct cost analysis per trip (as used by authors like Wergeland or Mulherin et al.) 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 et al., 2009; Srinath, 2010; Chernova and Volkov, 2010; Arpiainen and Kiili, 2006).

3.1. First scenario: Rotterdam–Asia across the NSR, summer navigation

Origin–destination. We first considered the couple Rotterdam–Shanghai, especially in the frame of a 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 favors the NSR over the Suez route. I also applied the model to the Northwest Passage.

NSR tariff. Obviously official tariffs are very restrictive for the NSR, especially for container cargo as the official rate (1048 Rb/ton, or 30\$/t in January 2014), is very high. Tschudi Shipping (Falck, 2012) claims it used the NSR with a tariff of 5 \$/t for iron ore and says it could pay 8.5\$/t for LNG, but such low tariff (150 Rb/t and 255 Rb/t) is nowhere to be found in updated NSR tariffs, where bulk cargo is rather priced at 707 Rb/t and LNG at 530 Rb/t (Northern Sea Route Administration, 2012)⁴: 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 case⁵, and by the Center for High North Logistics (CHNL), a think-tank dedicated to research on and promotion of Arctic shipping along the NSR⁶. NSR tariffs can thus be adjusted on an *ad hoc* basis, and no figures are published on these since they reflect specific negotiations between the NRS Administration and the shipping firm. 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 competitive⁷. 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) for a Panamax bulk ship (unit used in Falck's simulation), beam 107 ft, draft 38

⁴ Order dated June 07th 2011, No122-T/1, Maximum rates for services of the icebreaker fleet on the Northern Sea Route to ensure the transportation of cargo, reproduced at www.arctic-lia.com/nsr_tariffsystem, accessed Feb. 15, 2014.

⁵ According to Ulf Hagen, Managing Director, Tschudi Arctic Transit, the official NSR tariffs are prohibitive. The NSR Administration will agree on substantial rebates if the shipping firm pledges to use the NSR on a regular basis. *Ad hoc* transits will not be given significant discounts however. Interview with author, October 23, 2012.

⁶ Correspondence with Serguey Balmasov, Head of the Arctic Logistics Information Office, Center for High North Logistics, Murmansk, February 12, 2014.

⁷ "In April 1987, SCA adopted flexible marketing policies so as to encourage vessels to use the Suez Canal and to attract new customers", Suez Canal Authority, www.suezcanal.gov.e.g./sc.aspx?show=31, accessed February 21, 2014.

Table 5

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

	NSR	Suez	
Distance, km	15 793	19 550	Calculated on GIS Mapinfo
Load factor, eastbound	45%	60%	After Damas (2012)
Load factor, westbound	70%	87%	
TEU transported per trip, eastbound	2025	2700	
TEU transported per trip, westbound	3150	3915	
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, days		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, knots	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 (days)	22,6	32,2	Sailing time + stop days on 180 days less maintenance days
Total possible segments during summer	7,73	5,46	
	Rounded at 8	Rounded at 6	
Total TEUs transported	20 700	19 845	
Cost analysis			(for 6 months)
Crew, thousand US\$	858	780	Suez: Verny and Grigentin 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, thousand US\$	1 200	800	For a standard ship: Somanathan et al. 2009 : 425,000\$/yr; Wergeland 2012: 339,450\$/yr; Srinath 2010 : 1,400,000\$/yr. Conversely, Verny and Grigentin 2009 suggest 1,204,000\$/yr for the NSR, and Srinath 2,4 M\$/yr. We therefore opted for a conservative 800,000\$/yr value and a 50% premium (Srinath, DNV, Somanathan)
Capital cost, thousand US\$	5 646	4 516,8	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 (108 M\$), same depreciation, 940 995\$/month.
Maintenance, thousand US\$	360	300	Schøyen:+20%; Wergeland:+23%. Somanathan 2009 indicates 320,000\$/yr. In 1992, Wergeland considered 1100\$/d = 401 500\$/y. We opted for 600,000\$/y for 2012. Premium considered for NSR:+20%
Transit fees, thousand US\$	2 310,1	1 440	Discounted NSR tariff: 223,22 Rb/t = 7,44\$/t. Average loaded TEU weight : 15t/TEU. Suez: 240 000\$/transit, Suez Canal Authority, www.suezcanal.gov.e.g
Average transit fee per trip, thousand US\$	288,8	240	
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. Wergeland (2012) uses formula as a function of cube of speed, but Notteboom and Vernimmen (2009) underline consumption rate stabilizes at low speeds and stops decreasing. From their calculation, at 14 kts, 40 t/d. Alphaliner (2012b) asserts consumption rate is 65t/d for a 8500 TEU ship, which seems to be consistent with Notteboom & Vernimmen. 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, tons	1625,88	2262,73	
Bunker price, IFO 380, US\$/t	602	602	Average price in October 2012, according to Bunker Index, www.bunkerindex.com
Fuel cost per leg, thousand US\$	978,8	1 362,2	
Fuel cost, total thousand US\$	7 830,2	8 173	
Total cost, 6 months, thousand US\$	18 204,3	16 009,8	
Cost per TEU, US\$	879,46	806,74	

ft, gross tonnage 38 000⁸. [Verny and Grigentin \(2009\)](#) assume NSR tariffs are likely to remain double that of Suez, but this would already be a major 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 where NSR tariffs for container cargo represent the same maximum reduction as that applied for Tschudi Arctic Transit with bulk cargo, rather than the reduction used in their simulation for LNG: 22,322 Rb/t, or

⁸ For a Panamax ship (unit used in the simulation), beam 107 ft, draft 38 ft, gross tonnage 38 000. Our calculation online, Nov. 1st, 2012.

Table 6

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

	NSR	Suez	
Distance, km	13 400	21 200	Calculated on GIS Mapinfo.
Average sailing speed, knots	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 days
Total segment time (days)	20,3	34,5	Sailing time + stop days
Total possible segments during summer	8,62	5,15	
	Rounded at 9	Rounded at 5	
Total TEUs transported	23 850	15 930	
Cost analysis			
Crew, thousand US\$	858	780	
Insurance: H&M, P&I, thousand US\$	1 200	800	
Capital cost, thousand US\$	5 646	4 516,8	
Maintenance, thousand US\$	360	300	
Transit fees, thousand US\$	12 622,5	1 200	
Average transit fee per trip, thousand US\$	1 377	240	
Fuel consumption rate, tons/day	75,02	100	
Sailing days per segment	18,3	24,5	
Fuel consumed, tons	1373,13	2453,70	
Bunker price, IFO 380, US\$/t	602	602	
Fuel cost per leg, thousand US\$	826,6	1 477,1	
Fuel cost, total, thousand US\$	7 439,6	7 385,6	
Total cost, 6 months, thousand US\$	18 165,2	14 982,4	
Cost per TEU, US\$	761,67	940,52	

7.44\$/t (Falck, 2012; Northern Sea Route Administration, 2012)⁹. Such a discounted tariff (78.7% discount from the official tariff) would still be about 53.8% above the official Suez rate (with a moderate hypothesis of an average container weight of 15 tons; (max. 28 t according to Nippon Yusen Kaisha (NYK) 2012)¹⁰.

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 survey we carried (Lasserre and Pelletier, 2011). So as to reflect this market reality, which none of the models considered tries to depict, I opted for dual load factors. Container traffic is much more sustained from Asia than to Asia (Damas, 2012; UNCTAD 2011 pp. 23–24; 2012, p. 21; 2013, p. 24): traffic from Asia to Europe was in 13.5 million TEUs and 5.6 M TEUs from Europe to Asia in 2010, in 2011, 14.1 M TEUs from Asia to Europe and 6.2 M TEUs from Europe to Asia; in 2012, 13.7 M TEUs and 6.3 M TEUs respectively. Besides, the recent container market outlook saw a deterioration in the load factor, going down on the Far East – Europe route, from 95% in 2010 to 84% in 2012 and going downwards, despite a recovery in early 2013 (Alphaliner, 2012a; 2013). In October 2013 it appeared to remain stable at 85% (BOCOM, 2013) I thus set the load factor at 87% (Asia to Europe) and 60% (Europe to Asia) for the Suez route, and 70% and 45% for the Arctic route.

I set up a baseline scenario, based on official NSR fees, describing a summer transit service between Rotterdam and Shanghai, and Rotterdam and Yokohama. Period: May 1st–Nov. 1st = 180 days. It is apparent that:

- The cost per TEU, between Rotterdam and Yokohama, is 1160\$ along the NSR and 934\$ across Suez; for Shanghai it is 1278\$ along the NSR and 802\$ across Suez.
- The ship plying arctic waters can make more rotations, but not necessarily a lot more TEUs given the lower load factor, especially along the Rotterdam-Shanghai line. The difference is more significative for service to Yokohama.
- 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 Ulf Hagen from Tschudi Arctic Transit, as already quoted. It is thus more interesting to see to what extent more realistic case studies, with discounted NSR tariffs, can present shipping firms with more interesting scenarios

Of course, scenarios with official NSR fees are largely fictional as it appears that the Northern Sea Route Administration is keen on offering attractive tariffs if the shipping company pledges to use the route on a regular basis, which is consistent

⁹ 150/707 is a 78,7% discount; 255/530 is a 52% discount. Assuming the Russians are trying to attract business, we opted for the largest discount, 78,7%. Applied to the official rate of 1048 Rb/t, it gives a discounted tariff of 223,22 Rb/t.

¹⁰ With a moderate hypothesis of an average container weight of 15 tons (max. 28 t according to NYK, www.2nykline.com/liner/container_specifications/dry.html, accessed Feb. 13, 2014).

with liner service. I therefore adapted the scenario to a situation where NSR tariffs are much lower, a situation that appears more realistic according to several testimonies. This is our benchmark case study, as all other figures are the same.

In this sub-scenario, 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.

An important element to notice is that everything costs more for the shipping service in the Arctic. So as to market a service along the NSR, crew, maintenance, insurance, capital costs, and even fuel, are all more important than for service along the Suez and Malacca route. What makes a difference is that the fuel cost per leg is inferior along the NSR, and that the shorter distance enables the shipping company to make more rotations, and thus to transport more containers. This advantage is even more striking on the route between Yokohama and Rotterdam where, despite higher costs, the service proves much more profitable because of lower cost of fuel per leg and a higher volume of transported TEUs (23850 against 15930 across Suez).

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 712\$, making it competitive against the classical route (11.3% 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 Jan. 2014 IFO 380 cost of 602\$/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 1129.55\$ with the NSR and 1079\$ through Suez, and thus remain uncompetitive: fuel cost is not, in itself, a factor so important as to be able to overcome market issues such as the load factor. This conclusion is still valid with the Northwest Passage scenario, see below.

3.2. Second scenario: Rotterdam–Asia across the NWP, summer shipping

The second scenario tackles with summer shipping across the Northwest Passage (NWP). Most parameters remain the same. However, the distance is a bit longer than with the NSR; fog, icebergs and drifting ice are more prevalent than along the NSR (Lasserre, 2010a) 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 presently a lot of ice in June; this factor as well as the absence of ports and of numerous icebreakers to

Table 7

Second scenario, summer transit across the Northwest Passage, Rotterdam–Shanghai. Period: May 1st– Nov. 1st = 180 days.

	NWP	Suez	
Distance, km	16 384	19 550	Calculated on GIS Mapinfo, NWP across McClure Strait.
Load factor, eastbound	70%	60%	NWP: eastbound is from Asia to Europe
Load factor, westbound	45%	87%	
TEU transported per trip, eastbound	3150	2700	
TEU transported per trip, westbound	2025	3915	
Maintenance, days per 6 months	5	2	
Suez canal delay, days		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, knots	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 (days)	24,4	32,6	Sailing time + stop days on 180 days less maintenance days
Total possible segments during summer	7,17	5,46	
	Rounded at 7	Rounded at 6	
Total TEUs transported	18 450	21 600	
Cost analysis			
Crew, thousand US\$	858	780	Same cost for NSR and NWP.
Insurance: H&M, P&I, thousand US\$	1 320	800	For the NWP, the risk is higher: 65% premium
Capital cost, thousand US\$	5 646	4 516,8	Same type of ship for the NSR and the NWP
Maintenance, thousand US\$	360	300	Same as for the NSR
Transit fees, thousand US\$		1 440	Suez: 240,000\$/transit, www.suezcanal.gov.e.g .
Average transit fee per trip, US\$		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, tons	1773	2262,73	
Bunker price, IFO 380, US\$/t	602	602	
Fuel cost per leg, thousand US\$	1 067,3	1 362,2	
Fuel cost, total, thousand US\$	7 471,4	8 173	
Total cost, 6 months, thousand US\$	15 655,4	16 009,8	
Cost per TEU	892,05	806,74	

Table 8

Second scenario, summer transit across the Northwest Passage, Rotterdam-Yokohama. Period: May 1st– Nov. 1st = 180 days.

	NWP	Suez	
Distance, km	14 470	21 200	Calculated on GIS Mapinfo, NWP across McClure Strait.
Load factor, eastbound	45%	60%	
Load factor, westbound	70%	87%	
TEU transported per trip, eastbound	3150	3375	
TEU transported per trip, westbound	2025	3825	
Maintenance, days per 6 months	5	2	
Suez canal delay, days		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, knots	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 (days)	22,2	34,5	Sailing time + stop days on 180 days less maintenance days
Total possible segments during summer	7,89	5,15	
	Rounded at 8	Rounded at 5	
Total TEUs transported	21 600	17 775	
Cost analysis			
Crew, thousand US\$	858	780	Same cost for NSR and NWP.
Insurance: H&M, P&I, thousand US\$	1 320	800	For the NWP, the risk is higher: 65% premium
Capital cost, thousand US\$	5 646	4 516,8	Same type of ship for the NSR and the NWP
Maintenance, thousand US\$	360	300	Same as for the NSR
Transit fees, thousand US\$		1 440	Suez: 240 000\$/transit, www.suezcanal.gov.e.g .
Average transit fee per trip, US\$		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, tons	1 533,75	2 453,7	
Bunker price, IFO 380, US\$/t	602	602	
Fuel cost per leg, thousand US\$	923,3	1 477,1	
Fuel cost, total, thousand US\$	7 386,5	7 385,6	
Total cost, 6 months, thousand US\$	15 570,5	14 982,4	
Cost per TEU	752,20	940,52	

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 loose ice had a marginal impact on consumption rates.

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. If the load factor was the same as with the Suez route, the cost per TEU would be 694 \$/TEU along the NWP, thus cheaper by 13.8% than the alternate classical route via Suez. The break-even point as regards the load factor along the NWP could be, for instance, 52% on westbound legs (Europe to Asia) and 75% on eastbound legs (Asia to Europe), with a cost per TEU of 803,46\$ compared to 806,74\$ for the Suez route.

A service to Yokohama, however, as with the NSR, displays much lower costs per TEU: it would be 20% cheaper per container despite the difference in load factor; with a load factor of 52/75%, the cost per TEU would drop to 681.12\$ compared to 940.52\$, thus 27.6% cheaper. Even if the average speed across the NWP dropped to 9 kts instead of 13 kts, then the cost per TEU would increase to 794.85\$, or still 15.5% cheaper than with the Suez route.

4. Sensitivity analysis

These scenarios highlight the fact, from a cost-analysis point of view, transit services along the NSR or the NWP can be profitable between Rotterdam and Yokohama, but are much less so between Rotterdam and Shanghai.

Adjusting a few variables, as detailed above, underlined the fact the profitability seems to respond more significantly (i.e. has a greater elasticity) for some variables.

First, let us summarize the cost component of total cost for the 4 scenarios comparing the NSR and Suez.

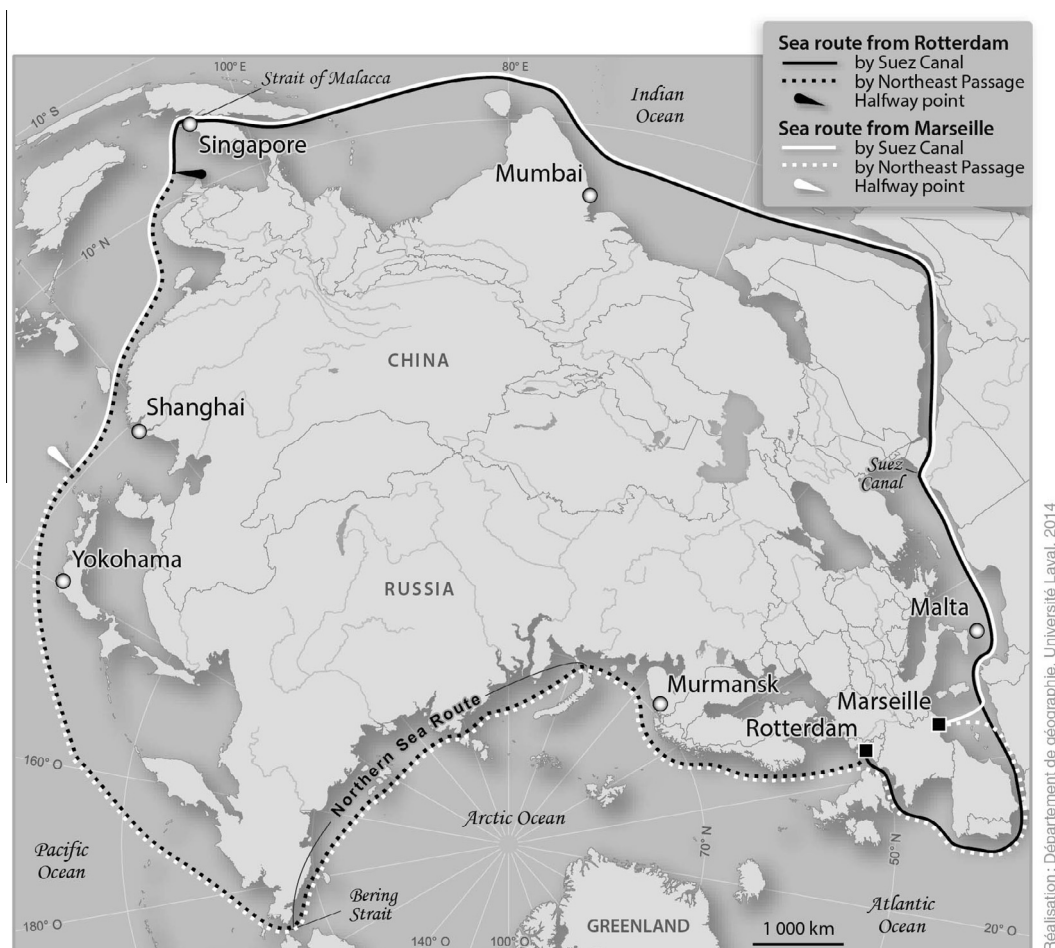
Unsurprisingly, fuel costs represent the largest share, between 40.95% and 51.05%. The second largest cost in these case studies is capital cost, between 28.21% and 31.08%. Transit fees come third with between 8.01% and 14.65%.

Capital cost is considered a fixed parameter here, as it is difficult to see how the shipping company could easily try and adjust it so as to potentially optimize its profit. It is a variable that will, however, affect the decision to go into the Arctic market or not.

Table 9

Cost analysis and components of total cost, depending on scenario.

	Rotterdam–Shanghai via NSR	Rotterdam–Shanghai via Suez	Rotterdam–Yokohama via NSR	Rotterdam–Yokohama via Suez
Crew	4,71%	4,87%	4,72%	5,21%
Insurance	6,59%	5%	6,61%	5,34%
Capital cost	31,01%	28,21%	31,08%	30,15%
Maintenance	1,98%	1,87%	1,98%	2,%
Transit fees	12,69%	8,99%	14,65%	8,01%
Fuel costs	43,01%	51,05%	40,95%	49,3%

**Fig. 1.** Halfway point for sea routes along the Northeast Passage and across the Suez Canal, from Rotterdam and Marseille. Source: author's own calculation and simulation using ARC GIS.**Table 10**

Analysis of the sensitivity of the cost differential per TEU for the four variables identified. Calculation for service to Shanghai along the NSR.

Shanghai	–50%	–30%	–20%	20%	30%	50%
Fuel costs	–94,54	–87,83	–84,47	–71,04	–67,69	–60,97
Variation from baseline	21,58	12,95	8,63	–8,64	–12,95	–21,59
NSR transit fees	–21,96	–44,28	–55,44	–100,08	–111,24	–133,56
Variation from baseline	–71,76	–43,06	–28,70	28,70	43,06	71,76
Transit speed in the NSR	–171,4	–117,89	–101,17	–62,15	–56,15	–46,54
Variation from baseline	120,42	51,61	30,11	–20,07	–27,79	–40,15
Load factor in the NSR	–845,62	–406,84	–269,72	50,22	99,44	ns
Variation from baseline	987,47	423,20	246,86	–164,58	–227,88	ns

Cost differential: Suez minus NSR. A positive result means the NSR is more cost effective) The baseline represents the price per TEU difference with the main scenario. For Shanghai, it is 806,74–879,43 = –72,69\$.

Table 11

Analysis of the sensitivity of the cost differential per TEU (NSR versus Suez) for the four variables identified. Calculation for service to Yokohama along the NSR.

Yokohama	–50%	–30%	–20%	20%	30%	50%
Fuel costs	96,73	127,07	142,24	202,91	218,08	248,42
Variation from baseline	–43,95	–26,37	–17,58	17,58	26,37	43,95
NSR transit fees	228,37	206,05	194,89	150,25	139,09	116,77
Variation from baseline	32,33	19,40	12,93	–12,93	–19,40	–32,33
Transit speed in the NSR	81,14	133,39	149,72	187,81	193,68	203,05
Variation from baseline	–52,98	–22,70	–13,24	8,83	12,23	17,66
Load factor in the NSR	–477,49	–106,2	10,06	280,92	322,59	ns
Variation from baseline	–376,69	–161,54	–94,17	62,79	86,93	ns

Cost differential: Suez minus NSR. A positive result means the NSR is more cost effective. The baseline represents the price per TEU difference with the main scenario. For Yokohama, it is 940,52 – 761,64 = 178,87\$.

Table 12

Parameters that favor Arctic or Suez routes in the scenarios.

Arctic routes	Suez route
<i>The values of these parameters favor either Arctic or the Suez route:</i>	
Average speed set at 14 kts for the NSR and 13 kts in the NWP for the whole summer. For now (2014), 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 recent trends of the shipping industry.
No friction effect of loose but dense ice in summer on fuel consumption rate was considered. This is a simplification advantaging fuel consumption along Arctic routes.	Conservative insurance premiums for the Arctic, based on the literature. It may be real premiums will be less, depending on risk assessment by insurance firms.
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 Fall. It is anyway very difficult to quantify such a parameter.	
NSR tariffs set with a 78% rebate on official tariffs, assuming the NSRA will provide the same rebate as the reduction granted to Tschudi Shipping.	

Given these calculations, it seems four variables could be considered in trying to assess the sensitivity of the model: how do they affect the price per TEU? I identified fuel costs and transit fees on the cost side; transit speed and the load factor on the operational side, since they largely contribute to the volume of TEUs that can be carried (see [Tables 10 and 11](#)).

From this analysis, it appears that:

- As was hinted above, fuel costs are an important variable, but not determining in the profitability when competing with classical routes. When fuel costs increase by 50%, the impact on the cost differential is less than 22% on the Shanghai route, and less than 44% on the Yokohama route. The sensitivity is greater on the Yokohama route since the legs are shorter, with the share of the NSR segment longer, crossed at a lower speed thus entailing increased fuel savings relative to the Suez route, but it remains inferior to 50%.
- NSR transit fees: for the Yokohama route, where shorter distances enable the ships to make more rotations and thus transport more TEUs, the impact of the tariffs appear less sensitive as well: 32.33% variation on the cost differential for a 50% variation. However, on the Shanghai route where this advantage of a shorter leg is less prevalent, then impact of the tariff level is more meaningful: 71.76% for a 50% variation.
- Transit speed is less sensitive on the Yokohama service, as the shorter leg can provide for a strong advantage even with a reduced speed; conversely, an improved speed will not impact the cost differential much: a 50% increase of the speed entails a mere 17.66% variation of the differential on the Yokohama service, whereas a 50% decrease of the transit speed along the NSR produces a 52.98% decline of the differential. Along the Shanghai route, a 50% improvement of the transit speed along the NSR provides for a 40.15% improvement of the differential, thus a moderate sensitivity, whereas a 50% decline impacts the cost differential by more than 120%: given the length of the route, if the transit along the NSR becomes slower, then what advantage there might have been in transiting in the Arctic is quickly eroded.
- Load factor appears by far to be the most important variable when determining the cost differential. Here only the NSR load factor was adapted. It appears a mere 10% improvement of the load factor impacts the cost differential by more than 164% on the Shanghai service, and by more than 62% on the Yokohama service.

5. Criticism on the value of parameters

As a critical look on the proposed simulation, some parameters may favor the Arctic or the Suez routes. [Table 12](#) summarizes the main biases the chosen parameters introduce.

Ice-breaking ships						Ice-strengthened ships					
Baltic Russian, old rules Commercial vessel						1AS	1A	1B	1C	II	
					ULA	ULA- UL LL4	UL	L1	L2	L3	
Icebreaker Russian, current rules Commercial vessel			LL1	LL2	LL3						
				LU9	LU7/ LU8	LU6	LU5	LU4	LU3	LU2	LU1
Icebreaker Lloyd's Register Canadian Arctic Shipping – CASPPR	LR3	LR2 CAC 1	LL9 LR1.5 CAC 2	LL8 CAC 3	LL7 LR1 CAC 4		LL6 1AS A	1A B	1B C	1C D	1D 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, V.; Matveev, G. & Grigoriov, A. 2005. A Methodology for Estimating Equivalency of the Existing Ice Classes. *Transactions of the Krylov Shipbuilding Research Institute*, 23(307):25–37; Lamb, Thomas (2004), *Ship Design and Construction*, vol. II. SNAME, Chapter 40: Ice-Capable Ships; International Association of Classification Societies (2006), *Requirements Concerning Polar Class*; Robert Bridges (2004), “IACS Polar Rules Harmonisation of Classes”, Lloyd’s Register, London, Sept. 7, 2004; D.J. Eyres (2001), *Ship Construction*, Elsevier, Oxford, pp. 35; National Research Council (2007), *Polar Icebreakers in a Changing World*, Washington, DC, pp. 57–58.

References

- Alphaliner, 2012a. Container shipping 2013 market outlook. In: Conference Transpacific Maritime (TPM). Asia, Shenzhen, Oct. 17, 2012.
- Alphaliner, 2012b. Annual Review 2012. London. <www.alphaliner.com/liner2/reports/AR2012.pdf> (accessed Feb. 7, 2014).
- Alphaliner, 2013. Supply & demand: does it still matter? In: Conference Transpacific Maritime (TPM). Long Beach, March 3–6, 2013.
- Arpiainen, M., Kiili, R., 2006. Arctic shuttle container link from Alaska US to Europe. Report K-63. Aker Arctic Technology, Helsinki.
- BOCOM International, 2013. Container Shipping Sector. Weekly container shipping commentary. Oct. 2, 2013. BOCOM International, Hongkong.
- Borgerson, S., 2008. Arctic meltdown. *Foreign Aff.* 87 (2), 63–77.
- Byers, M., 2009. Who Owns The Arctic? Douglas & McIntyre, Vancouver.
- Carmel, S., 2012. Commercial Shipping in the Arctic. Marine Board Workshop Safe Navigation in the Arctic. Seattle, October 15–16, 2012 (Maersk).
- Chernova, S., Volkov, A., 2010. Economic feasibility of the Northern Sea Route container shipping development. MSc Business and Transportation, Bodo Graduate School of Business.
- Cho, Y., 2012. The melting Arctic changing the world: new sea route. International Convention Energy Security and Geopolitics in the Arctic: Challenges and Opportunities in the 21st Century Jan. 9–10. Energy Studies Institute, National University of Singapore, Singapore.
- Clarkson Research Studies, 2004. The Tramp Shipping Market. London.
- Damas, P., 2012. Container shipping market outlook, freight rates and index-linked contracts, May 2, 2012. Drewry Supply Chains Advisors, Birmingham.
- <www.tradeextensions.com/resources/multimodal/2012/drewry_multimodal_2012.pdf> (accessed Oct. 31, 2012) and <<https://www.yumpu.com/en/document/view/10678693/container-shipping-market-outlook-freight-rates-trade-extensions>> (accessed Feb. 15, 2014).
- Damien, M.-M., 2008. Conteneurisation et dynamiques portuaires. In: Guillaume, J. (Ed.), *Les transports maritimes dans la mondialisation*. L’Harmattan, Paris, pp. 105–124.
- Det Norske Veritas (DNV), 2010. Shipping across the Arctic Ocean. DNV Research and Innovation, Høvik, Position Paper 4.
- Dowdeswell, J., Hambrey, M., 2002. *Islands of the Arctic*. Cambridge University Press, Cambridge.
- Dvorak, R., 2009. Engineering and Economic Implications of Ice-Classed Containerships. MSc Dissertation. Massachusetts Institute of Technology, Cambridge, MA.
- Falck, H., 2012. Shipping in Arctic Waters: the Northern Sea Route. Tschudi Shipping Company: Presentation to the Marine Insurance Seminar 2012. Mariehamn (Finland), April 26.
- Gedeon, J., 2007. Variable Ice, Harsh Weather Conditions make future of Arctic shipping tentative. Canadian Sailings – Transportation & Trade Logistics. March 12, 22–24.
- Guy, E., 2006. Evaluating the viability of commercial shipping in the Northwest Passage. *J. Ocean Technol.* 1 (1), 9–15.
- Griffiths, F., 2005. New illusions of a Northwest Passage. In: Nordquist, M., Moore, J.N., Skaridov, A.S. (Eds.), *International Energy Policy, the Arctic and the Law of the Sea*. Martinus Nijhoff Publishers, Leiden, pp. 303–309.
- Howell, S.E.L., Yackel, J.J., 2004. A vessel transit assessment of sea ice variability in the Western Arctic, 1969–2002: implications for ship navigation. *Can. J. Remote Sens.* 30 (2), 205–215.
- Hua, X., Yin, Z., Jia, D., Jin, F., Ouyang, H., 2011. The potential seasonal alternative of Asia–Europe container service via Northern Sea Route under the Arctic sea ice retreat. *Marit. Policy Manage.* 38 (5), 541–560.
- Juurmaa, K., 2006. Arctic Operational Platform: Integrated Transport System. ARCOP Final Report. Aker Finnyards Inc., Helsinki.
- Kamesaki, K., Kishi, S., Yamauchi, Y., 1999. Simulation of NSR Navigation Based on Year Round and Seasonal Operation Scenarios. INSROP Working Paper 8. INSROP, Oslo.
- Kitagawa, H., 2001. The Northern Sea Route. The Shortest Sea Route Linking East Asia and Europe. The Ocean Foundation, Tokyo.
- Lasserre, F., Pelletier, S., 2011. Polar super seaways? Maritime transport in the Arctic: an analysis of shipowners’ intentions. *J. Transp. Geogr.* 19, 1465–1473.
- Lasserre, F., 2010a. Changements climatiques dans l’Arctique: vers la disparition de la banquise? In: Lasserre, F. (Ed.), *Passages et mers arctiques. Géopolitique d’une région en mutation*. Presses de l’Université du Québec, Québec, pp. 11–32.
- Lasserre, F., 2010b. Mines et pétrole. Vers une rapide expansion de l’exploitation des ressources naturelles du sous-sol dans l’Arctique? In: Lasserre, F. (Ed.), *Passages et mers arctiques. Géopolitique d’une région en mutation*. Presses de l’Université du Québec, Québec, pp. 373–410.
- Lasserre, F., 2010c. Vers une autoroute maritime? Passages arctiques et trafic maritime international. In: Lasserre, F. (Ed.), *Passages et mers arctiques. Géopolitique d’une région en mutation*. Presses de l’Université du Québec, Québec, pp. 449–479.
- Lasserre, F., 2011. Arctic shipping routes. From the Panama myth to reality. *Int. J.* 66 (4), 793–808.
- Laulajainen, R., 2009. The Arctic sea route. *Int. J. Ship. Transp. Logistics* 1 (1), 55–73.
- Liu, M., Kronbak, J., 2010. The potential economic viability of using the Northern Sea Route (NSR) as an alternative route between Asia and Europe. *J. Transp. Geogr.* 18, 434–444.
- Lorange, P., 2008. *Shipping Company Strategies. Global Management under Turbulent Conditions*. Emerald, Bingley, UK.
- Loughnane, D., 2009. Mostly employed elsewhere: one of the biggest challenges in developing Arctic shipping has nothing to do with ice, Canadian Sailings – Transportation & Trade Logistics. 2 March 23–24.
- MacLeod, B., 2012. Personal communication. Supply Team Leader, Fuel and Construction Products Division, Public Works and Government Services Canada. Correspondence with author, October 10, 2012.
- Mejlaender-Larsen, M., 2009. ARCON – Arctic container. DNV Container Ship Update 2, 9–11.
- Mulherin, N., 1996. The Northern Sea Route. Its Development and Evolving State of Operations in the 1990s. Cold Regions Research & Engineering Laboratory, CRREL Research Report 96–3. US Army Corps of Engineers, Hanover, NH.
- Mulherin, N., Eppler, D., Proshutinsky, T., Proshutinsky, A., Farmer, L.D., Smith, O., 1996. Development and Results of a Northern Sea Route Transit Model. CRREL Research Report 96–5. US Army Corps of Engineers, Hanover, NH.
- National Post, 2013. Northwest Passage crossed by first cargo ship. Sept. 27, 2013.
- Niini, M., Kaganov, S., Tustin, R., 2007. Development of Arctic double acting shuttle tankers for the Pirazlomnoye project. TSCF 2007 Shipbuilders Meeting, Busan, Oct. 24–25, 2007.
- Notteboom, T., Vernimmen, B., 2009. The effect of high fuel costs on liner service configuration in container shipping. *J. Transp. Geogr.* 17, 325–337.
- NSRA, Northern Sea Route Administration, 2012. Order dated June 07th 2011, No. 122-T/1, Maximum rates for services of the icebreaker fleet on the Northern Sea Route to ensure the transportation of cargo. Moscow. Reproduced at <www.arctic-lho.com/nsr_tariffsystem> (accessed Feb. 15, 2014).
- NSRA, Northern Sea Route Administration, 2013. Transit Statistics 2012 and 2013. Reproduced at <www.arctic-lho.com/nsr_transits> (accessed Feb. 18, 2014).
- NYK (Nippon Yusen Kaisha), 2012. Container specifications. NYK, Tokyo. Url: <www.nykline.com/liner/container_specifications/dry.html> (accessed Feb. 16, 2014).

- Ouellet, J., 2011. Personal communication. Planning & Arctic Operations Officer, Central & Arctic Region, Canadian Coast Guard, Sarnia (Ontario). Correspondence with author, December 15, 2011.
- Paterson, T., 2011. Cost comparison of shipping in the Arctic. Fednav: Presentation at Arctic Shipping North America 2011, St John's (Nfld), October 12–14.
- Schøyen, H., Bråthen, S., 2011. The Northern Sea Route versus the Suez Canal: cases from bulk shipping. *J. Transp. Geogr.* 19, 977–983.
- Somanathan, S., Flynn, P., Szymanski, J., 2007. Feasibility of a Sea Route through the Canadian Arctic. *Marit. Econ. Logistics* 9, 324–334.
- Somanathan, S., Flynn, P., Szymanski, J., 2009. The Northwest Passage: a simulation. *Transp. Res. Part A* 43, 127–135.
- Srinath, B.N., 2010. Arctic shipping: commercial viability of the Arctic Sea Routes. MSc Dissertation, City University, London.
- Suez Canal Authority, 2012. Toll calculator. Suez Canal Authority, Suez. <www.suezcanal.gov.eg/calc.aspx> (accessed Dec. 8, 2013).
- Terrassier, N., 1997. *Stratégie de développement du transport maritime de lignes régulières*. Moreux, Paris.
- UNCTAD – United Nations Conference on Trade and Development, 2011. *Review of Maritime Transport 2011*. United Nations Publications, New York.
- UNCTAD – United Nations Conference on Trade and Development, 2012. *Review of Maritime Transport 2012*. United Nations Publications, New York.
- UNCTAD – United Nations Conference on Trade and Development, 2013. *Review of Maritime Transport 2013*. United Nations Publications, New York.
- Verny, J., Grigentin, C., 2009. Container shipping on the Northern Sea Route. *Int. J. Prod. Econ.* 122 (1), 107–117.
- Wall Street Journal, 2013. Cargo ship carves a path in Arctic Sea, Sept. 25, 2013.
- Wergeland, T., 1992. The Northern Sea Route – Rosy prospects for commercial shipping? *Int. Challenges* 12 (1), 43–57.
- Wergeland, T., 2013. Northeast, Northwest and Transpolar Passages in comparison. In: Østreng, Willy. (Ed.), *Shipping in Arctic Waters. A Comparison of the Northeast, Northwest and Trans Polar Passages*. Springer Verlag and Praxis, Berlin, pp. 299–352.
- Wergeland, T., Ivanov, Y., Isakov, N., Batsikh, Y., Høifødt, S., Nilsen, F., Armstrong, T., 1991. Commercial Shipping and the NSR. In: Willy Østreng, Arnfinn Jørgensen-Dahl (Eds.), *The Northern Sea Route Project. Pilot Studies Report*. Pilot Studies Report. Fridtjof Nansen Institute, Lysaker, pp. 180–232.