Case studies of Shipping along Arctic routes.

Analysis and profitability perspectives for the container sector.

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 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

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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 analysed 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.

1. 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 analysed 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.

1.1. 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 analysed: 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 destinational traffic (ie, 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 vessel[1]; 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).

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	*Pilot Studies Report*, 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

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

1992	Wergeland, T.	The Northern Sea Route - Rosy prospects for commercial shipping	*International Challenges*, 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	*CRREL Report 96-5*, 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 - Strekaloovsky-class bulker, 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	*INSROP Working Paper 8*. Oslo:WP-164	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 route : - 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.	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., *International Energy Policy, the Arctic and the Law of the Sea*,	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	Report K-63, Aker Arctic Technology, Helsinki	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
2006	Guy, E.	Evaluating the viability of commercial shipping in the Northwest Passage	*Journal of Ocean Technology*, 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: destinational shipping	NSR; pipelines across Russia and northern Europe	Oil tanker versus oil pipeline	Varandei - Rotterdam	Year-round Several scenarios

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2007	Somanathan, S. et al	Feasibility of a Sea Route through the Canadian Arctic	*Maritime Economics & Logistics*, 9, 324-334.	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, S.	Arctic Meltdown	*Foreign Affairs*, 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 TEU A1/1AS/PC6 A3/PC3 A5/PC1	None Objective is to determine the cost to exploit the ship	Not specified
2009	Mejlaender-Larsen, M.	ARCON - Arctic Container	*DNV Container Ship Update*, 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-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, S. et al	The Northwest Passage: a simulation	*Transportation Research Part A*, 43, 127-135.	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
2009	Verny, J. & Grigentin, C.	Container Shipping on the Northern Sea Route	*International Journal of Production Economics*, 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 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	DNV Research and Innovation, Position Paper 4	Evaluate transportation costs for a year	Northern NSR and 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, M. and Kronbak, J.	The potential economic viability of using the Northern Sea Route (NSR) as an alternative route between Asia and Europe	*Journal of Transport Geography* 18, 434-444.	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, T.	Cost comparison of shipping in the Arctic	*Arctic Shipping* 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	*Maritime Policy & Management*, 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	*Journal of Transport Geography* 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.	*Energy Security and Geopolitics in the Arctic: Challenges and Opportunities in the 21st Century.* 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	*Marine Board Workshop Safe Navigation in the US Arctic,* 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	*Marine Insurance Seminar* 2012, Marieham, April 26	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, T.	Northeast, Northwest and Transpolar Passages in comparison	*Shipping in Arctic Waters. A Comparison of the Northeast, Northwest and Trans Polar Passages*, 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

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1.2. 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 & Grigentin, 2009) to 54,2% (Schøyen & Bråthen, 2011), 54,3% (Chernova & 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, 2009; Chernova & 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 &

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, 2010c; 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 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:

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 to 35%
Liu & Kronbak, 2010	1B	+20%
Mulherin et al, 1996; Kamesaki, 1999; Kitagawa, 2001	PC7	+20 to 36%
Mulherin et al, 1996; Schøyen & Bråthen, 2011	PC7 to PC4	+20%
Mulherin et al, 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 & Volkov, 2010	DAS/"high ice class":	+30 to 40%

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 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) quotes 800 $/day as the average insurance cost for a ship plying Arctic waters year-round, whereas Somanathan (2009) sets this cost at 1 746 $/day, Wergeland (2013) at 1150 $/day for a containership along the NSR, and Verny and Grigentin (2009) at 3 344 $/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 ice[2] 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, 2002:95-96).

1.3.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 (2006), 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 (2009), Srinath (2010), Liu & Kronbak (2010), Wergeland (2013) offer detailed and accounted for hypotheses with several parameters.

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.

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 Panama Suez scenario : 22,2 $/t via NSR; 34,16 $/t via Suez All costs before depreciation
1992	Wergeland, T.	Same as Wergeland 1991.
2006	Arpiainen, M. and Kiili, R.	With 5000 TEU ship, TEU unit cost is between 354$ 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/ton By pipeline: 20 euros/ton
2008	Borgerson, S.	Savings up to 20% - from 17,5 M$ per trip to 14M$.
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).

[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.

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 : 8 264 000 $
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

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 50000 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. & 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

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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 175000 $ 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.

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 transhipments 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 & Kiili, 2006: 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: 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 them[3]. They rest on simplifications of

[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).

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 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 & 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 & Pelletier, 2011).

2- 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 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 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).

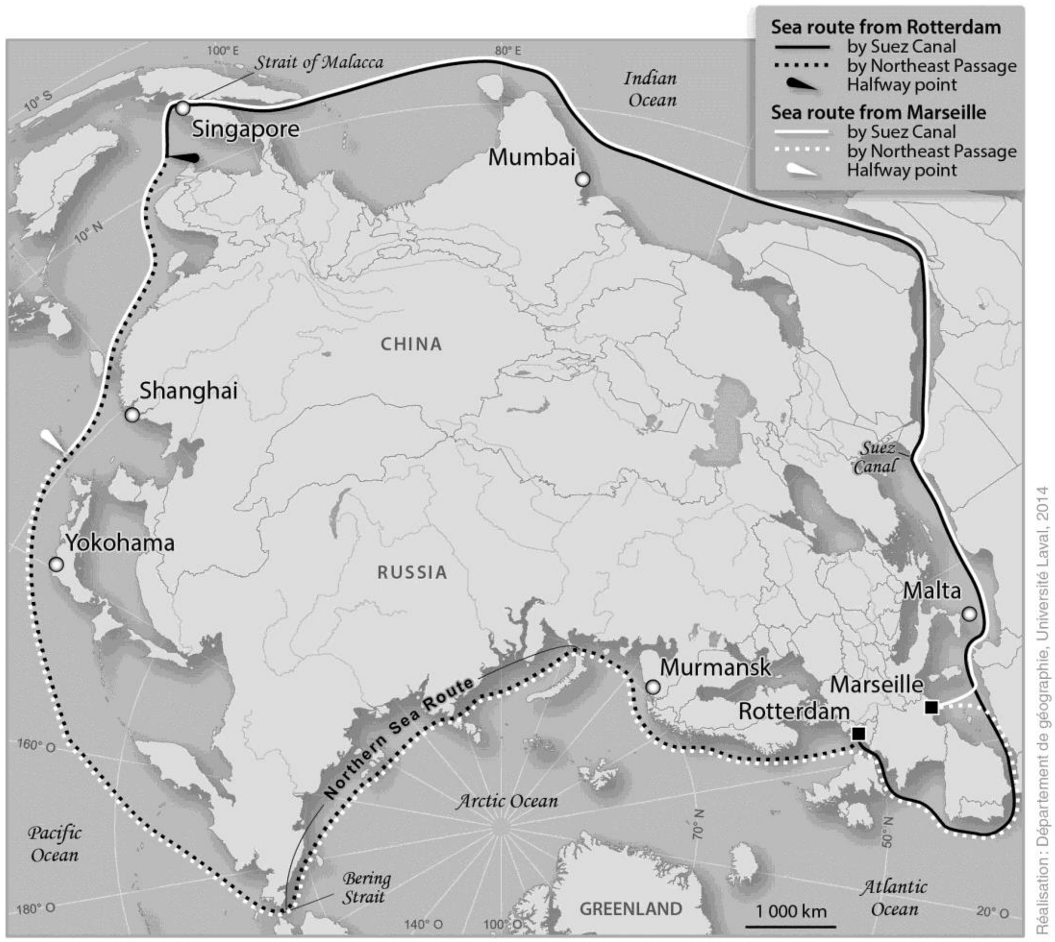

Fig. 1. Halfway point for sea routes along the Northeast Passage and across the Suez Canal, from Rotterdam and Marseille.

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 &

Grigentin 2009; Somanathan 2009; Srinath 2010; Chernova & Volkov 2010, Arpiainen & Kiili 2006).

2.1. 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, 2011)[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 case[5], and by the Center for High North Logistics (CHNL), a think-tank dedicated to research on and promotion of Arctic shipping along the NSR[6]. NSR tariffs can thus be adjusted on an ad hoc basis, and no figures are published on these sinbce they reflect specific negociations 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 competitive[7]. 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 bulker ship (unit used in Falck's simulation), beam 107 ft, draft 38 ft, gross tonnage 38 000[8]. Verny & Grigentin (2009) assume NSR tariffs are likely to remain double that of Suez, but this would already be an major improvement over official tariffs.

[4] Order dated June 07th 2011, №122-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-lio.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.eg/sc.aspx?show=31, accessed February 21, 2014.

[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.

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: 223,22 Rb/t, or 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 & 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 2011:23-24 ; 2012:21 ; 2013:24) : 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 MTEUs and 6,3 MTEUs 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 1 160$ 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.

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[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, www2.nykline.com/liner/container_specifications/dry.html, accessed Feb. 13, 2014).

- 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 & 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 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.

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		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	20 700	19 845	
Cost analysis			(for 6 months)
Crew	858 000	780 000	Suez: Verny & 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	1 200 000	800 000	For a standard ship: Somanathan 2009: 425 000$/yr ; Wergeland 2012: 339 450$/yr; Srinath 2010: 1 400 000$/yr. Conversely, Verny & Grigentin 2009 suggest 1 204 000$/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	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$/month.
Maintenance	360 000	300 000	Schøyen: +20%; Wergeland: +23%. Somanathan 2009 indicates 320 000$/yr. In 1992, Wergeland considered 1100$/d= 401 500$/y. We opted for 600 000$/y for 2012. Premium considered for NSR: +20%
Transit fees	2 310 120	1 440 000	Discounted NSR tariff: 223,22 Rb/t = 7,44$/t. (NSRA 2012). Average loaded TEU weight : 15t/TEU. Suez: 240 000$/transit, Suez Canal Authority, www.suezcanal.gov.eg
Average transit fee per trip	288 765	240 000	
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 & 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	1625,88	2262,73	
Bunker price, IFO 380, $/t	602	602	Average price in October 2012, according to Bunker Index, www.bunkerindex.com
Fuel cost per leg	978 776,75	1 362 164,35	
Fuel cost, total $	7 830 214,00	8 172 986,11	
Total cost, 6 months	18 204 304,00	16 009 786,11	
Cost per TEU	879,46	806,74	

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	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	23 850	15 930	
Cost analysis			
Crew	858 000	780 000	
Insurance: H&M, P&I	1 200 000	800 000	
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	602	602	
Fuel cost per leg	826 621,25	1 477 129,63	
Fuel cost, total	7 439 591,25	7 385 648,15	
Total cost, 6 months	18 165 221,25	14 982 448,15	
Cost per TEU	761,67	940,52	

In this sub-scenario, is 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 (23 850 against 15 930 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 1 129,55$ with the NSR and 1 079$ 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.

2.2. 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 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.

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		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	1 320 000	800 000	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	602	602	
Fuel cost per leg	1 067 346	1 362 164,35	
Fuel cost, total	7 471 422	8 172 986,11	
Total cost, 6 months	15 655 392,00	16 009 786,11	
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		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	1 320 000	800 000	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	602	602	
Fuel cost per leg	923 317,5	1 477 129,63	
Fuel cost, total	7 386 540	7 385 648,15	
Total cost, 6 months	15 570 510	14 982 448,15	
Cost per TEU	752,20	940,52	

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 still15,5% cheaper than with the Suez route.

3. 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 (ie 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.

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%

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.

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.

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

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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$.

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 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.

4. 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 13 summarizes the main biases the chosen parameters introduce

Table 12. Parameters that favor Arctic or Suez routes in the scenarios

The values of these parameters favor 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 (2014), these are average speeds that can be reached only	Load factor, set according to the literature and reflecting the recent trends of the shipping industry.

during a few weeks in August, September and early October.	
No friction effect of loose but dense ice in summer on fuel consumption rate was considered. This is a simplication 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.	

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 one where 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 & Pelletier, 2011).

It appears that:

- 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. It is likely the practice of giving rebates will become permanent, but the extent of the discounts remain obscure as of now (February 2014).
- Summer transit to Shanghai is usually not cost-competitive for a liner service, unless fuel costs are higher and, more strategically, the load factor is much improved. Fuel costs in themselves are not important enough to account for the profitability of Arctic routes.
- 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.

- 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.
- These calculations tackle merely with cost considerations, and barely consider operational aspects, like the reliability, a very important factor for an industry dominated by the logistical constraints of just-in-time. Even if costs were on a par, it remains to be seen to what extent shipping companies would decide to enter the Arctic shipping market for regular liner service in the container sector.

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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

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