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Feasibility of a Sea Route through the Canadian Arctic

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One predicted consequence of global warming is the thinning of Arctic sea ice. This raises the question whether the fabled Northwest Passage can be used for year round ship traffic, and whether the distance saved by using the polar route justifies the incremental investment in ice-breaking ships. A conceptual study using computer simulation was conducted to evaluate the Northwest Passage versus *the Panama Canal routes between eastern North America and Japan. Recent historical ice conditions were modelled stochastically to calculate ship transit time. The economic performance was then evaluated by estimating the port-to-port shipping cost component of the overall required freight rate, again using stochastic modelling for a variety of cost factors. The most critical economic variable is the incremental capital cost between an ice capable and a standard Panamax ship. Shipping from St John's Newfoundland to Yokohama is economic through the Northwest Passage even with an incremental capital cost of 80%. Extending the route to New York would make the Northwest Passage non-competitive. We report the sensitivity of the port-to-port shipping cost for a number of economic factors, with capital and fuel cost being the most significant.*
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INTRODUCTION

A sea route to the Orient through the Arctic was passionately pursued by early European mariners, including Franklin, whose entire crew lost their lives in the process (Canadian Geographic, 2007). However, the Northwest Passage across northern Canada proved impossible due to difficult ice conditions and is used as a shipping route only during a short summer thaw. Recently, milder ice conditions have been reported and linked to global warming (Black, 2005; Amos, 2007). These conditions may present new opportunities for merchant shipping since east-west voyages through the polar latitudes are shorter than southerly alternatives. In a previous work, we reported on a detailed model of the transit speed of fast and slow ships using the Northwest Passage and the Panama Canal from New York and St John's Newfoundland to Yokohama incorporating recent data on sea ice (Somanathan *et al*, 2006). In this work, we combined this transit model with a detailed stochastic model of shipping cost to evaluate key factors affecting the economic viability of a year round Arctic route. We calculated the port-to-port shipping cost that includes all ship costs including capital recovery. Note that the shipping cost is only one component of an overall freight rate; port charges, documentation cost, container lease or rental costs, container handling costs, and any charges for intermodal transfer of containers are not included. We also calculated the degree of uncertainty in shipping cost that arises from the uncertainty in cost parameters. We rank cost factors by their impact on shipping cost. The Northwest Passage is shown in Figure 1.

METHODS

We developed a complex simulation in which transit time is first modelled, allowing calculation of the number of round trips that can be made per year for each route for two ship types carrying dry containers, a bluewater Panamax and Arctic class vessel, described below. We then use these data in an economic model that incorporates cost data for each ship type and calculates the shipping cost on each route to recover all costs, including a return on capital. There is a high degree of uncertainty for the Northwest Passage in both transit time and capital and operating cost. Uncertainty in the Panama Canal route is lower, but there are still variable factors such as wait time to enter the Panama Canal and actual ship speed in open water. To account for uncertainty, we use a stochastic approach with a Monte Carlo simulation of both transit and economic data. To avoid a bias due to ship size, we limit the size of the ship through both routes to 4,500 TEU, the largest ship size that can transit the Panama Canal (a Panamax ship, limited to a length of 294.13 m, a beam of 32.31 m, and a draft of 12.04 m as defined in MR Notice to Shipping, 2007). Note, however, that there is not a physical limitation to larger ships transiting the Northwest Passage.

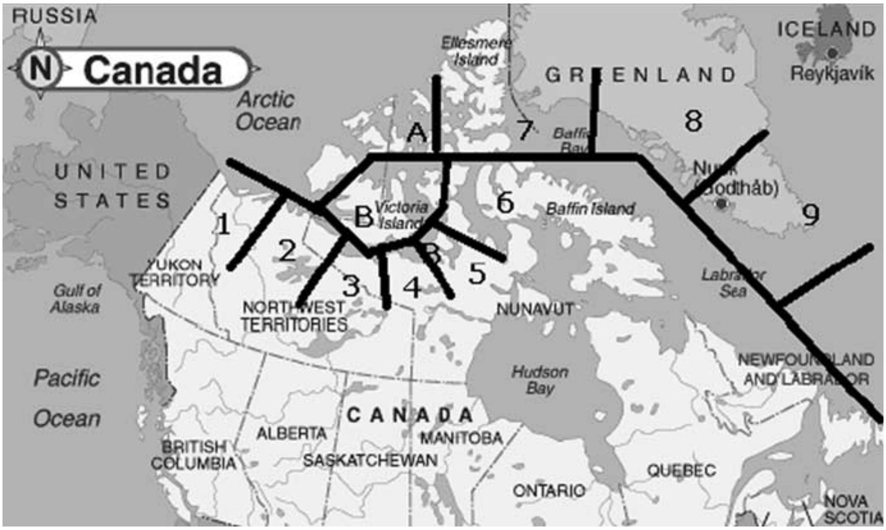

Figure 1: Alternate route through the Northwest Passage (map courtesy of Maps.com).

Transit model

The transit models are described in detail in a previous work (Somanathan *et al*, 2006). In brief, Canadian sea ice data is drawn from historical ice records over the period 1999 to 2003. Early analysis confirmed that alternative route A in Figure 1 was not feasible for shipping due to extensive thick multi-year ice. Alternative route B was broken into nine legs, illustrated in Figure 1. VSLAM^{TM} software was used to model the distribution of ice conditions for each leg, and to stochastically assign ice conditions. Merchant ships for ice service in Canada are rated by a system known as Canadian Arctic Class (CAC). Transport Canada has standards for the class of ship required as a function of the ice condition (Transport Canada, 1998). Analysis of ice data showed that a CAC 3 ship would be required for year round transit. A CAC 3 Class ship is a commercial cargo carrying ship designed for unrestricted travel in heavy first year ice and second year ice less than 2 m thick. It would proceed through multi-year ice only when it is unavoidable and would do so in a controlled manner that would normally include ramming. CAC 3 ships are equipped with ship stress monitoring systems. Since no commercial CAC 3 merchant ships operate today, speed through ice was estimated by extrapolating from values for existing ships of lower capability. Transit through ice included periods of being beset, and in extreme cases, periods of awaiting the service of an icebreaker.

The transits were modelled for two rated open water speeds for both the Arctic and Panamax ships: 11 and 20 knots. Within the simulation, the actual

Table 1: Transit model results

Ship type	Route	Round trips/year (Mean)	Round trips/year (Std dev)
Fast Ship Arctic	Yokohama–New York	8.52	0.11
Fast Ship Panama	Yokohama–New York	7.55	0.02
Fast Ship Arctic	Yokohama–St John's	9.74	0.13
Fast Ship Panama	Yokohama–St John's	7.08	0.02
Slow Ship Arctic	Yokohama–New York	5.03	0.07
Slow Ship Panama	Yokohama–New York	4.40	0.01
Slow Ship Arctic	Yokohama–St John's	6.60	0.61
Slow Ship Panama	Yokohama–St John's	4.11	0.01

open water speed is stochastically modelled as a triangular distribution with the rated speed as the maximum and modal value, and a range of 85%–100%. Four routes were modelled: New York and St John's Newfoundland to Yokohama and return, each by an Arctic and Panama Canal passage. Similarly, average values and the range of values for Panama Canal wait times were estimated from data provided by the Panama Canal Authority (Panama Canal, 2004). Table 1 shows the results of the transit model. The difference in round trips per year for slow ships between the Arctic and Panama Canal routes is low, and we dropped slow ships from further consideration. The focus of this work is on the stochastic modelling of variable cost factors for fast ships to further evaluate the alternative shipping routes.

Cost model

The starting point for capital cost analysis is a bluewater ship specification for a 22 knot maximum and 20 knot economic speed, 4,500 TEU Panamax fast container ship powered by a 28,000 kW diesel engine (MAN B&W, 2004). The TEU rating is a measure of a ship's container carrying capacity. New ships show a surprising degree of variability in capital costs over time (Stopford, 1997). The reported cost of 2,500 TEU ships was $26million in 1985, $52 million in 1990, $38 million in 2003, and $42 million in 2005 (UNCTAD, 2006). To model the capital cost of a bluewater 4,500 TEU ship, we use a range of $40–$75 million (all figures in the cost model are expressed in 2007 US$). In this analysis, all variables are assumed to be uniformly distributed, an approach that is recommended when there is a high degree of uncertainty about likely values within a range (Mulherin *et al*, 1999). Return on capital is also highly variable in the shipping industry, and we model the pre-tax return on total capital from 7% to 12%. Our estimate of a CAC 3 ship is scaled from the bluewater ship by assuming a second identical engine and a propeller to provide both redundancy and sufficient power for ice breaking. There is a high degree of uncertainty in the capital cost of the CAC 3 ship, since no merchant carriers of this type have been built. For the base case, we assume that the CAC 3 ship cost is 30% higher than a Panamax ship, based on the estimation that the additional power plant equipment adds 20% and that thicker steel work adds 10%. However, the capital cost premium is highly uncertain, and is such a critical factor in overall cost that we explore the sensitivity of this value over a wide range of capital cost premium for the CAC 3 ship, from 110% to 200% of the cost of the Panamax ship.

For operating and maintenance costs, a number of variables were identified for which values were not certain; Table 2 lists these and the range of values used in the study. We assumed that each ship was operated by a ship management company. In this study, management fees are based on industry estimates (Nagarajan, General Manager (Operations), Fleet Management Ltd., Hong Kong, 2007, personal communication regarding operational costs (22 August 2007)) and cover the cost of crewing, including wages and provisions, and normal maintenance including stores, but do not include fuel and lubricating oil, dry docking and steel repair work. For the Panama Canal route, the value is \$4,000–\$5,000 per day. For the Arctic ship, we increased this range to include an ice navigator (\$265 per day), an additional second engineer (\$150 per day), an additional engine room crew and two deckhands (\$150 per day to cover all three positions), and additional spares and repairs for the second engine (\$650 per day) (Nagarajan, 2007, personal communication), thus increasing the management fee to a range from \$5,225 to \$6,225 per day. For the Panama Canal ship, two dry dock maintenance periods per 5 years are assumed,

Table 2: Ranges for key operating, maintenance and voyage costs[1]

	Arctic		Panama	
	Low	**High**	**Low**	**High**
Management fee (million \$/year)[2]	1.90	2.27	1.46	1.83
H&M premium (million \$/year)[2]	0.30	0.45	0.20	0.30
P&I premium (million \$/year)[2]	0.23	0.30	0.15	0.20
Dry docking (million \$/year)[2]	0.60	1.0	0.24[1]	0.40[1]
Steel quantity (tons)	150	200		
Steel rate /ton (\$/ton)[2]	1200	1800		
Propulsion power (kW)	42,000	56,000	19,600	25,200
Specific fuel consumption[3] (g/kW-h)	160	171	160	171
Bunker price (\$/ton)[4]	360	420	340	400
Lube oil price (\$/l)[2]	1.6	1.8	1.6	1.8
Specific lube oil consumption (grams/kW-h)[2]	0.7	1.1	0.7	1.1

[1]Based on two dry docking per 5 years.
[2]Nagarajan (2007, personal communication).
[3]MAN B&W and Wartsila Diesel (2004).
[4]Bunker fuel prices at Panama and New York from Bunker World (2007).

which meets the statutory requirement, with no steel work required; this frequency is increased to once per year for the Arctic ships, and we assume that steel repair work is required during every dry dock maintenance. The key variables in dry dock maintenance are the cost of dry docking itself, the amount of steel for the Arctic ship, and the cost of steel work. Two types of insurance were estimated for each ship type: Hull and Machinery (H&M) and Protection and Indemnity (P&I). A range of values for the Panama Canal ship were based on industry estimates (Nagarajan, 2007, personal communication). The estimate of insurance premium for the Arctic route is judgmental, since no commercial premiums for year round trans-Arctic shipping are now quoted. We assume a 50% increase over Panamax rates, but due to the high degree of uncertainty we explore the impact of a wide range of values for this increase, up to 100%.

Voyage costs typically refer to fuel, canal, and port fees; we included lube oil costs, often covered under management fees, in order to assess the impact of its uncertainty. Average propulsive power is taken as a range of maximum propulsive power, and hence the actual values in kilowatts for the Arctic ship will be twice that of the Panama Canal ship, reflecting the second engine. Note that the second engine is assumed to operate only when the ship is in the Northwest Passage itself; the ship operates on one engine and has the same performance characteristics as the Panama Canal ship when operating in open water. The range for specific fuel consumption is taken from engine manufacturers (MAN B&W, 2004; Wartsila Diesel, 2004) and the range for cost of bunker fuel oil is taken from historical price data (Bunker World, 2007). Ships on the Arctic route are assumed to fuel in North America, and ships on the Panama Canal route fuel in Panama. Values for cylinder lube oil specific consumption and the cost of lube oil are based on industry estimates (Nagarajan, 2007, personal communication).

Several cost values were deterministic in the model, that is, with no range of uncertainty: fuel consumption for generators (0.1 tonne per hour in open water, twice than that in ice) and crankcase lube oil consumption (0.5 l per operating hour), both taken from industry estimates (Nagarajan, 2007, personal communication) and Panama Canal fees calculated from per TEU rates provided by the Canal Authority (Panama Canal, 2007). Port charges were assumed to be paid by the charterers, and are not included in the model.

The @risk™ simulation software, an add-in to Excel™ spreadsheet software, was used to conduct a Monte Carlo simulation of the cost of transit. Round trips per year were calculated as a distribution from the transit model and input to @risk™ . The software sampled this distribution along with all variable cost elements, and a shipping cost was calculated for each simulation run in units of dollars per TEU; each ship is assumed to have a capacity of 4,500

Table 3: Correlation matrix between cost elements

	H&M premium	P&I premium	Capital cost	Management fees	Dry dock cost	Steel work cost
H&M premium	1					
P&I premium	0.2	1				
Capital cost	0.8	0.2	1			
Management fees	0	0	0.2	1		
Dry dock cost	0	0	0.6	0	1	
Steel work cost	0	0	0.6	0	0.6	1

TEUs. Multiple runs of the model (1,000) gave a distribution of calculated values of shipping cost.

While an equal probability of occurrence was assigned to each uncertain variable over its range, it is likely that some correlation would exist between these variables. For example, when the cost of steel used in ship maintenance is very high, a sign of high construction activity, it is highly probable that the cost of labour to install the steel and the capital cost of ships would also be high. To account for this, we estimated the correlation between cost variables; initial judgmental values are analysed by the @risk™ software which then calculated an internally consistent correlation matrix, shown in Table 3.

RESULTS

Table 4 shows the statistics of shipping cost for the four routes from the base case values in this study, a 30% premium for capital cost for the CAC 3 Arctic ship and a 50% premium on insurance. The results show that the Northwest Passage route offers a saving of almost 10% relative to the Panama Canal for freight from St John's. The longer distance through the Northwest Passage from New York and the corresponding shorter distance through the Panama Canal means that the Canal route is favoured from New York. The difference is significant, although perhaps not compelling given the higher risk and uncertainty for the Northwest Passage. If, however, ice continues to be thin, the Arctic Passage economics will improve over time.

Modelling transit cost allows the calculation of the sensitivity of shipping cost to each of the uncertain cost variables as well as the key output of the transit model, round trips per year. @risk™ software does this by calculating the change in shipping cost, measured as a fraction of its standard deviation, for a one standard deviation change in the cost variable. Note that in this study all variables were assumed to be uniformly distributed over the range of

Table 4: Shipping cost, $ per TEU for base case (capital cost premium of 30%)

	Yokohama–St John's		Yokohama–New York	
	Mean	**Standard deviation**	**Mean**	**Standard deviation**
Arctic	348.41	25.9	388.1	29.5
Panama	383.7	25.8	358.4	23.9

uncertainty. For such a distribution, the standard deviation is given by (range)/($12^{0.5}$). Figure 2 shows the relative ranking of the impact of variability in costs. The most significant cost variables relate to the capital cost of the ship and fuel usage, and each may decrease if Arctic ice continues to be thin, as discussed further below.

Because the capital cost of the CAC 3 ship is both highly uncertain and of very high impact on shipping cost, we analysed this variable over a wider range of values. In the base case, the model samples from the range of bluewater ship costs and increases this value by 30% for the CAC 3 ship. We reran the model for a CAC 3 ship capital cost premium over the range of 10% to 100%, calculating average cost based on 1,000 stochastic runs for each value of the capital cost premium. Figure 3 compares the shipping cost for the Northwest Passage routes, which increase with the CAC 3 ship capital cost premium, to the shipping cost through the Panama Canal. The Northwest Passage route is never economic for the New York to Yokohama route, but is economic for the St John's origin for a capital cost premium of up to 80%.

DISCUSSION

This study illustrates the power of stochastic modelling to analyse the impact of many uncertainties when evaluating a new shipping route. The transit model described in a previous work captures many environmental uncertainties, for example, the distribution of sea ice conditions through the Northwest Passage. If climatic change has a significant impact on sea ice the model can be updated to recalculate the distribution of transit speed, from which round trips per year is derived. The cost model discussed in this work focuses on uncertainty in financial factors, and allows the impact of these to be ranked. This allows those considering a shipping route through the Northwest Passage to focus on reducing uncertainty in critical variables.

This study identifies two general areas that most impact shipping cost for an Arctic shipping route: ship capital cost and fuel cost. Ship cost is reflected in two variables, initial ship cost and the return on capital. Fuel consumption is

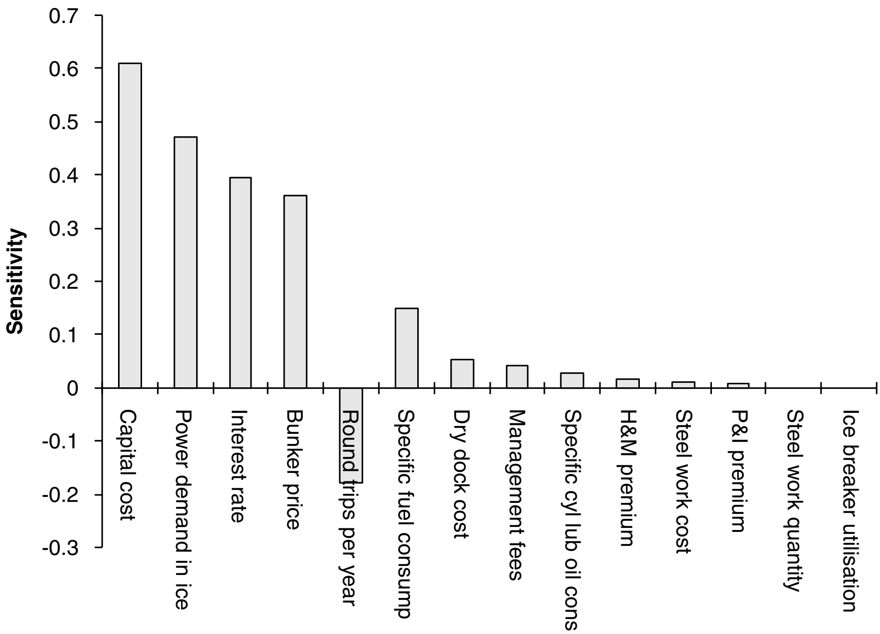

Figure 2: Change in standard deviation of shipping cost for a one standard deviation change in input variables.

reflected in four variables, power demand in ice, the price of bunker fuel oil, power demand in open water, and engine efficiency as measured by specific fuel consumption per unit of power. These six variables and the average round trips per year are the critical variables affecting a comparison of transit through the Northwest Passage to a Panama Canal route.

Ice conditions sampled for this study, from 1999 to 2003, preclude the use of a CAC 4 ship. By far the largest uncertainty in evaluating the Northwest Passage route is the capital cost of a merchant CAC 3 ship, since none have been built. If the cost of an Arctic ship is more than 80% higher than a bluewater ship, the Northwest Passage is uneconomic for all ports of origin in North America. Hence this study makes clear that anyone contemplating the route should focus on a more detailed and reliable estimate of the ship's capital cost.

In order to focus on route selection, this study assumed identical sized ships for the two alternatives. However, the Panama Canal imposes size limitations on ships that are not required for the Northwest Passage, and a CAC 3 ship could be built to carry more cargo than the Panama Canal ship. One environmental unknown is whether transit of the Northwest Passage on a repeated basis would help to open up a clear channel or one with thin ice,

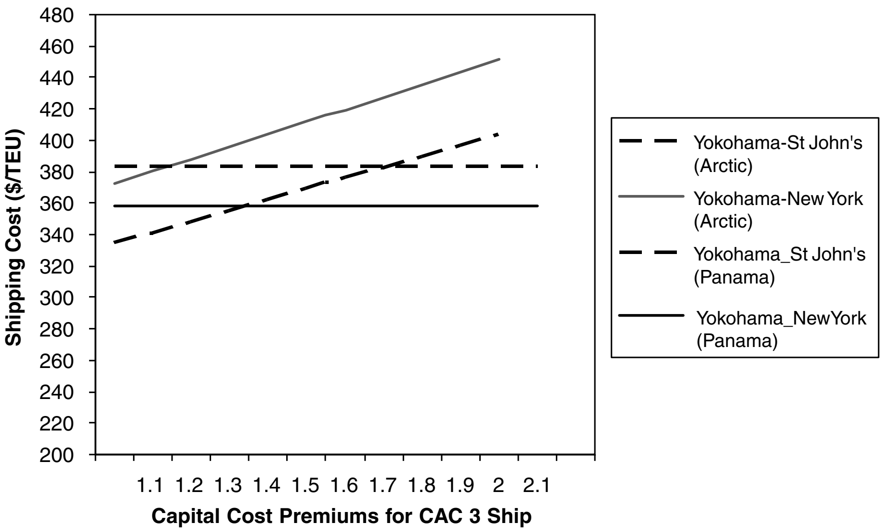

Figure 3: Impact of CAC 3 ship capital cost premium on shipping cost.

leading to faster speed and lower fuel consumption relative to what is modelled in this study. Factors such as these can be incorporated into a future analysis if the trend in ice thinning continues.

CONCLUSIONS

A stochastic model of shipping through the Panama Canal and the Northwest Passage using identically sized ships calculates that the Northwest Passage would be more economical for freight between St John's Newfoundland and Yokohama, but less economic for New York and Yokohama. The base case in the model assumes a 30% premium in the cost of a ship suitable for the Arctic Route, a CAC 3 ship. There is a high degree of uncertainty in many of the environmental and cost variables for the Northwest Passage route. Ship cost and fuel consumption are the most critical variables affecting the comparison of the two routes. For example, if the premium for a CAC 3 ship relative to a bluewater ship is more than 80% the Northwest Passage is uneconomic for all ports in North America. The model can be updated to incorporate new data as sea ice conditions change or more information becomes available on cost factors. The model can help shippers, insurers and governments to assess the risk of opening up a shorter northern route between the Atlantic and Pacific Oceans.

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