Marine Policy 153 (2023) 105647

Contents lists available at ScienceDirect

Marine Policy

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

Full length article

Socio-economic impacts of shipping along the Northwest Passage: The cost to locals

Shengda Zhu [a,*], Adolf K.Y. Ng [b,c], Mawuli Afenyo [d], Roozbeh Panahi [e], Michael G.H. Bell [a]

[a] Institute of Transport and Logistics Studies (ITLS), The University of Sydney Business School, The University of Sydney, Sydney, Australia
[b] Faculty of Business and Management, BNU-HKBU United International College, Zhuhai, China
[c] Centre for Earth Observation Science and St. John's College, University of Manitoba, Winnipeg, MB, Canada
[d] Department of Maritime Business Administration, Texas A & M University, Galveston, USA
[e] Jacobs Solutions Inc., Toronto, ON, Canada

ARTICLE INFO

Keywords:
Arctic shipping
Northwest Passage
Northern Canada
Socio-economic impacts

ABSTRACT

This paper presents a novel approach to assessing the cost of container liner shipping through the Northwest Passage (NWP) on northern local communities. Based on some representative communities, concerns of the residents of these Canadian Arctic regions were assessed. Two essential factors to the well-being of the community members—air pollution and oil spills—are considered in our model. The approach was therefore used to evaluate the socio-economic impact of Arctic container liner shipping in Canadian Arctic regions. More specifically, the approach adopted a) uses a logit model to estimate the market share of NWP for commercial liner shipping; b) investigates different scenarios to evaluate the feasibility of commercial liner shipping through the NWP; c) incorporating concerns from the local communities, conducts a socio-economic analysis for the communities. With the analysis of the socio-economic impacts on local communities, the study would help guide governments on how to evaluate and calculate transit fees for transiting NWP. The study is imperative in supporting decision-making to shape Arctic policy. Furthermore, it gives stakeholders an idea of the market dynamics of shipping in the Arctic area.

1. Introduction

The recent COVID-19 supply chain problems as evidenced both in the early stages [51], during the COVID-19 [8] and also the aftermath, particularly the recovery of the impacted supply chains [37] has created uneasiness about how resilient our supply chains are. Furthermore, the mega ship Ever Given blockage of the Suez Canal has further heightened the debate on the need to further develop the polar routes. While the Northern Sea Route has experienced extensive developmental efforts and also a major route for the LNG transport, the NWP has not experience similar trajectory of development [2]. The arguments often put forward are the short distance and the saving of money when the polar routes are used as an alternative to the Suez and Panama (for example, [42,24,30]).

That being said, there are still discussions on the economic feasibility of using these new waterways. Some of the concerns include the cost of using ice-breakers and the environmental-related cost [1]. Natural resources, including hydrocarbons and rare minerals, are another incentive for Arctic shipping growth. For example, through the Yamal LNG plant in the Russian Arctic area, 15 LNG ice breaker tankers were commissioned to export gas, and the vessel successfully embarked on its first voyage in 2019 without the use of additional ice-breakers. [1]

Among the Arctic routes, the two most discussed are the Northern Sea Route (NSR) and NWP, mainly because of their viability. The NSR runs along the Russian Arctic coast and connects Europe to the Far East Asia ports. The use of the NSR is said to help reduce the distance to travel by approximately 40%. The NSR was adopted since the Soviet era as a critical part of the 'Northern Deliveries' programme, but the infrastructure along it has not been well developed [17,18,21].

Analogous to the NSR, the NWP on the Canadian side recorded approximately three times the volume of shipping activities from 1990 to 2015 due to reductions in sea ice concentration [9,39,5]. Because of the potential growth of transport in the NWP, different levels of governments initiated a wide range of plans to develop marine

* Corresponding author.
E-mail address: shengda.zhu@sydney.edu.au (S. Zhu).

[1] Source: https://www.total.com/energy-expertise/projects/oil-gas/lng/yamal-lng-cold-environment-gas

https://doi.org/10.1016/j.marpol.2023.105647
Received 29 January 2023; Received in revised form 29 April 2023; Accepted 1 May 2023
Available online 10 May 2023

infrastructure along the NWP [23,40]. Despite the increasing economic activities and prospects, local residents in the Canadian Arctic area have expressed serious concern about the impacts of the increasing transport volume in their jurisdiction, citing the effect on hunting and culture.

Therefore, successive Arctic governments have presented a series of Arctic policies to the public, and the Canadian government has proposed the Low Impact Shipping Corridors initiative to reduce the possibility of shipping incidents [32,46]. A critical issue remains, that is how the proposals within the policy are going to be implemented. For example, some of the key items to be addressed include the provision of internet and infrastructure for health care, education and security. It is not very clear where the money is coming from, but both China and Norway have expressed their interests to get involved [14].

The liner shipping companies are not in agreement on adopting Arctic shipping for delivering their containerised goods, and the shortened distance [26] and melting of sea ice [27] do not directly lead to massive traffic in the Arctic routes. While some liners like CMA CGM and Hapag-Lloyd reject Arctic shipping routes mainly because of environmental concerns, COSCO and Maersk have conducted many test voyages since 2013 to explore the possibility of new container services in the North [4]. This development then brings up the challenges on both developing the Arctic and creating jobs as well as focusing on the socio-economic implications of shipping activities in the Arctic. In both cases, there is a need to find common ground to take full advantage of the prospect of the Arctic.

Current literature is mainly focused on the economic and navigational viability of Arctic shipping, and there are limited studies on the social and economic impacts of operating liner ships on the local population [31]. This is even more the case for the Northwest Passage, where much has not been done to study the implication of shipping activities on the indigenous community along the NWP. Therefore, this study assesses the socio-economic impacts of shipping on northern local communities along the NWP. In this study, a) we use a logit model to evaluate the market share of NWP for commercial liner shipping and thus estimate the corresponding transport volume of NWP in its voyage period; b) We conduct a socio-economic impact analysis for shipping in the; c) We consider different scenarios to evaluate the feasibility of the NWP in terms of cost for commercial liner shipping and guidance is given to governments on how to decide the fee for transiting the NWP.

The rest of the paper is as follows. Section 2 reviews the relevant literature. Section 3 summarises the impacts of the opening of the NWP on its local communities. Section 4 presents the economic model and Section 5 is the analysis of different future scenarios using the model presented in Section 4. Discussion and conclusions are presented in Sections 6 and 7.

2. Literature review

Previous studies indicate that economic and safety issues are shipping companies' primary concerns on Arctic shipping. Tseng and Cullinane [47] incorporated different concerns of Arctic shipping in a Fuzzy based Analytic Hierarchy Process (FAHP). Sixteen attributes are broken into four categories, namely economic (five attributes), technical (four attributes), political (three attributes) and safety (four attributes). They found that the economic factors are the most important, among which fuel cost has the highest weight. Safety-related factors are the second and more vital than economic factors when deciding the vessel types. All four attributes under the safety category are ranked the top six, in which risk of crew health and safety ranked first, and weather and geographic complexity ranked second in all the 16 attributes. Fu et al. [12] looked specifically into the safety and security issues and identified human factors as the most important risk influencing factor of Arctic shipping.

As NSR is predicted to be more navigable in the near future than NWP [11] and the NWP countries' Arctic policy is changing over time [35], there are more studies focused on the NSR (For example, [50,29,13,25,53,55,20,15]). As reviewed by Theocharis et al. [45], the assumptions and conclusions made in these publications were given based on the comparisons between the Arctic routes and the traditional Suez and Panama canals routes. All the studies confirmed the distance reduction effect in favour of the Arctic routes, but this does not necessarily translate into savings in time and cost proportionately, as noted by some researchers. Even during the summer, the navigability of the Arctic is more hazardous than conventional routes, and most vessels require some kind of ice-breaker escort. Due to changing ice conditions, multi-year ice and extreme weather, vessels need to move slower and more carefully, leading to a higher cost per unit distance. Therefore, there is no consensus on the profitability of Arctic shipping [30].

Although shipping is among the least harmful transport modes in terms of per ton-km, in absolute terms, it is still a major source of atmospheric emissions and other climate change related concerns including impact on human health [7]. Other externalities, including oil and chemical spills, discharges, noise, and ballast water, are also worth noting [34]. The International Maritime Organisation (IMO)'s *Marine Pollution Convention* (MARPOL) is an international convention aimed at preventing ship pollution on both operational and accidental levels. Studies argue that IMO regulation is not strict enough. Chu Van et al. [6] stated that IMO regulations on the fuel type for emission control areas would require extra energy consumption through the fuel refinery and in return, increase the greenhouse emission. Because of the vulnerability of the Arctic area, Lindstad et al. [28] pointed out that the economic benefit of shorter travel distance by adopting NSR is not enough to offset its negative effects of additional emission, even with cleaner fuel.

Ng et al. [31] emphasised the importance of the 'landside', namely Arctic shipping's socio-economic impacts on local communities. For instance, Zheng and Kim [54] assessed how climate change might influence shipping companies' scheduling strategies in Mackenzie River—a major route serving many Northern Canadian communities and provided suggestions on how to better adapt to the changing environmental conditions. Olsen et al. [33] conducted case studies in three Arctic communities in Norway, Russia, and Canada. This was done by interviewing locals to ascertain their perspectives on increasing shipping traffic. To further investigate the impacts of Canada's Low Impact Shipping Corridors, Dawson et al. [10] surveyed 14 northern communities and recommended preferred corridors, restrictions and areas to avoid.

The first gap in current literature is that the NSR is more frequently investigated, while little attention was given to the other potential Arctic shipping route, like the NWP. The second gap is, admittedly there are a few research works that discussed the intertwined social and environmental issues of Arctic shipping, they are focusing more on how the new shipping routes could contribute to the global economy while insufficient in the social-economic impacts on the nearby communities. To fill the research gaps, this study investigates how container liner shipping would affect local communities in northern Canada along NWP. Based on the estimation of future NWP's market share and the number of transits, different scenarios are analysed to evaluate how much governments should charge the ships using NWP and subsidise to compensate for negative impacts on local communities.

3. Social-economic impacts on local communities

According to Olsen et al. [33], communities in Norwegian, Russian, and Canadian Arctic areas could benefit from the shipping traffic in terms of food security, community accessibility, and (eco-)tourism. Concerns expressed in these three cases include consequences of shipping accidents, disturbance on the mobility of both people and animals, noise, and the possibility of oil spills.

Based on the location of NWP, the Arctic communities along the passage are considered as "focused communities" in this study. These nine communities, or Culturally Significant Marine Areas (CSMAs) [49] include Aklavik, Cambridge Bay, Gjoa Haven, Inuvik, Pond Inlet, Paulatuk, Sachs Harbour, Tuktoyaktuk, and Ulukhaktok. Some of the focused communities prefer to completely not have shipping and icebreaking activities around their residential areas. The others recommend that oil spills and docking equipment should be installed, and the vessels should have ballast water control and limit their voyaging and icebreaking season. To achieve the Low Impact Shipping Corridors (LISC) in the Arctic area, all shipping activities need to be miles away from the coast and not disrupt marine mammal habitats and marine flora [48].

In this study, we focus on assessing the implications of air pollution and oil spills in the focussed area. Furthermore, the income from the transit fee for using the NWP is also evaluated.

3.1. Air pollution cost

The focus of this study is on the Canadian Arctic's communities, and air pollutants considered for calculations include non-methane volatile organic compound (NMVOC), sulphur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter (PM). The cost is described in terms of health effects, crop loss, biodiversity loss and material damage. Similar to Zhu et al. [55], the total cost of air pollution (TC_{AP}) per trip can be expressed as shown in Eq. 1:

$$TC_{AP} = V * \Sigma_{i=1}^{n} f_i * p_i \tag{1}$$

Where f_i (kg/ton) is the emission factor of pollutant i and p_i is the damage cost of each unit of pollutant i. The total fuel consumption of each trip $V(t, e) = d * e$ is determined by the transport time d (days) and fuel efficiency e (ton/day). Emission factors are approximated from Peters et al. [38] and the unit cost of each pollutant (p_i) is retrieved from Huib et al. [19]'s report on transport externalities. As the costs are evaluated based on the average value of 28 European Union (EU) countries, they are modified by the population densities of 28 (EU) countries and the focused communities investigated in this study.

3.2. Oil spills cost

The oil spills impact is calculated using algorithms presented in Afenyo et al. [1] and [2]. The summary of the algorithm is shown in Eq. 2.

$$TC_{OS} = N_j + S_j + R_j + X_j \tag{2}$$

Where for the pollutant j (in this case oil) N is the natural damage, S is the economic damage, R is the cost related to response (clean up) and X is the other related cost not captured.

These are integrated into an influence diagram. Some of the many factors considered for developing the model include the cultural disruption due to oil spills, days spent at sea by the shipping vessel, destruction of flora and fauna as a result of oil spills, disruption in the association of community members as a result of oil spills, ice cover, and the level of thrust. For details on the development of the model and calculations, readers are advised to refer to Afenyo et al. [1] and Afenyo et al. [2].

4. The model

To predict the market share that NWP can derive from the Panama Canal Route (PCR), the market share of NWP in the two markets are estimated, which are Europe-North America western coast and East Asia-North America eastern coast. These two routes account for in total about 38% of the traffic in PCR.

The Yokohama-New York route is selected as representative of East Asia-North America east coast routes. Compared to the traditional PCR's distance of 20,032 km, travelling via NWP can save up to 32% of the travelling distance (13,611 km). For the Europe-North America western coast route, Rotterdam-Vancouver is selected. Its PCR distance is 17,714 km while the NWP distance is 13,310 km, saving 25% distance.

Fig. 1 shows the steps adopted to model the socio-economic costs of the focused communities. A logit model is applied based on the general costs of NWP routes and traditional PCR routes to estimate the market share of NWP and then its transport volume. The overall costs of air pollution and oil spills are then calculated and summed up as the total socio-economic costs in NWP. Weighted by the local communities' proportions in the total population of NT and NU, the total socio-economic costs of all the focused communities are obtained.

The logit model from Tavasszy et al. [44] is used here to estimate NWP's future market share. It is widely used in route selection problems, and aggregate market share estimation as its compensatory nature can show each option's overall quality instead of one dominant attribute. Among N viable options, the probability θ_i to select option i is:

$$\theta_i = \frac{\exp(-\lambda * c_i)}{\Sigma_{k=1}^{N} \exp(-\lambda * c_k)} \tag{3}$$

And the generalised cost c_i of option i is:

$$c_i = p_i + vot * t_i \tag{4}$$

The generalised cost has two components: the first part is the price of this option (p_i), in this study, it is approximated as the total cost; the second component is the time cost determined by the value of time (vot) and transport time (t_i).

This study considers a voyage period of 180 days per year. The data of container ship size traversing the NWP are limited. Based on the transit data released in 2022,[2] no container ship transit was recorded. As a comparison, the deadweight tonnage of general cargo ships is around 20,000 (for example, *Taagborg* for 21,338 and *Trinityborg* for 21,277), which is similar to handy sized container ships with capacity of around 1700 TEUs (for example, *Maersk Victoria* for 23,550 DWT and 1740 TEUs capacity). Another reference point is *Venta Maersk,* which successfully transited the NSR in 2018 and has 3600 TEUs capacity. Therefore, the ship size in NWP is assumed to be 2500 TEUs which is reasonable considering the current facility level and near-future development plan along the area. The ship size in the Panama Canal is assumed to be 15,000 TEUs, and the load factors are assumed to be the same in PCN and NWP. Parameters and attributes are compiled from Zhu et al. [55], Lasserre [25], Solakivi et al. [41], and other online resources to reflect the most updated situation. Specific costs are summarised in Table 1:

When there is no transit fee or fuel requirement, NWP's shipping cost is slightly higher than its Panama rival. Travelling time from Yokohama to New York via NWP is about 21 days, and it saves about 30% transport time compared to PCR. The time saving of the Vancouver to Rotterdam route is about 26%. Though the voyage speed in the Arctic area is slower than other areas, traditional PCR is assumed to have more port of calls alongside and therefore, offsets some of its sailing speed merits. The transport cost of Yokohama-New York is estimated to be 829 USD/TEU in NWP and 605 in PCR. A similar cost of 819 USD/TEU is estimated for the Vancouver-Rotterdam via NWP, while the PCR price is 569. $\lambda = 0.0045$ obtained by Tavasszy et al. [44] and cargo value of 25,000 USD/TEU are used to estimate the market share. In 2018, 10.1 million loaded TEUs were recorded transport through the Panama Canal and together with the proportions of the routes' transport volumes [36], the transport volume of NWP could be estimated. Under such conditions, the results are summarised in Table 2. When no socio-economic cost is considered, NWP can get 28.07% market share in Yokohama-New York and 24.98% in Vancouver-Rotterdam during its voyage period.

[2] Source: https://www.spri.cam.ac.uk/resources/infosheets/northwestpassage.pdf

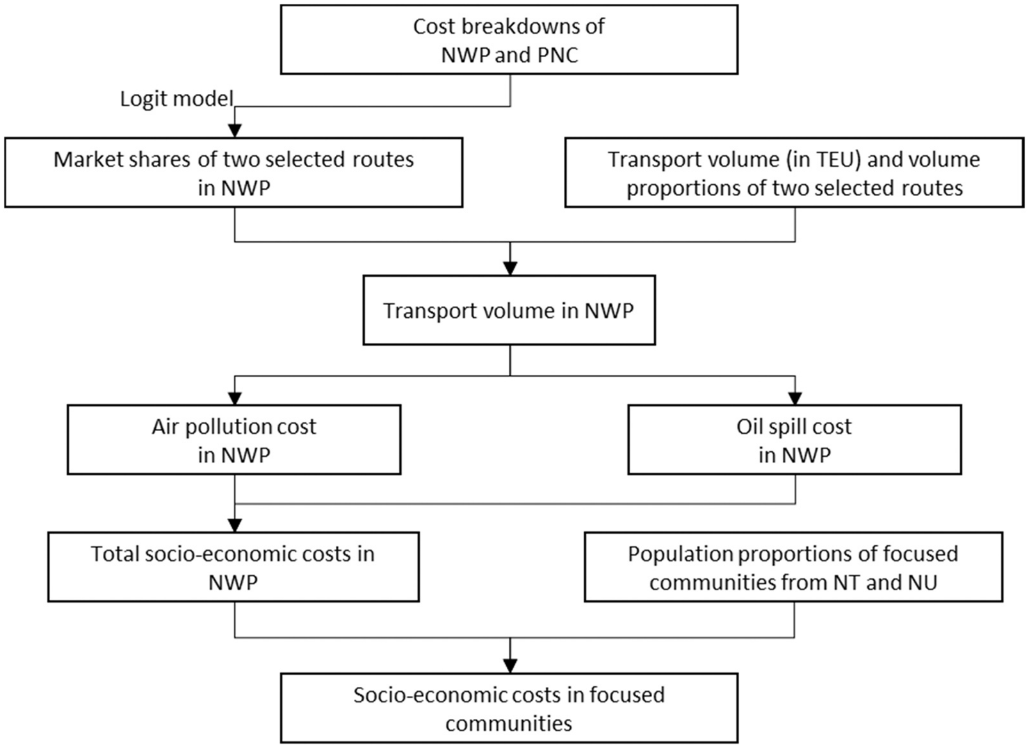

Fig. 1. Steps followed in developing the model to calculate the socio-economic costs.

5. Scenario analysis

Three scenarios are analysed to see how an 'NWP transit fee' should be charged to compensate for its social-economic impacts on northern local communities. The first scenario is a base scenario where no emission control area fuel is required along either route or oil spills facilities are assumed to be state of the art. After several adoptions of Emission Control Areas (ECAs), such as in the Baltic Sea, North Sea, and North America, it is reasonable to analyse the second scenario as strict fuel requirement is set on using NWP. The third scenario discusses how improvement in rescue facilities in the focused communities would lower the expected cost of oil spills.

5.1. Base scenario

Four pollutants' (SO_x, NO_x, NMVOC and PM) emission factors are assumed according to Peters et al. [38]. Due to the lack of data in NWP, each pollutant's air pollution cost is derived from Huib et al. [19]'s report in Europe. We assumed the air pollution cost is proportional to the population density. Therefore, the population density of EU28 (114.71 people/km^2) and the 9 Northern Canadian communities included in this study (10.22 people/km^2) are used to estimate the costs. It is calculated that there is 2159.26 USD of air pollution cost for each ton of fuel consumed while voyaging (see Table 3).

The expected oil spills cost is assumed according to Afenyo et al. [1] that each oil spills accident would cost 86 million USD and each ship transit has an oil spills occurrence rate of 0.2% in its 180 days' voyage period. Also, it is assumed that no transit fee is charged. For each focused community, the socio-economic costs are assumed to be proportional to their population. The resulting air pollution and expected oil spills costs for all the focused communities are summarised in Table 4. The air pollution cost is about 8.88 million USD while the expected oil spills cost is 8.41 million USD for the 373 estimated transits in NWP's voyage period.

Charging a transit fee in the NWP would create a circular effect. Initially, this would impact route choice and cause the market share in the NWP to decrease due to the increased transport cost. However, the reduction in transit volume would subsequently decrease the social-economic costs, leading to a decrease in the transit fee collected to compensate for these costs. Assuming the transit is to be re-allocated to the focused communities proportionally, the breakeven point is determined by setting the fee to totally cover the socio-economic costs. When charging a fee of 354 thousand USD to each transit vessel using the NWP, the toll incomes allocated to the communities could compensate for socio-economic costs. With the transit fee, the total socio-economic costs would decrease to 17.29 million USD, with 11.43% and 9.92% market shares for the Yokohama-New York and Vancouver-Rotterdam routes, respectively, making a total of 152 transits (Table 5).

5.2. Emission control area

When the NWP is regulated as an emission control area, and there is a fuel requirement in the passage, the vessels would use cleaner but more expensive fuel. The fuel cost is assumed to be 600 USD/ton, with emission factors and air pollution costs as below (Table 6).

When there is no transit fee, solely because of the increased fuel cost, the number of transits in NWP would be 171, causing 1.18 million USD in air pollution cost and 3.85 million USD in expected oil spills cost. The breakeven transit fee is calculated as 225 thousand USD for each transit. With the transit fee, NWP's market share of Yokohama-New York is now 6.81% and 5.97% for Vancouver-Rotterdam (Table 7). The total socio-economic cost is 2.66 million USD in this scenario, most of which is from the expected oil spills cost (76.61%).

5.3. Improved rescue infrastructure

The third scenario discusses the situation where rescue facilities in the focused communities are improved. As a major concern of the focused communities, the local population is worried about not having enough facilities to cope with potential oil spills incidents. In this scenario, it is assumed that the oil spills rate would drop to 0.1% and government could charge 268 thousand USD on each transit vessel to

Table 1
Transport assumptions and calculated costs of NWP and PCR.

	Yokohama to New York		Vancouver to Rotterdam		Source
	NWP	PCR	NWP	PCR	
Construction cost, million US$	44.12	148.87	44.12	148.87	[41]
DWT	35,000	170,000	35,000	170,000	Assumed based on similar ships
Main engine power, kW	22,723	98,109	22,723	98,109	[41]
TEU capacity, TEU	2500	15,000	2500	15,000	
Load factor, eastbound	45%	60%	45%	60%	[25]
Load factor, westbound	70%	87%	70%	87%	[25]
Distance, km	13,611	20,032	13,310	17,714	Calculated with Google map
in Arctic area, km	5018	0	5018	0	Calculated with Google map
Maintenance days, per 180 days	5	2	5	2	[25]
Ports called at	2	5	2	5	[25]
Port days per segment	4	10	4	10	2 days in each port
Average sailing speed, knots	18.59	23.00	18.51	23.00	Arctic area: 14 kts; outside: 20 kts
Sailing time, days	16.91	20.12	16.61	17.79	
Total segment time, days	20.91	30.12	20.61	27.79	
Total possible segments, 180 days	8.37	5.91	8.49	6.40	
Total TEUs transported	12,030	65,155	12,207	70,613	
Cost analysis, 180 days					
Crew, thousand US$	858	780	858	780	130,000 US $/month for a crew of 23, NWP: + 10% premium [25]
Insurance: H&M, P&I, thousand US$	91	255	91	255	0.343%/yr of construction cost, NWP: + 20% [25]
Capital cost, thousand US$	2206	7444	2206	7444	10-year straight-line depreciation
Maintenance, thousand US$	242	815	242	815	1.095%/yr of construction cost
Port dues, thousand US$	376	2580	382	2796	0.428 US$/ton/call
Transit fee per trip, thousand US$	0	124	0	124	PCR: official website
Transit fees, thousand US$	0	733	0	794	
Fuel consumption rate, tons/day	75	325	75	325	
Fuel consumed, tons	1273	6538	1250	5781	
Bunker price, IFO 380, US $/t	356	356	356	356	3-year average Port Rotterdam
Fuel cost per leg, thousand US$	453	2327	445	2058	
Fuel cost, total thousand US$	3792	13,754	3779	13,182	
Total cost, 180 days, thousand US$	7564	26,361	7557	26,066	
Handling cost per TEU	200	200	200	200	100 US$/TEU for each handling
Total cost per TEU, US$	829	605	819	569	

Table 2
Market shares of different transport options, no transit fee.

	Yokohama to New York		Vancouver to Rotterdam	
	NWP	PCR	NWP	PCR
Total segment time, days	16.91	20.12	16.61	17.79
Cost per TEU, US$	828.78	604.59	819.06	569.14
General cost, US$	908.12	698.99	896.98	652.61
Market share (6 months)	28.07%	71.93%	24.98%	75.02%
Market share (annual)	14.03%	85.97%	12.49%	87.51%
Number of transits	331		42	

Table 3
Total air pollution cost per ton fuel consumed, conventional fuel.

	NOx	SOx	NMVOC	PM
Emission factor (kg/ton)	78	54	2.4	5.3
Air pollution cost (US$/kg)	13.99	12.10	1.33	77.70
Total air pollution cost (US$/ton)	2159.26			

Table 4
Socio-economic costs of NWP, base scenario, no transit fee.

	Expected Oil Spill cost, USD	Air pollution cost, USD
Aklavik	486,603	513,635
Cambridge Bay	1,456,511	1,537,424
Gjoa Haven	1,091,971	1,152,633
Inuvik	2,674,669	2,823,254
Pond Inlet	1,333,623	1,407,709
Paulatuk	218,559	230,701
Sachs Harbour	84,949	89,669
Tuktoyaktuk	740,627	781,771
Ulukhaktok	326,602	344,745
Total	8,414,116	8,881,540
Total environmental cost	17,295,656	

Table 5
Market shares of different transport options, base scenario with a transit fee.

	Yokohama to New York		Vancouver to Rotterdam	
	NWP	PCR	NWP	PCR
Total segment time, days	16.91	20.12	16.61	17.79
Cost per TEU, US$	1074.73	604.59	1065.01	569.14
General cost, US$	1154.07	698.99	1142.93	652.61
Market share (6 months)	11.43%	88.57%	9.92%	90.08%
Market share (annual)	5.71%	94.29%	4.96%	95.04%
Number of transits	135		17	

Table 6
Total air pollution cost per ton fuel consumed, clean fuel.

	NOx	SOx	NMVOC	PM
Emission factor (kg/ton)	20	1	2.4	4.24
Air pollution cost (US$/kg)	13.99	12.10	1.33	77.70
Total air pollution cost (US$/ton)	624.46			

Table 7
Market shares of different transport options, emission control area (clean fuel) with transit fee.

	Yokohama to New York		Vancouver to Rotterdam	
	NWP	PCR	NWP	PCR
Total segment time, days	16.91	20.12	16.61	17.79
Cost per TEU, US$	1200.98	604.59	1187.40	569.14
General cost, US$	1280.32	698.99	1265.32	652.61
Market share (6 months)	6.81%	93.19%	5.97%	94.03%
Market share (annual)	3.41%	96.59%	2.98%	97.02%
Number of transits	80		10	

cover the socio-economic costs. With lower expected oil spills costs, NWP gains some competitiveness that could lead to 191 transits annually (Table 8). The total socio-economic cost is 6.72 million USD, with 4.56 million USD air pollution cost and 2.16 million USD expected oil spills cost.

Socio-economic costs and transit volume under different scenarios are shown in Fig. 2. In all scenarios, charging a transit fee would lower both the transit number and therefore the total socio-economic costs. Applying ECA induces higher fuel cost in NWP and leads to lower total transit volume. Improving NWP rescue infrastructure would not directly change per TEU costs in both NWP and PCR routes. Thus, when no transit fee is charged, the scenario with improved infrastructure would have less socio-economic costs but the same transit volume as the base scenario. The scenario with both ECA and improved facilities is also presented for comparison.

6. Results

6.1. & Discussions

The study has analysed the socio-economic costs on the Canadian Arctic communities by estimating the market shares under different scenarios. We found that adopting emission control area would profoundly undermine NWP's attractiveness because of the requirement on cleaner fuel and hence, the higher fuel and transport costs. The transit fee under each scenario is calculated to compensate the socio-economic costs. Though raised the total transport cost of NWP, the transit fee estimated in this study is in a comparable range to Suez and Panama. In addition, the moderate market share adjusted after charging the transit fee provides the communities a soft start and solid platform to get involved in the use of NWP for container transport.

Factors that were not included in the model presented but are essential include impacts on fishing, noise, and accessibility. There is a lack of data to implement them in the model. Although the climate change would increase access to Arctic marine fish stocks [43], the International Agreement to Prevent Unregulated Fishing in the High Seas of the Central Arctic Ocean came into force in 2021 to prevent commercial fishing.[3] It is generally agreed that more scientific information need to be acquired and local ecosystems should be considered to better understand the viability and sustainability of the fishing potential in Arctic area [22,52].

Noise is a major externality to both human health and fishing activities. Halliday and Dawson [16] modelled the noise from shipping activities in the Northwest Passage, while it should also be noted that icebreaking could also vary the local communities hunting areas and animal habitats [10]. Though the lack of real data to quantify the above in the socio-economic costs, the proposal of Low Impact Shipping Corridors is estimated to lower the impacts of shipping activities on local communities.

Due to the harsh climate and sparse population, road, and rail infrastructure level in the focused communities, is underdeveloped. Therefore, in most northern communities, air transport is the only year-round option to move people and goods around. The opening of NWP for liner shipping could bring some benefits to local people in terms of accessibility and lower transport cost of goods compared to aviation. The difficulty to incorporate accessibility benefit to the model is that there is limited literature on how opening a route would benefit the area it traverses through. Although transit NWP liner service will not cover all our focused communities, it could increase their accessibility with local transport options.

In terms of policy implications for this study, the results are very essential, especially for planning and administering resources to vulnerable communities in a logical way. The model is very robust and so can be modified for application to any Arctic region in Canada and other countries. This feature would enable stakeholders to have a handy tool for making objective and scientific decisions especially when it comes to evaluating the profitability of shipping through these regions as well as the potential losses and consequences that accompany such.

Furthermore, regulations can also be informed about the outcome of this work. While resources are in abundance, it is important that during emergency response and preparedness, the highly vulnerable communities are protected. In this case, laws need to be enacted to protect such, especially the most impacted areas. Elders and Chiefs of these communities will need to be educated about what to do in order to galvanise the communities.

7. Conclusions

The paper takes the northern local communities' perspective to study the viability of Arctic shipping through the Northwest Passage (NWP). We used a logit model to estimate the market shares of NWP. Two routes, namely Yokohama-New York and Rotterdam-Vancouver have been selected because we assume that the opening of NWP can reduce traffic from the Panama Canal and these two routes are representatives of Panama Canal's two most served markets. When no policy is applied, NWP can take about 25% market share for both routes.

Two socio-economic impacts are included from all the concerns of the Canadian Arctic communities, which are the air pollution cost and the expected oil spills cost. Scenario analyses are conducted to design the transit fee of NWP to cover the negative externalities posed to the local communities. When there is no requirement on fuel and the oil spills rescue infrastructure is at the current state-of-the-art, NWP needs to charge 354 thousand USD to cover its socio-economic costs to the local communities and get about 10% market share of the two routes. When NWP is designed as an emission control area, and a strict requirement on fuel is executed, the estimated transit fee decreases to

Table 8
Market shares of different transport options, improved rescue infrastructure with a transit fee.

	Yokohama to New York		Vancouver to Rotterdam	
	NWP	PCR	NWP	PCR
Total segment time, days	16.91	20.12	16.61	17.79
Cost per TEU, US$	1014.90	604.59	1005.19	569.14
General cost, US$	1094.24	698.99	1083.11	652.61
Market share (6 months)	14.45%	85.55%	12.60%	87.40%
Market share (annual)	7.22%	92.78%	6.30%	93.70%
Number of transits	170		21	

[3] Source: https://www.arctic-council.org/news/introduction-to-international-agreement-to-prevent-unregulated-fishing-in-the-high-seas-of-the-central-arctic-ocean

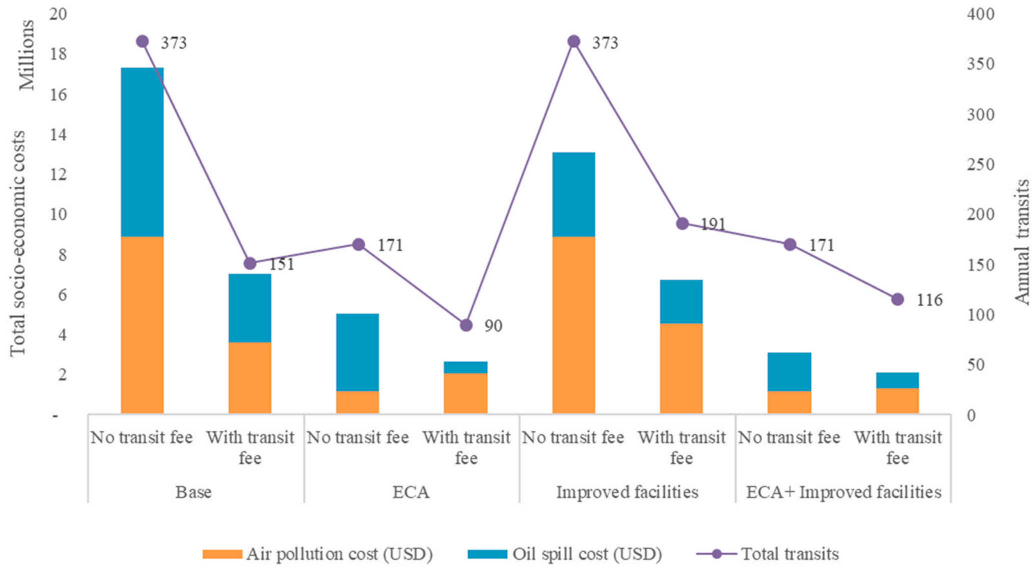

Fig. 2. Summary of socio-economic costs and market shares.

around 225 thousand USD. However, because of the higher fuel cost, the market share of NWP is reduced to around 6%. As the oil spills possibility decreases, the expected oil spills cost also drops, and the transit fee becomes 268 thousand USD. As a comparison, the icebreaking assistant cost of a DWT 35,000 vessel is approximately 234 thousand USD in NSR. The tolls of the Panama Canal and Suez Canal are 225 thousand and 220 thousand USD, respectively, supporting our estimated transit cost is in a reasonable range. While the transit fee would lower the market share of NWP, it would also be a reasonable source to subsidise the local communities' socio-economic costs. A relatively small market share to start the commercial use of NWP would be an good opportunity to trail the Public-Private-People Partnership (P4) in the Arctic development [3].

Some impacts are not included in the analyses, especially about fishing, accessibility, and noise as a result of the lack of data. Only container liner shipping is considered while shipping activities related to tourism and natural resources exploration are not included. More research is needed to fill in these research gaps.

This study provides an insight with regards to future studies on Arctic shipping routes' impacts on northern local communities. The opening of Arctic shipping routes is likely to shift the pattern of global maritime transport. Thus, it is essential to evaluate how the route would influence communities along these routes and how to help them benefit from these routes. We believe that it can also give some directions to governments on how to determine a transit fee that could cover shipping activities' socio-economic costs. Further, research on the socio-economic impacts of Arctic shipping from the perspective of local communities needs to be expanded.

CRediT authorship contribution statement

Shengda Zhu: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization. **Adolf K.Y. Ng:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Mawuli Afenyo:** Methodology, Software, Writing – review & editing. **Roozbeh Panahi:** Writing – review & editing. **Michael G.H. Bell:** Writing – review & editing, Supervision.

Data Availability

Data will be made available on request.

Acknowledgments

The support from CCAPPTIA and BNU-HKBU United International College Research Funds (#R72021201) is gratefully acknowledged.

References

[1] M. Afenyo, C. Jiang, A.K. Ng, Climate change and Arctic shipping: a method for assessing the impacts of oil spills in the Arctic, Transp. Res. Part D: Transp. Environ. (2019).
[2] M. Afenyo, A.K. Ng, C. Jiang, A multiperiod model for assessing the socioeconomic impacts of oil spills during Arctic shipping, Risk Anal. (2021).
[3] M. Afenyo, Y. Lin, A.K. Ng, C. Jiang, 12 The opportunities and challenges of developing the Arctic area and shipping in Canada, Arct. Shipp.: Clim. Change, Commer. Traffic Port. Dev. 216 (2019).
[4] A. Boyd, Charting a new course in a melting Arctic: why the northern shipping debate is heating up, Star (2020).
[5] B.M. Boylan, Increased maritime traffic in the Arctic: Implications for governance of Arctic sea routes, Mar. Policy 131 (2021), 104566.
[6] T. Chu Van, J. Ramirez, T. Rainey, Z. Ristovski, R.J. Brown, Global impacts of recent IMO regulations on marine fuel oil refining processes and ship emissions, Transp. Res. Part D: Transp. Environ. 70 (2019) 123–134.
[7] K. Cullinane, S. Cullinane, Atmospheric emissions from shipping: The need for regulation and approaches to compliance, Transp. Rev. 33 (2013) 377–401.
[8] K. Cullinane, H. Haralambides, Global Trends in Maritime and Port Economics: The COVID-19 Pandemic and Beyond, Springer, 2021.
[9] J. Dawson, L. Pizzolato, S.E. Howell, L. Copland, M.E. Johnston, Temporal and spatial patterns of ship traffic in the Canadian Arctic from 1990 to 2015+ supplementary appendix 1: Figs. S1–S7 (see article tools), Arctic 71 (2018) 15–26-15–26.
[10] J. Dawson, N. Carter, N. VAN Luijk, C. Parker, M. Weber, A. Cook, K. Grey, J. Provencher, Infusing inuit and local knowledge into the low impact shipping corridorS: An adaptation to increased shipping activity and climate change in Arctic Canada, Environ. Sci. Policy 105 (2020) 19–36.
[11] Ellis, B. & Brigham, L. 2009. Arctic marine shipping assessment 2009 report.
[12] S. Fu, X. Yan, D. Zhang, M. Zhang, Risk influencing factors analysis of Arctic maritime transportation systems: a Chinese perspective, Marit. Policy Manag. 45 (2018) 439–455.
[13] M. Furuichi, N. Otsuka, Cost analysis of the Northern Sea Route (NSR) and the conventional route shipping, Proc. IAME (2013). Conference, 2013.
[14] Government Of Canada [Gc]. 2019. Canada's Arctic and northern policy [Online]. Available: https://www.rcaanc-cirnac.gc.ca/eng/1560523306861/1560523330587 [Accessed 12/10/2019].
[15] J. Guo, S. Guo, J. Lv, Potential spatial effects of opening Arctic shipping routes on the shipping network of ports between China and Europe, Mar. Policy 136 (2022), 104885.
[16] W.D. Halliday, J. Dawson, Ship-source Noise Modeling from 2015-2018 in the Kitikmeot Region and Lancaster Sound (Northwest Passage). Nunavut, 2021.
[17] R.R. Hermann, N. Lin, J. Lebel, A. Kovalenko, Arctic transshipment hub planning along the Northern Sea Route: a stematic literature review and policy implications of Arctic port infrastructure, Mar. Policy 145 (2022), 105275.
[18] E. Hill, M. Lanore, S. Véronneau, Northern sea route: an overview of transportation risks, safety, and security, J. Transp. Secur. 8 (2015) 69–78.

[19] V.E. Huib, V.W. Lisanne, S. Arno, D.B. Sander, S. Daniel, B. Cuno, M. Silvia, B. Marco, F. Davide, F. Francesca, P. Riccardo, E.B. Kareen, Handbook on the external costs of transport, Luxemb.: Publ. Off. Eur. Union (2019).

[20] M. Jiang, M. Hu, M. Leibrecht, Profitability of container shipping via the Arctic Northeast Passage: a simulation and regression analysis, Mar. Policy 133 (2021), 104738.

[21] O.M. Johannessen, V. Alexandrov, I.Y. Frolov, S. Sandven, L.H. Pettersson, L. P. Bobylev, K. Kloster, V.G. Smirnov, Y.U. Mironov, N.G. Babich, Remote Sensing of Sea Ice in the Northern Sea Route: Studies and Applications, Springer Science & Business Media, 2006.

[22] B.A. Kaiser, M. Kourantidou, D. Ahsan, S. Bakanev, A. Burmeister, G. Eckert, L. M. Fernandez, H.P. Hong, A.A. Monsalve, D. Mullowney, Global ecological and economic connections in Arctic and sub-Arctic crab markets, Mar. Policy 127 (2021), 104442.

[23] A. Lajeunesse, Finding 'Win-Win'–China's Arctic Policy and what it means for Canada, Sch. Public Policy Publ. (2018).

[24] F. Lasserre, Arctic shipping routes: from the Panama myth to reality, Int. J. 66 (2011) 793–808.

[25] F. Lasserre, Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector, Transp. Res. Part A: Policy Pract. 66 (2014) 144–161.

[26] F. Lasserre, S. Pelletier, Polar super seaways? Maritime transport in the Arctic: an analysis of shipowners' intentions, J. Transp. Geogr. 19 (2011) 1465–1473.

[27] Lasserre, F., Beveridge, L., Fournier, M., Têtu, P.-L. & Huang, L. 2016. Polar seaways? Maritime transport in the Arctic: An analysis of shipowners' intentions II.

[28] H. Lindstad, R.M. Bright, A.H. Strømman, Economic savings linked to future Arctic shipping trade are at odds with climate change mitigation, Transp. Policy 45 (2016) 24–30.

[29] M. Liu, J. Kronbak, The potential economic viability of using the Northern Sea Route (NSR) as an alternative route between Asia and Europe, J. Transp. Geogr. 18 (2010) 434–444.

[30] Q. Meng, Y. Zhang, M. Xu, Viability of transarctic shipping routes: a literature review from the navigational and commercial perspectives, Marit. Policy Manag. 44 (2017) 16–41.

[31] A.K. Ng, J. Andrews, D. Babb, Y. Lin, A. Becker, Implications of climate change for shipping: opening the Arctic seas, Wiley Interdiscip. Rev.: Clim. Change 9 (2018), e507.

[32] Office Of Minister Of Justice [Omj] 2010. Northern Canada Vessel Traffic Services Zone Regulations. In: OFFICE OF MINISTER OF JUSTICE (ed.) SOR/2010–127.

[33] J. Olsen, N.A. Carter, J. Dawson, Community perspectives on the environmental impacts of Arctic shipping: case studies from Russia, Norway and Canada, Cogent Soc. Sci. 5 (2019) 1609189.

[34] W. Ostreng, K. Eger, A. Jorgensen-Dahl, B. Floistad, L. Lothe, M. Mejlaender-Larsen, Shipping in Arctic Waters, Springer, 2015.

[35] R. Panahi, A.K. Ng, M. Afenyo, Y.-Y. Lau, Reflecting on forty years contextual evolution of arctic port research: the past and now, Transp. Res. Part A: Policy Pract. 144 (2021) 189–203.

[36] Panama Canal Authority [Acp] 2019. Annual Report 2018.

[37] S.K. Paul, P. Chowdhury, M.A. Moktadir, K.H. Lau, Supply chain recovery challenges in the wake of COVID-19 pandemic, J. Bus. Res. 136 (2021) 316–329.

[38] G. Peters, T. Nilssen, L. Lindholt, M. Eide, S. Glomsrød, L. Eide, J. Fuglestvedt, Future emissions from shipping and petroleum activities in the Arctic, Atmos. Chem. Phys. 11 (2011) 5305–5320.

[39] L. Pizzolato, S.E. Howell, J. Dawson, F. Laliberté, L. Copland, The influence of declining sea ice on shipping activity in the Canadian Arctic, Geophys. Res. Lett. 43 (2016) 12,146–12,154.

[40] D.C. Ruffilli, Arctic marine and intermodal infrastructure: challenges and the government of Canada's response, Libr. Parliam. (2011).

[41] T. Solakivi, T. Kiiski, L. Ojala, On the cost of ice: estimating the premium of Ice Class container vessels, Marit. Econ. Logist. 21 (2019) 207–222.

[42] Somanathan, S., Flynn, P.C. & Szymanski, J. 2006. The northwest passage: a simulation. Proceedings of the 38th conference on Winter simulation. Monterey, California: Winter Simulation Conference.

[43] T.C. Tai, N.S. Steiner, C. Hoover, W.W. Cheung, U.R. Sumaila, Evaluating present and future potential of arctic fisheries in Canada, Mar. Policy 108 (2019), 103637.

[44] L. Tavasszy, M. Minderhoud, J.-F. Perrin, T. Notteboom, A strategic network choice model for global container flows: specification, estimation and application, J. Transp. Geogr. 19 (2011) 1163–1172.

[45] D. Theocharis, S. Pettit, V.S. Rodrigues, J. Haider, Arctic shipping: a systematic literature review of comparative studies, J. Transp. Geogr. 69 (2018) 112–128.

[46] Transport Canada [Tc], Government of Canada introduces new measures to protect the marine environment and coastal communities in Canada's Arctic. Cambridge Bay, Nunavut (2017).

[47] P.-H. Tseng, K. Cullinane, Key criteria influencing the choice of Arctic shipping: a fuzzy analytic hierarchy process model, Marit. Policy Manag. 45 (2018) 422–438.

[48] Uottawa & Espg 2021a. Community Identified Recommendations for Low Impact Shipping Corridors [Online]. Available: https://www.arcticcorridors.ca/corridors-recommendations/ [Accessed 30/12/2021].

[49] Uottawa & Espg 2021b. Culturally Significant Marine Areas (CSMAs) [Online]. Available: https://www.arcticcorridors.ca/culturally-significant-marine-areas/ [Accessed 10/12/2021].

[50] J. Verny, C. Grigentin, Container shipping on the northern sea route, Int. J. Prod. Econ. 122 (2009) 107–117.

[51] L. Veselovská, Supply chain disruptions in the context of early stages of the global COVID-19 outbreak, Probl. Perspect. Manag. 18 (2020) 490–500.

[52] A.N. Vylegzhanin, O.R. Young, P.A. Berkman, The Central Arctic Ocean Fisheries Agreement as an element in the evolving Arctic Ocean governance complex, Mar. Policy 118 (2020), 104001.

[53] Y. Zhang, Q. Meng, S.H. Ng, Shipping efficiency comparison between Northern Sea Route and the conventional Asia-Europe shipping route via Suez Canal, J. Transp. Geogr. 57 (2016) 241–249.

[54] Y. Zheng, A.M. Kim, Rethinking business-as-usual: Mackenzie River freight transport in the context of climate change impacts in northern Canada, Transp. Res. Part D: Transp. Environ. 53 (2017) 276–289.

[55] S. Zhu, X. Fu, A.K. Ng, M. Luo, Y.-E. Ge, The environmental costs and economic implications of container shipping on the Northern Sea Route, Marit. Policy Manag. 45 (2018) 456–477.