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Strategic investments for traffic development of the Northwest Passage of Canada

by

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Résumé

Tout au long de l'histoire, les communautés autochtones des régions arctiques se sont engagées dans l'exploration et les voyages dans les eaux arctiques pour obtenir de la nourriture, des approvisionnements et des terres de peuplement. Cependant, le réchauffement climatique entraîne des changements sociaux et économiques importants dans l'Arctique à travers le développement des infrastructures maritimes, l'exploitation des ressources naturelles et le tourisme de croisière. L'examen systématique de la littérature sur la navigation dans l'Arctique révèle des discussions approfondies sur des études comparatives sur la viabilité commerciale entre le passage du Nord-Ouest (PNO) et les routes maritimes traditionnelles. Le transport maritime dans l'Arctique a récemment attiré l'attention des médias et du milieu universitaire en raison de sa croissance rapide et de son potentiel au sein de l'industrie du transport maritime. Cette thèse vise à développer un modèle analytique pour évaluer les principaux critères d'investissement soutenant le développement du traffic sur le PNO du point de vue canadien. À la lumière de cela, la thèse entend répondre à la question de recherche : « quels investissements sont nécessaires et devraient être prioritaires pour améliorer la navigation dans le PNO ? » Sept critères d'investissement sélectionnés dans la littérature seront évalués à l'aide du processus de hiérarchie analytique (AHP), une technique d'analyse multicritères permettant de trouver les critères d'investissement les plus critiques et de déterminer les classements relatifs entre eux. Le résultat attendu de cette thèse devrait servir d'outil de référence stratégique précieux pour les décideurs canadiens, les aidant à identifier les domaines potentiels d'amélioration et à naviguer dans les défis et les opportunités présentées par la navigation dans l'Arctique.

Mots clés : Passage du Nord-Ouest (PNO), Arctique canadien, navigation arctique, Analyse Hiérarchique des Procédés (AHP), Développement du trafic maritime, Investissement stratégique, Références en matière de prise de décision.

Méthodes de recherche : Analyse Hiérarchique des Procédés (AHP)

Abstract

Throughout history, Indigenous communities in Arctic regions have engaged in exploration and travel across Arctic waters to secure food, supplies, and settlement lands. However, global warming brings on significant social and economic changes in the Arctic throughout the development of maritime infrastructure, natural resource exploitation, and cruise tourism. Systematic literature review on Arctic shipping reveals extensive discussions on comparative studies on the commercial viability between the Northwest Passage (NWP) and traditional maritime routes. Arctic shipping has recently attracted significant attention from both the media and academia due to its rapid growth and potential within the shipping and maritime industry. This thesis aims to develop an analytic model to assess the key investment criteria supporting the traffic development on the NWP from a Canadian's perspective. In light of this, the thesis intends to address the research question: *Which investments are required and should be prioritized to enhance navigation in the NWP?* Seven investment criteria selected from the literature will be evaluated with the use of Analytic Hierarchy Process (AHP), a multi-criteria analysis technique to identify the most critical investment criteria and determine the relative rankings among them. The expected outcome of this thesis is envisioned to serve as a valuable strategic reference tool for Canadian policymakers, helping them identify potential areas of improvement and navigate the challenges and opportunities presented by Arctic shipping.

Keywords : Northwest Passage (NWP), Canadian Arctic, Arctic shipping, Analytic Hierarchy Process (AHP), Traffic development, Strategic investment, Policy-making references

Research methods : Analytic Hierarchy Process (AHP)

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List of abbreviations and acronyms

Term	Definition
ACIA	Arctic Climate Impact Assessment
AHP	Analytic Hierarchy Process
AMSA	Arctic Marine Shipping Assessment
ANP	Analytic Network Process
ARCTIS	Arctic Resources and Transportation Information System
ASPPR	Arctic Shipping Pollution Prevention Regulations (Canadian)
BWM	(International Convention for the) Control and Management of Ships' Ballast Water and Sediments
BWMC	Canadian Ballast Water Control and Management Regulations
CHNL	Centre for High North Logistics
CISDA	Canadian Ice Service Digital Archive
CR	Consistency ratio
DEA	Data Envelopment Analysis
DWT	Dead-weight tonnage
EEZ	Exclusive Economic Zone
EMO	Evolutionary Multi-objective Optimization
EU	European Union
GA	Genetic Algorithm
GHG	Greenhouse gases
GP	Goal Programming
IACS	International Association of Classification Societies
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
LNG	Liquefied natural gas
MADM	Multi-attribute decision making
MARPOL	(International Convention for the) Prevention of Pollution from Ships
MCDA	Multi-criteria decision analysis
MCDM	Multi-criteria decision making
MODM	Multi-objective decision making
MCTS	Marine Communications and Traffic Services (Canadian's Coast Guard's)
MT	Metric ton
NCEP-NCAR	National Centers for Environmental Prediction – National Center for Atmospheric Research
NEP	Northeast Passage
NIS	Non-indigenous species
nm	Nautical mile

NMTC	Northern Marine Transportation Corridors
NORDREG	Northern Canada Vessel Traffic Services Zone
NSR	Northern Sea Route
NWP	Northwest Passage
OD	Origin – destination
PAME	Protection of the Arctic Marine
RCMP	Royal Canadian Mounted Police
RFR	Required freight rate
RI	Random Index
SAR	Search and rescue
SD	Standard deviation
SOLAS	(International Convention for the) Safety of Life At Sea
STCW	(International Convention of) Standards of Training, Certifications and Watchkeeping for Seafarers
TEU	Twenty-equipment unit
TPP	Transpolar Passage
TSR	Transpolar Sea Route
UNCLOS	United Nations Convention on the Law of the Sea
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
USA	United States of America
USSR	United Socialist Soviet Republic
VTS	Vessel Traffic Systems

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This thesis marks the completion of my two-year journey in obtaining my Master's Degree in Global Supply Chain Management at HEC Montréal. First of all, I would like to thank Dr. Jacques Roy, my thesis director and professor, who has guided and supported me from my first pitch of the thesis idea to him, until the last day of final submission. Dr. Roy has provided constant guidance throughout the course of my thesis, whereas the original research problem took turns a few times and thus the research question evolved accordingly. Dr. Roy has always been patient, attentive, receptive and supportive with my countless questions. I also wish to thank my partner, Triet Pham, who will soon to be a PhD. I would never even make it to this day without his endless support, logistically and emotionally, even when I am at my lowest. Finally, I am grateful for HEC Montréal's support, by providing every possible guidance during each thesis's stage in the most comprehensive documentation forms, and for granting me generous scholarships that helped me stay persistent in research and focused on my studies.

1. Introduction

1.1 Overview of the Arctic

The Arctic region is defined as the area containing the Arctic Ocean and the respective territories of the state of latitude higher than the Arctic Circle. It is an important geographical limit that marks the border of the Arctic region, positioned in the Northern Hemisphere. The Arctic Circle is the southern limit of the midnight sun, where north of the circle there is at least one day each year when the sun does not set. The position of the Arctic Circle is not fixed and shifts every year, its coordinate was recorded at 66°33′49.0″ north of the Equator in 2014 and at 66°33′46.7″ by 2018 (Dalaklis et al., 2018). In terms of statistics, the Arctic region consists of 20 million square kilometers (7.7 million square miles), roughly 4% of Earth’s surface (Marsh & Kaufman, 2013), and the home to a population of 4 million people (Hassol, 2004). The latitude encompasses the Arctic Ocean and multiple regions including the Scandinavian Peninsula, North America, Greenland and North Asia, and thus, the land within the Arctic Circle is divided among eight nations: Norway, Sweden, Finland, Denmark (Greenland), the United States of America (Alaska), Canada, Iceland and Russia (Dalaklis et al., 2018). Only five of these states have an Arctic coastline, these countries are the Arctic states, and include Canada, the United States of America (USA), Denmark, Norway, and Russia. Therefore, these circumpolar states have the right to project their sovereignty seaward according to the 1982 United Nations Convention on the Law of the Sea (UNCLOS) – the main legal instrument of oceans’ governance and they indeed have raised formal claims regarding continental shelf of the Arctic Ocean, which was established by UNCLOS (Bartenstein, 2011).

Since the beginning of time, Indigenous people in Arctic regions have been exploring and traveling through Arctic waters for thousands of years in search of food, supplies and settlement area. Then our modern society came into the picture with the global warming phenomenon, posing enormous consequences on the geography of places, commodity markets, and passenger flows (Verny & Grigentin, 2009). Climate models by the Intergovernmental Panel on Climate Change (IPCC) predicted that global warming would heat up the Arctic around 3-4ºC, more than double the global average temperature increase (IPCC, 2007). Climate records observed that air temperature increased at twice the rate of the global average temperature in the last hundred years, resulting in the decline of total ice coverage at a rate of 3-5% per decade, affecting directly the Arctic marine ecosystem (Bobylev et al., 2003). According to Hoegh-Guldberg & Bruno (2010), the warming effect in the Arctic would be even amplified more than two times faster than the planet rate, as a result of the effect of the positive loop, "ice and snow melting that decreases surface albedo, atmospheric stability that traps temperature anomalies near the surface, and cloud dynamics that magnify change" (Wassmann et al., 2011, p.1236). Products of human activities including industrial activities, farming, transportation, consumption and so on, rendered as global emission of greenhouse gases (GHG) and short-lived climate forces (e.g., black carbon) that increase atmospheric and sea surface temperatures, eventually resulting in the retreat of sea-ice and reduction of sea-ice thickness. The sea ice extent was reported to decline at a rate of 10% per decade, and consequently, simulations portraited the Arctic Ocean to be ice-free in summer by 2050 (Arzel et al., 2006). Even more progressive models predicted the Arctic Ocean would be ice-free in the summer by 2037 (M. Wang & Overland, 2009). As ice melts, the volume of fresh water in the Arctic Ocean has increased and would continue to rise rapidly due to the above-average heating of surface layers in ice-free regions (Wassmann et al., 2011).

1.2 Global warming and its impact on the Arctic

According to the Arctic Marine Shipping Assessment 2009 Report (2009), the natural ice in Arctic regions is categorized into four groups: young ice (newly formed sea ice less than 30 centimeters thick), first-year ice (whose thickness ranges between 1 to no more than 2 meters by end of winter), old ice (the first-year ice survives the summer melt season and sub-categorized into second-year and multi-year ice, whose thickness ranges between 1 to 5 meters and is extremely hard) and icebergs (large masses of floating ice originally from glaciers, extremely dangerous on impact with vessels). Global climate models used the IPCC report (IPCC AR4 released in 2007) and the ACIA (Arctic Climate Impact Assessment), approved by the eight Arctic countries, called for by the Arctic Council and the International Arctic Science Committee to simulate a continuous decline in sea ice coverage through the 21st century. Together with IPCC, the assessment confirmed, by processing a wealth of current Arctic research, that declining Arctic sea ice is a key climate change indicator (the model projected a continuous decline in Arctic sea ice coverage as seen in Figure 1.1), to enable future evaluation of Arctic marine transport systems. For the Arctic ice to melt completely in the summer as one of the models suggested by the timeline of 2050, such a physical scenario would mean for old year ice to possibly disappear entirely: no ice would survive more than one winter season – all next winter's ice would be first-year ice.

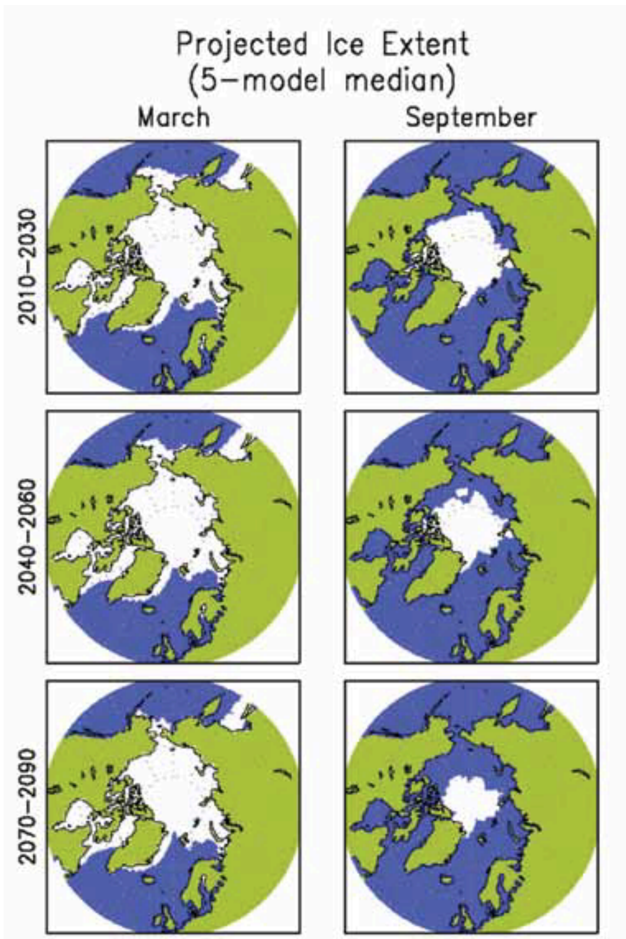


Figure 1.1: Arctic sea ice simulations for the 21st century.
Source: Arctic Climate Impact Assessment (2009)

Such ice-free Arctic Ocean, from a strategic planning perspective, is a key factor of great significance for viable future Arctic maritime shipping activities and offshore development: natural energy exploration and extractions, mining of minerals, fishing and tourism industry. The prospect of shorter voyages from Asia to Europe and/or the Americas and vice-versa across the newly opened Arctic waters with travel time to be faster than traditional maritime routes is very enticing for shipping companies as well as other actors within the extended maritime transport industry; therefore, their future plans are strongly influenced by the viability of principal Arctic shipping routes connecting the Atlantic and Pacific oceans: the Northwest Passage, the Northern Sea Route, and the Transpolar Sea Route.

The Northwest Passage (NWP) is a subset of multiple routes connecting the Northern Atlantic and Pacific Oceans via the Arctic Ocean, traversing the north of mainland North America through the Canadian Arctic Archipelago. As sea ice diminishes, the NWP has the potential of a main global maritime route with significantly shorter distance: up to 30% between Northwest Europe and Asia through the Suez Canal, and up to 20% between Asia to East Coast than a Panama Canal voyage) (Hansen et al., 2016).

On the east side, the Northeast Passage spans from the Bering Strait (the most important point in this region with respect to maritime transport – positioned between Russia and USA (Alaska), from where vessels can take several routes to reach Western Europe or North America) to the edge of Norwegian Barents Sea via waters north of Eurasia. The term Northern Sea Route (NSR), as defined by Russian law, relates to the portion of the Northeast Passage between the Novaya Zemlya Archipelago and the Bering Strait. If put under a similar term to the NWP, NSR plays a crucial role in connecting Asian and European markets as it is up to 40% shorter of a passage than through the Suez Canal (Hansen et al., 2016).

The last passage is the Transpolar Sea Route (TSR) which runs directly through the North Pole and is the most direct route between the Atlantic and Pacific Oceans. At this time, multi-year ice renders this route uneconomical, but as sea ice continues to recede, the TSR may offer substantial voyage distance savings in the latter half of this century (Hansen et al., 2016). A spatial distribution of these three Arctic routes is illustrated in Figure 1.2.

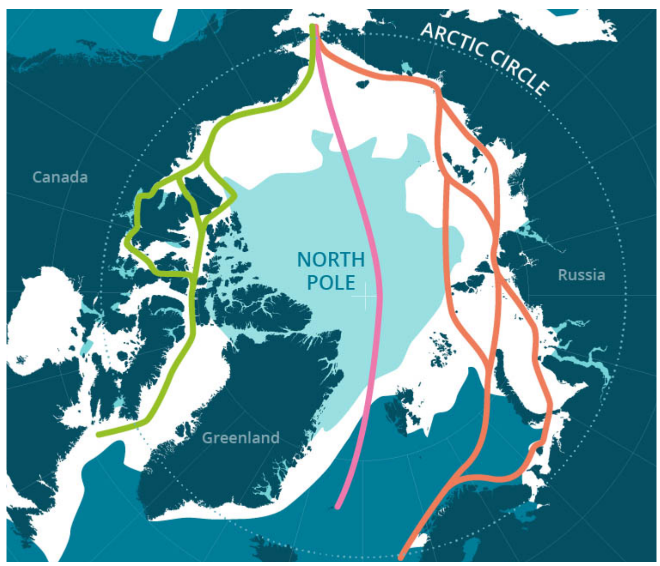


Figure 1.2: Arctic sea routes opening for commercial vessels.
Legend: The green line indicates the Northwest Passage, the orange line indicates the Northern Sea Route and the pink indicates the Transpolar Sea Route.
Source: The Arctic Institute, 2018.

Maritime travel using Arctic routes claims to have shorter distances, faster transit time, lower fuel consumption and lesser greenhouse gas (GHG) and non-GHG emissions, better network connectivity, and overall, lower transportation cost than traditional maritime routes (Lasserre & Faury, 2021). Therefore, the race between Arctic nations: Russia, Canada, Norway, and the US, to prove their sovereignty and assert their geopolitics influence in the region through active physical presence is fierce, as studies have shown economic potential of Arctic routes surpassed traditional routes (Theocharis et al., 2018) and their competitiveness increases for liner shipping operations in the long term (Khon & Mokhov, 2010). Arctic routes and their traditional alternative routes are illustrated in Figure 1.3.

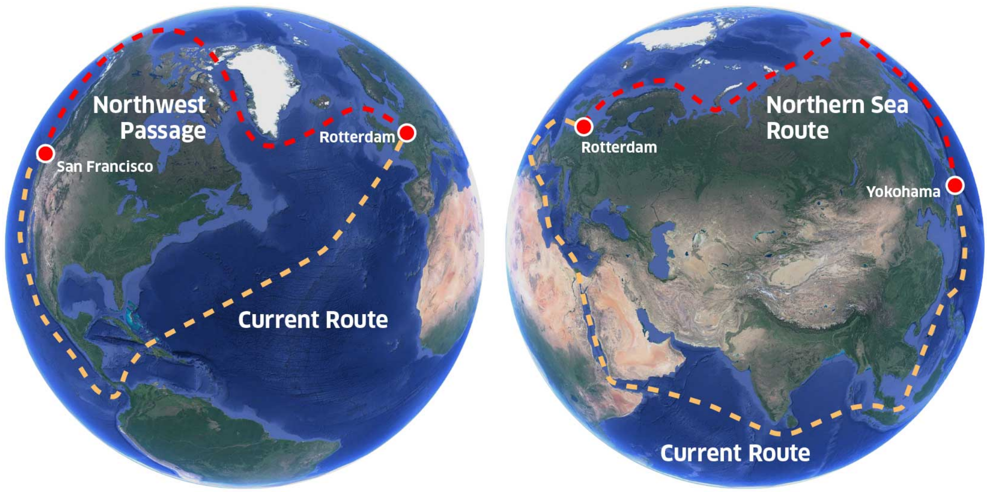


Figure 1.3: The NWP and the Panama Canal (left), the NSR and the Suez Canal (right).
Source: Discovering the Arctic, 2020.

A great extent of research on economic benefits of using Arctic routes shows that their foremost notable advantage is their shorter distances, translating to immense savings in terms of fuel and operational expenses for vessels in international voyages. The difference in distances using the Arctic passages compared to traditional maritime routes is displayed in Table 1.1.

Table 1.1: Distance comparison between Arctic routes and traditional maritime routes

Rotterdam	**Shanghai**			
Arctic alternative route	**Traditional routes**	**Alternative route distance (nm)**	**Traditional route distance (nm)**	**% improvement**
TSR	Suez	7,300	10,525	+31%
NSR	Suez	8,200	10,525	+22%
NWP	Suez	8,900 – 9,500	10,525	+15%

New York	**Shanghai**			
Arctic alternative route	**Traditional routes**	**Alternative route distance (nm)**	**Traditional route distance (nm)**	**% improvement**
TSR	Panama	9,800	10,582	+8%
NSR	Panama	10,741	10,582	Not applicable
NWP	Panama	9,450	10,582	+11%

Source: By author (adapted from "Commercial shipping in the Arctic: new perspectives, challenges and regulations" (Guy & Lasserre, 2016)). No political impediment to navigation was considered.

Although the melting of sea ice in the Arctic Ocean has created vast possibilities for maritime transportation, the remote and hostile Arctic Ocean still implies several adverse challenges for the industry including hazardous, unpredictable ice and wind conditions, sub-zero temperature and lack of general marine facilitating technology and infrastructure.

There is a consensus amongst climate scientists that ice-free ocean during September would be possible within this century; however, seasonal ice cover variations and hazardous environmental conditions in the Arctic could still create a fluctuating amount of possible navigation days and expand the risk of getting trapped in a sudden freeze during autumn (Hansen et al., 2016). The winter season ice coverage was forecasted to prolong in foreseeable future; therefore, marine activities during six months (or more) of winter would not be feasible yet. In the summer, there are still mild currents and unpredictable wind conditions which can rapidly accelerate into virulent wind phenomena descending the surrounding area to minus 50^{o} degrees Celsius and causing sea splash to instantly freeze on vessels' hulls (Arctic Council, 2009).

1.3 Challenges and opportunities for the NWP from Arctic's global warming effect

The Arctic Ocean is a dangerous operational environment for vessels and crew alike since shallow unmapped regions along the continental coasts have not been charted completely and accurately. To travel safely, there is a need for extensive shoreside infrastructure for search and rescue (SAR) operations as well as deep-water ports, providing repair and refueling services (Arctic Council, 2009). Currently, the infrastructure for SAR is underdeveloped in large regions of the Arctic Ocean: the nearest assets can only be located at a distance of more than 1,000 kilometers from the potential emergencies (Hansen et al., 2016). Moreover, the Canadian and Russian slow-speed, aging ship fleets and general shortage of SAR facilitating equipment including aircraft, icebreakers and patrol vessels, add more complexity to the rescue operation apart from the vast distances between facilities, resulting in the non-sufficient, pivotal shortage in coverage between SAR checkpoints and the distressed vessel (Hansen et al., 2016).

Alongside SAR activities, there is a need for technological infrastructure investment including effective satellite connections and communications of local conditions. To further reduce risk of ice hazards and vessel groundings, this requires better forecasting of ice movements, weather conditions and ocean currents from sophisticated satellite communication systems. Radio and radar transmission are crucial for vessels to maintain contact with relevant (port) authorities and vice versa; however, it is now unavailable in large regions of the high Arctic (Hansen et al., 2016). As Arctic shipping activities thrive, it entails the risk of accidents and challenges to the currently limited infrastructure – stressing hefty investments for the high Arctic coastal states to consider in order to provide a safer operational environment for its stakeholders.

In such a prospering scenario, increased maritime traffic is forecasted to bring social and economic changes to the Arctic region through development of shipping-related infrastructure, natural resources or tourism enterprises (Arctic Council, 2009). On the other side, amplified activities would negatively threaten the sensitive biodiversity balance of wildlife and natural habitats of the Arctic Ocean. Development of maritime and port infrastructure entailing noise, pollution and vessel-related impacts can adversely affect natural landscape and marine resources. Vessel presence causing displacement of hunting stock results in food security and social disruption to native communities (Arctic Council, 2009). The more we economically reap the benefits from exploitation of the Arctic, the more we eventually contribute to the deterioration of the Arctic and the globe itself (Mikkola & Käpylä, 2013). According to Mikkola & Käpylä (2013), if the economic benefits of the Arctic were to be exploited completely, climate change would have most likely reached the “point of no return”. Modern Arctic coastal states tread on thin ice, balancing their development priorities and trade-off for the future of the Arctic – their strategic planning must prioritize achievements of sustainability objectives before consideration of expanding human carbon footprints in the area. As stated in Arctic Marine Shipping Assessment (AMSA) 2019 Report, the three broad and inter-related fundamental themes in present Arctic strategy are first to enhance Arctic marine safety, second to protect Arctic people and their environment, and finally to build Arctic marine infrastructure (Pahl & Kaiser, 2018).

Among the Arctic nations, Russia is a primary stakeholder as their geography enhanced their sovereignty over the NSR. The NSR has been one of the focuses of development projects back in the United Socialist Soviet Republic (USSR) era with strategic planning and ambition to be the new "silk road" that Russia controls, with multiple deep-water ports and Arctic rescue posts along the Siberian coastline. The project was put on standby with the collapse of the USSR in the late 1990s. However, public interest in the passage has sparked recently in the event that the Russian Federation government released a development plan for the NSR up to the year 2030, highlighting state investment for safer and more reliable navigation for domestic ships that are exporting Russian natural resources, as well as for those transiting with international cargo transport (Pahl & Kaiser, 2018). There has been significant progress for Russia to successfully put up 24 existing large and medium-sized ports including the largest, deep-water port Murmansk, which has a natural river entrance, and medium-sized Dudinka and Arkhangelsk which are also accessible via a river (Pahl & Kaiser, 2018). In addition, Russia has around 20 small or very small ports along the shores of the NSR, which is a considerably greater number of ports than the existing two ports along the NWP (Pahl & Kaiser, 2018). These ports serve two main cargo types on the Russian parts of the NSR, the first is goods for re-supply of the population living along the NSR and the second is the cargo project consisting of materials to build the Yamal liquefied natural gas (LNG) plant to proceed with natural resource extraction on the Yamal peninsula (Pahl & Kaiser, 2018). The transported cargo volume using the NSR could reach up to 100 million tons per year in 2030, including transportation to European and Asian markets (if sanctions are removed), as well as LNG and Arctic hydrocarbon resource extractions within Russian territories (Gunnarsson, 2016).

It is a huge contrast with Canada's current progress on NWP: there is only one deep-water port in Iqaluit and a small craft port in Pangnirtung in the Nunavut area (Eger, 2010). The UNCLOS 1982 justified the NWP residence within the body waters of the Canadian Arctic Archipelago; therefore, the NWP belongs to Canada (Bartenstein, 2011). The NWP has remained little utilized for international traffic in comparison with the NSR, mainly because of complicated natural conditions and environmental concerns, but also because the Canadian government has not supported sufficiently the fundamental infrastructure required (Lasserre & Faury, 2021). As stated by Pahl & Kaiser (2018), even though it is too early to consider shipping year-round Arctic trade routes, it is “not too early for concerning private and public interests to start planning” (Pahl & Kaiser, 2018, p.143).. Therefore, now is the time we brought up the vital question: how Canada can seize this opportunity to develop the route and further enhance the country's national strategy, economy and geopolitics position.

According to a recent systematic literature review on Arctic shipping, there have been extensive studies discussing comparative studies between the Arctic and traditional maritime routes, making a total of 33 papers, contributed by 12 countries and published in 22 journals during the period from 1980 to 2017 (Theocharis et al., 2018). However, on the execution side, apparently to date, there have been no previous studies to discuss what strategic investments are required to be made and should be prioritized, by the Canadian government, to facilitate navigation in the NWP and support maritime traffic development in the Canadian Arctic. Remoteness, hazardous climate, high maintenance cost, low draft, limited hinterland with low density of population, sovereignty issues and the variation of raw materials value misshapes and hinders the Artic ports development (Pahl & Kaiser, 2018).

1.4 The research problem and the research question

For decades, Panama Canal has brought wealth and power to the US and continues to be the backbone of the Republic of Panama's economy (Pagano et al., 2012), as it is regarded as the most used trade route connecting China – US – Europe trade markets. Countries owning trade routes gain an absolute competitive advantage for national economy and possess a powerful tool to cast their influence on global trade. Now, the time may have come for Canada to become such a key player and global gateway. By focusing on critical investment to facilitate the development of a supply chain network and infrastructure in the North, Canada can target simultaneously three-fold aims: 1) social security through stable maintenance of supply for high north communities, 2) economic development through the exportation of crude oil and minerals and 3) global dominance through complete control of the international transit shipping via NWP. Therefore, the research hopes to answer the following question: *What investments are required and should be prioritized to facilitate navigation in the NWP?* We hope that the expected outcome will serve as a strategic reference tool to identify potential areas of improvement for Canadian policymakers to consider.

The research employs the Analytical Hierarchy Process (AHP) method, a structured multi-criteria decision analysis tool used for complex decisions by organizing criteria hierarchically and evaluating their importance based on quantitative and qualitative rankings. AHP is chosen to answer the research question since it helps represent the landscape of the strategic decision as thoroughly as possible, considering environmental factors and identifying the key attributes to the solutions and list of stakeholders associated with the problem (Saaty, 1990). The research plans to use seven investment criteria (ice-class fleet, search and rescue capability, refuge port, climatic forecast, crew capability, communication infrastructure and legal stand) to find the order of criticality of the investments required through rankings. The motivation to select the seven investment criteria will be analyzed in the Literature Review chapter. The spatial illustration of the NWP in the Arctic can be found in Figure 1.4.

Figure 1.4: The Northwest Passage
Source: The Encyclopaedia Britannica

In the first section of the research, an overview introduction of the Arctic region has been introduced, including geographical limits, the country's stakes and the context of Arctic routes as well as their economic potentiality and the challenges the Arctic shipping industry is facing. Moving on to the literature review, the research would first, take a step back to review historical shipping activities in the NWP and then, review the commercial viability of the route. The research would also highlight the challenges in navigating the NWP including climatic, technical, and legal aspects and consequently, discuss the strategic investment criteria critical for the development of the passage. The research will review various studies in the literature, specifically the use of multi-criteria decision analysis (MCDA), the motivators and the requirements of the MCDA tool, in this research – the AHP model.

In the third chapter, the research describes the methodology used by specifying the determinants for investment criteria and the data collection process. The AHP model would employ secondary data, the questionnaire is used to collect experts' qualitative input; then the input from these questionnaires will be analyzed through a ranking mechanism. The following chapter will develop the analysis of the model and present the findings to prepare for the conclusion in the final chapter. In the last section, the research highlights the limitations of the model performed and recommends further research ideas for developing the NWP.

2. Literature review

2.1 Historical shipping activities of the NWP

2.1.1 Shipping activities in the Arctic

Shipping history record in the Arctic

Alongside centuries-old Indigenous people being the first to travel using maritime transportation in the Arctic and still do until present days, historic Arctic shipping activities comprise of non-indigenous exploration, supply and re-supply for coastal communities and the modern advent of global shipping (Pahl & Kaiser, 2018). Unlike the modern shipping industry who views sea ice as obstacles and ice-prone straits as maritime chokepoints, Indigenous people – the Inuit and their predecessors, have embraced the presence of ice in narrow waterways as a surface that connects people, animals, land and sea (Aporta et al., 2018). Important to indigenous people's livelihood is the polynyas – the open-water features surrounded by sea ice during winter, are biologically productive landmarks whereas marine mammals which remain in the Arctic region gather throughout winter (Aporta et al., 2018). To them, "chokepoints" are important terms for sea ice features, such as cracks and leads, which often encode relative position to shores and floating edges, disclosing an entanglement of sea and land in the core definition of sea ice. Traditional sled trails transition between snow-covered land and sea several times over winter seasons, and in summers, walking trails and boat routes are intrinsically linked; altogether, revealing deep connections between land and sea in Inuit life (Aporta, 2009).

Long before the waters and shores today were explored and charted to construct the map of the Arctic coastal line, European explorers had envisioned a waterway connecting the Atlantic and Pacific oceans through the North Pole (Aporta et al., 2018). Early Western marine voyages were driven by searches for the Northwest Passage (NWP) and the Northeast Passage (NEP); and as the passages were gradually graphed, the focus shifted from mapping to improving these routes (Arctic Council, 2009). Many notable Arctic voyages took place as listed in Table 2.1 and the scope of Arctic marine shipping advanced dramatically thanks to the innovation in shipping technology and ever-growing national interest in the 19th century.

Table 2.1: Significant early history of Arctic marine transport

Date	Event
Since time immemorial	Indigenous people are the original explorers, founders and settlers of the Arctic region.
1490	John Cabot first proposed the existence of the NWP.
1596	William Barents discovered Spitsbergen and sought the NEP.
1778	James Cook made the first attempt at locating the NWP from the west.
1854	Robert McClure received the Admiralty's prize for 'discovering' the NWP.
1903-06	Roald Amundsen in the Gjøa (his herring ship) successfully completed the first transit of the NWP by ship.
1932	The Soviet expedition led by Otto Schmitt was the first to sail in one season transit the NSR.
1940-42	Henry Larsen in the St. Roch, the second vessel to transit the NWP, was the first to do so from west to east.
1944	St. Roch is the first vessel to make a one-season transit (in only 86 days going east to west)

Source: By author (adapted from Arctic Marine Shipping Assessment 2009 Report)

Main shipping events and their impact on modern shipping discussion

The NWP's history dates to the early 1900s with the most notable event being the first complete ship transit of the NWP, which took place during three years from 1903-06 by Norwegian explorer of polar regions, Roald Amundsen. This event has had a tremendous impact on history, and thanks to his discovery, later Amundsen was named after the Amundsen Route (see Figure 2.1) and the Amundsen Gulf. The gulf's coordinates are 71°0′1″N, 124°0′10″W, located mainly in the Inuvik Region, Northwest Territories of Canada and is a crucial checkpoint on the NWP. It lies between Banks Island, Victoria Island and the mainland, has approximately 250 miles (400 km) in length and about 93 miles (150 km) across where it meets the Beaufort Sea (Government of Canada, n.d.). In 1940, Royal Canadian Mounted Police (RCMP) Sergeant Henry Larsen, commanding the ship St. Roch, marked the first time the Northwest Passage had been navigated in a single season. Until then, only one person had ever sailed a ship through the famed NWP, that was Amundsen, from east to west (Marsh, 2013). Sergeant Larsen was the first to sail the passage from west to east, from Vancouver to Halifax, and later in 1944, Larsen and St. Roch made a return trip from Halifax to Vancouver; this time, the voyage lasted only 86 sailing days (Kenney, 2013).

On the eastern hemisphere, the quest for a new route to reach China and India from the Atlantic via north of the Russian coastline spanned more than five centuries, commencing in the 15th century. In primeval days, English, Dutch and Russian navigators sailed along the northern coast of Russia and far into the Arctic seas. Early explorers of the area including William Barents and Olivier Brunel set the foundation of the NSR. The history of commercial use of the NSR can be distinguished by four distinct stages: exploration and settlement (1917 – 1932), development of ports and fleet (1932 – early 1950s); development of regular operating transportation lines during summer-autumn periods (early 1950s – late 1970s); and efforts to establish year-round shipping (late 1970 – present) (Arctic Council, 2009). The NSR finally opened as an international shipping route for non-Russian ships on January 1, 1991 (Moe, 2014; Arctic Council, 2009)

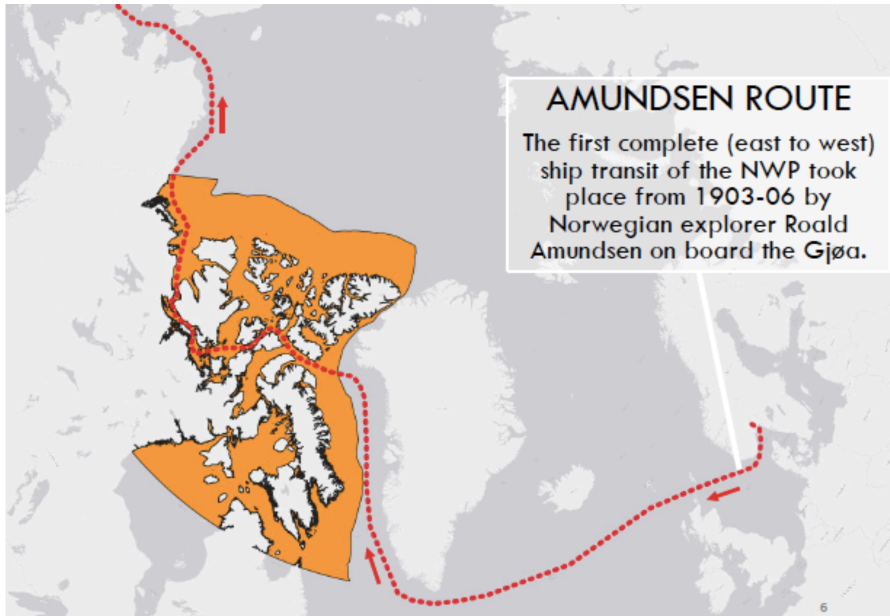


Figure 2.1: Amundsen Route in the NWP.
Source: Arctic Shipping Status Report (ASSR) #3, Hreinsson (2021)

Increased shipping activity in the Arctic

"With the support of advanced shipping technology and accumulating knowledge of modern icebreaking technology" (Arctic Council, 2009, p. 41), maritime traffic in the Arctic has developed significantly in the past two decades. With the development of natural resources extraction activities (oil, gas, rare earth metals) along Arctic shorelines (Hansen et al., 2016), expanding polar local population (Heleniak, 2021) and the reduction of the Arctic ice cap, future predications stated that these motivators will open up new geographical territories and improve the viability of the region to be increasingly used for international shipping (Liu & Kronbak, 2010). Shipping in the Canadian Arctic from 1990 to 2015 demonstrated a statistically significant correlation between shipping activity and ice coverage in most regions (Dawson et al., 2018), indicating the contribution of the decreasing sea ice. Other factors including tourism trends and declining commodity prices also had been suggested to be more important drivers of increased shipping activity in the Arctic than the amount of ice coverage (Dawson et al., 2014). Therefore, climate changes and substantial development in industrial activities both mutually support increased shipping activity in the Arctic (Pahl & Kaiser, 2018).

There are various indicators to measure the increasing trend of shipping activities in each geographic area over a period of time. In this section, three indicators are discussed: the number of trips counted, the number of unique ships counted (this method considers each vessel only once even if it enters the geographic area multiple times (Hreinsson, 2020)), the volume of ballast water as byproduct discharge of shipping activities.

For the first indicator, the 2020 Protection of the Arctic Marine (PAME) report shows that maritime traffic in the Arctic has increased from 2013 to 2019 (Boylan, 2021). During this period, the number of vessels rose from 1,298 to 1,628, a 25% increase over six years (Hreinsson, 2020). The breakdown of the unique vessel count per year and the growth year-on-year are listed in Table 2.2.

Table 2.2: Number of unique ships entering the Arctic region during September 2013 – 2019

Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Number of unique ships	1,298	1,370	1,398	1,446	1,477	1,494	1,628
YoY growth	Baseline	5.6%	2.0%	3.4%	2.1%	1.2%	9.0%

Source: ASSR #1, PAME's Arctic Ship Traffic Data

In conjunction with the count of vessels, the distance sailed is a byproduct statistic of the number of ships and serves as an additional sub-indicator indicating increased shipping activities. As defined in ASSR #1 (Hreinsson, 2020), distance sailed is the aggregated nautical miles (nm) vessels traveled in a certain area over a certain period. Using the same data set of unique vessels during 2013 – 2019, the total distance sailed increased by 75%, from 6.51 million nm to 10.7 million nm (Hreinsson, 2020).

In terms of single trip counts, the NWP's statistic during 2005 – 2014 is 184 total trips, while the NSR sees up to 212 total trips (Guy & Lasserre, 2016) (See Table 2.8 in Section 2.1.3). Regarding NWP's traffic in the period 2008 – 2018, vessels were mainly adventure craft or cruise ships, making most of the 222 complete transits in this period (Boylan, 2021). For the NSR, a total of 8,329 different voyages were completed (1,705 in 2016, 1, 908 in 2017, 2,022 in 2018 and 2,694 in 2019, during 2016 – 2019 (Gunnarsson, 2021).

Apart from annual trips and vessel statistics, another indicator for increased marine shipping activities is the increasing ballast water exchange, as ballast water capacity varies as a function of cargo carrying capacity and ship type. Only until the late 19th century, ship design and construction made it possible to use water as ballast instead of solid materials including rocks and sand to control list, draught, stability and stresses of the ship, and to balance in compensation for changes in cargo loading and unloading between origin, transit and destination ports (IMO, 2016). The annual ballast water amount transported is enormous – around 10 billion tons globally (IMO, 2016), and it can be estimated as a function of the total cargo transported (Endresen et al., 2004). Marine experts observed that there is a proportional increase in ballast water being discharged in Arctic region ports, proving an increased shipping activities pattern in the area. Statistics estimated that the total amount of annual ballast water discharge in Svalbard port (Norway) in 2011 was 653,000 m^3, divided among 31 ships (Ware et al., 2014). Churchill port (Arctic Canada), during 2005 – 2008, recorded an average of 39 discharge events, an average of 41,000 m^3 per year (Figure 2.2) (Chan et al., 2013). This indicator implied not only a considerably growing traffic pattern but also posted an alarming environmental risk for Arctic waters; since ballast water is a major transportation means for spreading wide variety of aquatic non-indigenous species (NIS) originating from foreign waters. To protect the Arctic's aquatic ecosystems, international and national initiatives have developed both global and regional ballast water regulations. The ballast water exchange management is one of the critical metrics in protecting Canada's marine ecosystems from NIS invasions, because non-compliance will cause disastrous environmental impact in the long term, with expensive correctional measurements. Canada had documented several incidents, including the repeated invasions of Chinese mitten crabs in the St. Lawrence river, even invasive species that are cold-weather resilient like the 2007 European green crabs invasion in Newfoundland, and the Japanese skeleton shrimp in Québec (Scriven et al., 2015).

Therefore, Transport Canada, together with Environment and Climate Change Canada, Department of Fisheries and Oceans as partners, finalized the Ballast Water Regulations in June 2021, extending the application to Canada's domestic fleet to further increase environmental protection (Government of Canada, 2022). With the enforcement in action, Canadian vessels and foreign vessels navigating waters under Canadian jurisdiction are compelled to follow the IMO's International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWMC) (adopted in 2004, came into force in 2017) and Canadian Ballast Water Control and Management Regulations (Holbech & Pedersen, 2018; Jing et al., 2012; Scriven et al., 2015). Canada will also inspect and enforce the Convention's requirements on other ships operating in waters under Canadian jurisdiction (Government of Canada, 2022).

Defining and reasserting sovereignty in the Arctic waters, including the NWP, is crucial, especially in special occasions such as disaster distress, whereas instant measures of whose responsibility is immediately required, to assign promptly search and rescue operations and bear the costly impact of disaster aftermath. The Alaskan Arctic witnessed the cargo ship's incident – Selendang Ayu M/V – on December 8, 2004, when it was grounded by sea ice and then lost its engines, quickly broke into two pieces. Despite prompt reactions and much efforts of the operations performed by the U.S Coast Guard, the rescue of the crew from the Selendang Ayu still resulted in the loss of life for both rescuers and crew (six crew members' death and crash of a U.S. Coast Guard helicopter), adding adverse effects of the accident (Arctic Council, 2009). Upon sinking, the vessels discharged its cargo of 66 million metric tons of soybeans, 1.7 million liters of intermediate fuel oil, 55,564 liters of marine diesel and other contaminants into the marine environment (Arctic Council, 2009), which cost the US two years of clean-up efforts and immeasurable long term impacts on local wildlife populations and aquatic ecosystem.

In the future of expanding the traffic on the NWP, the fragile Arctic ecosystems in Canadian Arctic will be in grave danger without such prepared ratification of legal requirements in maritime shipping. Therefore, apart from sovereignty issues, Canada should focus on legal issues, especially with the purpose to protect the environment, the community and the sustainability of the Canadian Arctic.

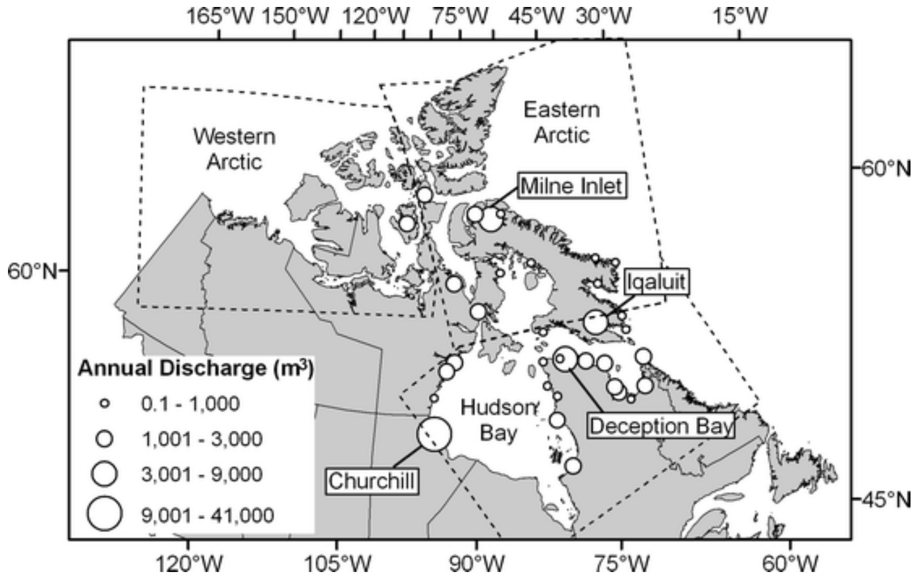


Figure 2.2: Spatial distribution of corrected ballast water discharges in the Canadian Arctic.
Legend: Top ports selected for environmental risk assessment caused by discharged ballast water are labeled, dotted-line polygons outline the boundaries of the Arctic regions.
Source: Chan et al., 2013

From the literature, modern Arctic maritime shipping was only initiated in the 19th century, since Arctic voyages require tremendous interest, preparation, and special skillsets in coordination due to the hostile conditions of the region. Multiple indicators have demonstrated that shipping activities in the Arctic areas are developing, proving that Arctic transit is an inevitable trend, and it is now time to prepare for the development of facilities to support this growth in the future.

However, even with the presence of ice-free summers, there is a large consensus that the projected ice and weather conditions in the NWP in 2020 and remaining of this century are still too dangerous and unpredictable for the development of year-round commercial shipping (Engler & Pelot, 2013). Projections agree that the NSR and even the TSR will become feasible commercial sea lanes before the NWP (Engler & Pelot, 2013). The constraints preventing the NWP from attracting more commercial traffic are: uncertainty from seasonality, ice conditions, complex geography of the archipelago, draft restrictions, chokepoints, lack of adequate charts, insurance limitations and high operational costs (Arctic Council, 2009). In the Introduction chapter, from Inuit people's perspectives, chokepoints in the Arctic are sea ice cracks and leads, connecting land and sea as a means of livelihood. On the contrary, from ocean law experts and shipping professionals' perspectives, Arctic chokepoints are geographically restrictive locations in the region with heightened ecological significance, where much shipping activity currently occurs and will be at risk from increased shipping (Arctic Council, 2009). The Arctic Ocean has multiple marine straits and navigational chokepoints, they have strategic importance in associating waterways that allow for access to and from the Arctic Ocean and ultimately, connecting with major oceans to facilitate trans-Arctic shipping (Rothwell, 2012). An observation from Honderich (1987) stated that, exit from Arctic Ocean can only be made from four points: 1) Bering Strait, 2) Davis Strait (thin gap between Greenland and Canada); 3) through the Canadian archipelago and the Northwest Passage and 4) the Greenland-Iceland-United Kingdom (or GIUK) Gap (guarded by NATO). Modern maritime navigation confirmed Arctic chokepoints list consist of Bering Strait in Alaska Arctic, Hudson Strait and Lancaster Sound in Canadian Arctic, Pechora Sea and the Kara Port in Russian Arctic (Arctic Council, 2009). The list of the Arctic essential chokepoints comprises of multiple locations with crucial roles located on the NWP, including Bering Strait, Lancaster Sound, Davis Strait, and Hudson Strait.

The reason to mention the cruciality of Arctic chokepoints is that chokepoint locations are always present in any maritime traffic traversing through or within the NWP. It is important to pinpoint the characteristics of each chokepoint and understand thoroughly what the challenges and the advantages are. A review of the list of chokepoints and their associated challenges based on different subsets of NWP routes will be discussed in Section 2.1.2.

2.1.2 Shipping activities on the NWP

Different water routes included in the NWP

The literature reviewing the definition of the NWP shares the same major approach: first is to construct geographical boundaries of the NWP and then list the subset routes.

In the introduction chapter, we have used the first definition of the NWP by Arctic Council (a high-level intergovernmental forum made up of eight state members and observer states, Indigenous "permanent participants" and observer organizations that addresses issues faced by the Arctic governments and the indigenous people of the Arctic). According to the AMSA report 2009, the NWP is “the name given to the various marine routes between the Atlantic and Pacific oceans along the northern coast of North America that span the Canadian Arctic Archipelago” (Arctic Council, 2009, p.20). Pullen & Swithinbank (1991) stated that the transit of the NWP is regarded as a voyage through one of several channels and straits across the Canadian Arctic Archipelago. This definition was quoted again in Headland (2010), and Headland agreed that the definition of the constituents of the NWP have been disputable. With the same view, the ASSR #3 report also concluded that there is no official definition of the NWP, but it is defined by listing out six primary routes that make up the NWP. Lu et al. (2014) defined the passage by setting up geographic landmarks that it crosses through: “the NWP runs between Greenland and Newfoundland in the Atlantic Ocean, and along the northern coast of Canada and Alaska, ending in the Bering Strait” (Lu et al., 2014, p. 62). Hansen et al. (2016) defined the NWP to be the combination of shipping routes connecting the Atlantic Ocean with the Pacific Ocean through the North American Arctic waterways. Dawson et al. (2017) provided more a specific definition based on the Northern and Southern entrance and egress of the NWP: the NWP bridges the Atlantic and Pacific Oceans, via Baffin Bay in the Eastern Arctic and the Beaufort Sea in the Western Arctic (Dawson, Copland, et al., 2017). The NWP is associated with one of the most complex archipelago structures on earth, the Canadian Arctic Archipelago. Stretching approximately 2,400 kilometers from east (Baffin Island) to west (Banks Island) and covering a triangular area roughly 2.1 million km^2 including land and ocean area with more than 36,000 islands, the Canadian Arctic Archipelago is a complicated geography but sparsely populated, making it extremely difficult to access (Arctic Council, 2009). Given the complexity of the Canadian Arctic Archipelago, from the literature, different sets of routes are observed, ranging from five, six and seven routes subsets. According to AMSA report, there are five recognized routes through the archipelago, with variations, making a total of six primary routes. The spatial illustration of the various routes after multiple expeditions searching for the NWP through the Arctic, during the period from 1576 to 1944, can be found in Figure 2.3. Detailed routing of the six routes is described in Table 2.3.

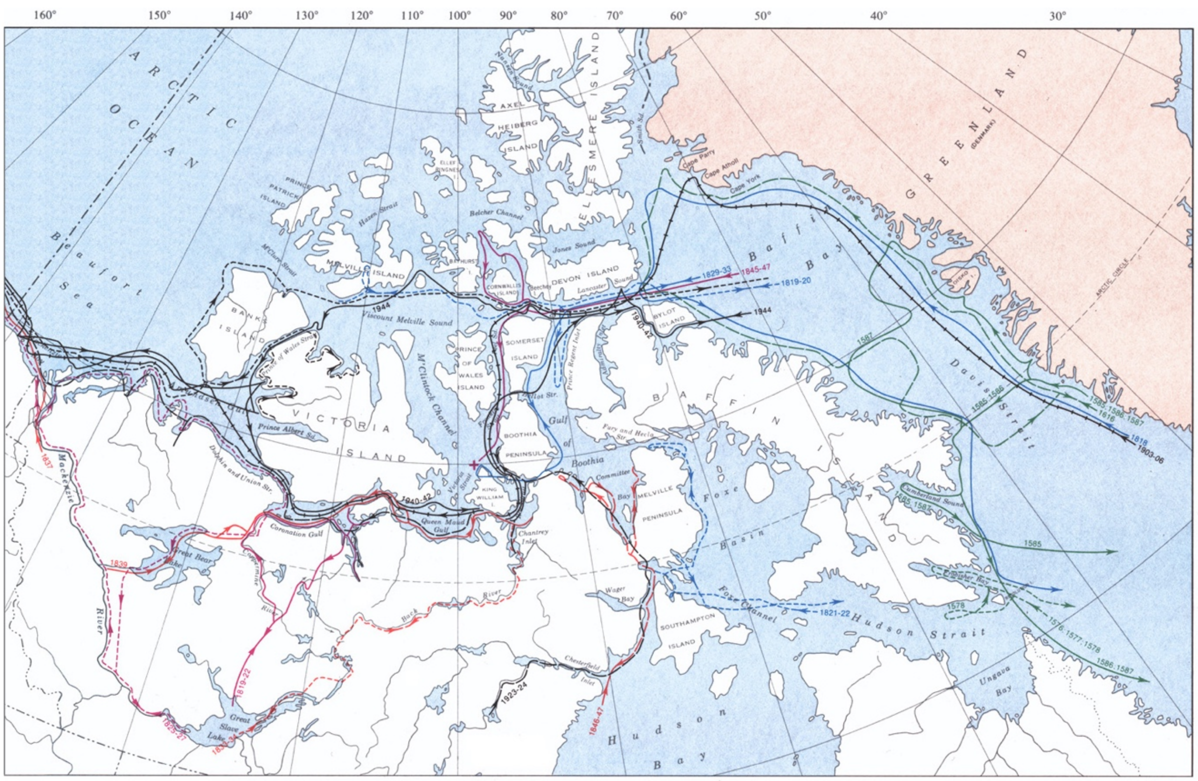


Figure 2.3: Spatial locations of different water routes during expedition time that comprise of the NWP.

Source: By author, compiled from "A map showing the routes of various expeditions searching for the NWP through the Arctic from 1576 to 1944" (Natural Resources Canada) – The Canadian Encyclopedia)

Legend: The list of expeditions in chronological order is shown in Table 2.3:

Expedition by	Year	Discovery	Notation on map	Illustration for notation
Martin Frobisher	1576-1577-1578	Frobisher Bay	Dashed green line	
John Davis	1585-1586-1587	Davis Strait	Arrowed green line	
Henry Hudson	1610	Hudson Bay		n/a
Robert Bylot and William Baffin	1616	Baffin Bay	Dashed, arrowed green line	
William Edward Parry	1819-1820	Parry Channel	Dashed blue line	
			Blue arrowed line	
			Pink arrowed line	

James Ross	1829-1833	Reached the north magnetic pole	Short dashed pink line	
John Franklin	1819-1839	Franklin Strait	Short dashed red line	
			Arrowed red line	
Britain and the United States' rescue	1847-1859	Rescue expedition	Dashed red line	
Roald Amundsen	1903-1906	The complete NWP	Black with vertical bar line	
Robert McClure	1923-1924	McClure strait	Dashed black line	
Sergeant Henry Larsen	1940-1942	The complete NWP route but from the west entrance	Arrowed black line	
Sergeant Henry Larsen's return	1944		Arrowed black line	

Table 2.3: Water routes of the NWP

Route	*Routing (from east to west)*	*Remarks*
1	Lancaster Sound – Barrow Strait – Viscount Melville Sound – Prince of Wales Strait – Amundsen Gulf	Route is suitable for deep draft navigation.
2	Lancaster Sound – Barrow Strait – Viscount Melville Sound – McClure Strait	
3	Lancaster Sound – Barrow Strait – Peel Sound – Franklin Strait – Larsen Sound – Victoria Strait – Queen Maud Gulf – Dease Strait – Coronation Gulf – Dolphin and Union Strait – Amundsen Gulf.	Draft limit of 10 meters only.
4	Lancaster Sound – Barrow Strait – Peel Sound – Franklin Strait – Larsen Sound – James Ross Strait – Rae Strait – Simpson Strait – Queen Maud Gulf – Dease Strait – Coronation Gulf – Dolphin and Union Strait – Amundsen Gulf.	This route is a variation of 3A. Rather than following Victoria Strait on the west side of King William Island, the route passes to the east of the island following James Ross Strait – Rae Strait – Simpson Strait.
5	Lancaster Sound – Barrow Strait – Peel Sound – Prince Regent Inlet – Bellot Strait – Rae Strait – Simpson Strait – Queen Maud Gulf – Dease Strait – Coronation Gulf – Dolphin and Union Strait – Amundsen Gulf.	Like 3A. Rather than following Peel Sound on the west side of Somerset Island, the route passes to the east of the island through Prince Regent Inlet and Bellot Strait.
6	Hudson Strait – Foxe Channel – Foxe Basin – Fury and Hecla Strait – Gulf of Boothia – Bellot Strait – remainder via routes 3A, 3B or 4.	Entrance on Hudson Strait, south of Baffin Island. This route is not generally considered a viable commercial passage for moderate to deep draft ships.

Source: By author (adapted from AMSA, ASSR #3 report)

Route 1 and Route 2 share similar entrance from Lancaster Sound to Barrow Strait, but upon reaching Viscount Melville Sound, Route 1 descends southwards to Prince of Wales Strait and exits at Amundsen Gulf while Route 2 ascends northwards to McClure Strait (rendered as McClure Strait) and exits to Beaufort Sea. McClure Strait is chronically blocked with severe ice but Route 2 is the shortest and deepest draft route, it is frequently used by submarines because of its depth (Headland, 2010). Therefore, Route 1 is more suitable for deep draft navigation to avoid the severe ice condition in McClure Strait. Route 3 is the most frequently used route, taken by most vessels of draft less than 10 meters (Headland, 2010). Route 4 and Route 5 are different variations of Route 3, with Route 4 deviating from Route 3 upon reaching Larsen Sound: Route 3 turns westwards to Victoria Strait while Route 4 turns eastwards King William Island to James Ross Strait; they eventually join when reaching Queen Maud Gulf. Route 5 shares with Route 3 a shorter entrance compared with Route 4, but when reaching Somerset Island, Route 5 deviates eastward to Bellot Strait while Route 3 turns westward to Franklin Strait; and similarly, Route 5 and Route 4 intersect at Queen Maud Gulf. The variations of Route 3, 4 and 5 are useful when different navigational obstacles take place: Victoria Strait blocked by ice, Simpson Strait is only 6.4 m deep and has difficult currents, or difficult currents run in Bellot and Simpson Straits (Headland, 2010). The last route, Route 6 is the most distinctive route since its entrance is completely different, starting at Hudson Strait, south of Lancaster Sound, and it is considered a difficult route owing to two constraints: severe ice at Fury and Hecla Strait, and strong currents of Bellot Strait (Headland, 2010).

Headland (2010) reviewed ten decades of shipping on the NWP based on a slightly different set of routes as in Table 2.4. Headland's subset of routes is considered homogeneous with AMSA's subset, except for additional variation of Route 5. The notation of Headland's routes compared with AMSA's routes is indicated in Table 2.4.

Table 2.4: Set of NWP water routes in Headland (2010)

Route	*Routing in Headland*	*Remarks*
1	Davis Strait, Lancaster Sound, Barrow Strait, Viscount Melville Sound, McClure Strait, Beaufort Sea, Chukchi Sea, Bering Strait. (similar to Route 2 (Arctic Council, 2009))	The shortest and deepest route, but most difficult way due to severe ice of McClure Strait. The route is used by submarines because of its depth.
2	Davis Strait, Lancaster Sound, Barrow Strait, Viscount Melville Sound, Prince of Wales Strait, Amundsen Gulf, Beaufort Sea, Chukchi Sea, Bering Strait. (similar to Route 1 (Arctic Council, 2009))	An easier variant of route 1 which may avoid severe ice in McClure Strait; suitable for deep draft vessels.
3	Davis Strait, Lancaster Sound, Barrow Strait, Peel Sound, Franklin Strait, Victoria Strait, Coronation Gulf, Amundsen Gulf, Beaufort Sea, Chukchi Sea, Bering Strait. (similar to Route 3 (Arctic Council, 2009))	The most frequently used route, taken by most vessels of draft less than 10 m.
4	Davis Strait, Lancaster Sound, Barrow Strait, Peel Sound, Rae Strait, Simpson Strait, Coronation Gulf, Amundsen Gulf, Beaufort Sea, Chukchi Sea, Bering Strait. (similar to Route 4 (Arctic Council, 2009))	A variant of route 3 for small vessels if ice from McClintock Channel has blocked Victoria Strait; Simpson Strait is only 6.4 m deep and has difficult currents.
5	Davis Strait, Lancaster Sound, Prince Regent Inlet, Bellot Strait, Franklin Strait, Victoria Strait, Coronation Gulf, Amundsen Gulf, Beaufort Sea, Chukchi Sea, Bering Strait. (similar to Route 5 (Arctic Council, 2009))	This route is dependent on ice conditions in Bellot Strait which has difficult currents; mainly used by eastbound vessels.
6	Davis Strait, Lancaster Sound, Prince Regent Inlet, Bellot Strait, Rae Strait, Simpson Strait, Coronation Gulf, Amundsen Gulf, Beaufort Sea, Chukchi Sea, Bering Strait. (similar to Route 5 (Arctic Council, 2009))	A variant of route 5 for small vessels if ice from McClintock Channel has blocked Victoria Strait; Simpson Strait is only 6.4 m deep, difficult currents run in Bellot and Simpson Straits.
7	Hudson Strait, Foxe Basin, Fury and Hecla Strait, Bellot Strait, Franklin Strait, Victoria Strait, Coronation Gulf, Amundsen Gulf, Beaufort Sea, Chukchi Sea, Bering Strait. (similar to Route 6 (Arctic Council, 2009))	A difficult route owing to two constraints: severe ice usually at the west of Fury and Hecla Strait, and the currents of Bellot Strait; mainly used by eastbound vessels.

Source: Headland, 2010.

The reason to review the different sets of routes is to identify the list of different locations that these routes cross and to verify which location(s) are vital for the development of traffic. Based on shipping professionals and modern navigation definition of chokepoints, the set of NWP routes bypass the following key locations: Davis Strait, Lancaster Sound, Prince of Wales Strait, Amundsen Gulf, Peel Sound, Franklin Strait, Dolphin and Union Strait, Rae Strait, Simpson Strait, Fury and Hecla Strait and Bellot Strait. If we trace along all water routes of the NWP, the key location list contains: Prince of Wales Strait, Peel Sound, Franklin Strait and Bellot Strait in the upper north-east section of the NWP, Rae Strait, Simpson Strait and Fury and Hecla Strait in the south-east section of the NWP, Amundsen Gulf and Dolphin and Union Strait in the south-west section. Therefore, these locations are predicted to be decisive in projecting the improvements required to facilitate easier and safer transport through them.

Based on the literature, we can identify the challenges associated with navigating through these locations. Table 2.5 summarized the bathymetric and geographical characteristics of these critical locations.

Table 2.5: Critical locations on the NWP and their characteristics

Region of the NWP	Location	Characteristics	Reference
Northeast	Prince of Wales Strait	Multi-year ice	Engler & Pelot, 2013
Northeast	Peel Sound	Hazardous multi-year ice	Engler & Pelot, 2013
Northeast	Franklin Strait	Severe ice	Engler & Pelot, 2013
Northeast	Bellot Strait	Strong, unpredictable currents and severe ice	Headland, 2010
Southeast	Rae Strait	n/a	
Southeast	Simpson Strait	Strong, unpredictable currents and shallow depth (6.4m)	Headland, 2010
Southeast	Fury and Hecla Strait	Severe ice	Headland, 2010
Southwest	Amundsen Gulf	Sufficient depth	Headland, 2010
Southwest	Dolphin and Union Strait	Shallow depth	Paterson, 2011

Source: By author, compiled from Engler & Pelot (2013); Headland (2010); Paterson (2011).

Modern maritime navigation listed Arctic chokepoints as Bering Strait in Alaska Arctic, Hudson Strait and Lancaster Sound in Canadian Arctic, Pechora Sea and the Kara Port in Russian Arctic (Arctic Council, 2009). The list of the Arctic essential chokepoints comprises of multiple locations with crucial roles located on the NWP, including Bering Strait, Lancaster Sound, Davis Strait, and Hudson Strait. To support the navigation growth on the NWP, it is important to better realize potential threats to human safety and the Arctic marine environment and understand the characteristics of these critical locations and how they can turn into potential accidents. The AMSA report prepared a summary of the incidents and accidents occurring in the Arctic region between 1995 – 2004, using input from the Lloyd's Marine Intelligence Unit Sea Searcher Database, the Canadian Hydraulics Centre Arctic Ice Regime System database and the Canadian Transportation Safety Board (Marine) (Arctic Council, 2009), which is a direct metric to illustrate the challenges for navigating the Arctic waters posted to maritime industry. There were a total of 293 incidents and accidents logged and categorized into seven types, with the most frequent order taking place as: machinery damage/failure (71), grounded (68), damage to vessel (54), sunk/submerged (43), fire/explosion (25), collision (22) and miscellaneous (10) (Arctic Council, 2009). The hazardous and constantly changing sea ice dynamics which cover a very large geographic area, severe ice condition and strong currents accompanied with shallow depth are the main contributors to machine failures and grounded incidents, leading to further vessel damage and sinking which can be seen through the geographic distribution of the incidents during 1995 – 2004 shown in Figure 2.4. There is a complete absence of incidents reported in the Russian Arctic while there appears to be a concentration of incidents in Hudson Strait, the Bering Strait and

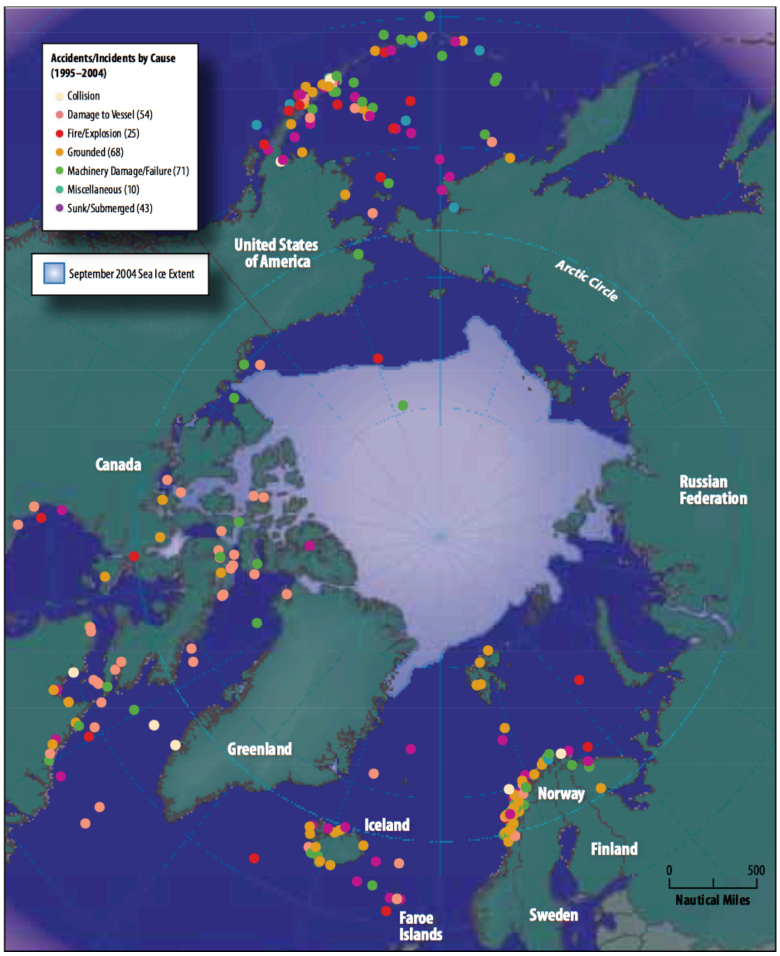


Figure 2.4: Arctic shipping accidents and incidents causes, period 1995 – 2004.
Source: AMSA Report (Arctic Council, 2009)

Labrador coast (Canada, east entrance of the NWP), in the Aleutian Island chain (Alaska, west entrance of the NWP), together with along the northern coast of Norway, Iceland and the Faroe Islands (Denmark). These concentrations of incidents are consistent with our prediction of the essential chokepoints and aligned with the busiest Arctic shipping traffic patterns. Therefore, elaborate and up-to-date hydrographic charts and just-in-time weather forecasts are always in demand.

The history of maritime navigation on the NWP

The NWP's record book started with the event that marked the birth of the passage when Roald Amundsen in the Gjøa (his Norway-flagged herring ship) completed the first transit of the NWP. According to Pullen & Swithinbank (1991), from 1906 to 1990, the Arctic Operations Division of the Canadian Coast Guards preserved a log of 50 official transits, alongside with unofficial partial and incomplete transits. The record consists of 27 trips (54% of the total trips) with Canadian flag of registry vessels (Pullen & Swithinbank, 1991). Followed in second place is 15 trips (30%) with USA flag vessels, 2 trips from Britain-flagged vessels and the rest are Holland, Japan, Bahamas, each contributed a single trip (Pullen & Swithinbank, 1991). Headland (2010) proposed a more comprehensive review of trip records based on Pullen & Swithinbank (1991) and complemented with extended period from 1991 to 2009. By the end of the 2009 navigation season, 135 transits of the Northwest Passage have been made (Headland, 2010). Headland and his colleagues continue to maintain the NWP's transit record with the most latest updates of up to the shipping season of 2022, with a total of 324 voyages (Headland, 2022). A route analysis with route detail, with breakdown trip categorizing into subgroups – whether the trip entered from east or west entrance with Route 3 and Route 6 (most frequently used routes), are shown as in Table 2.6.

Within a 19-year period from 1991 to 2009, there were 85 additional voyages, it was three times the number of passages compared to the period 1906 to 1990. Regarding flag of registry, the nation numbers expanded exponentially. The vessels are from 20 registries including: Canada (42), Russia (22), United States (18), Bahamas (15), France (8), Britain (7), Germany and New Zealand (3), Australia, Belgium, Norway, Poland, and Sweden (2), and Barbados, Cayman Islands, Croatia, Ireland, Japan, Netherlands, and Singapore (1) (Headland, 2010).

Table 2.6: Transit statistics on seven routes of the NWP from 1906 to the end of navigation season in 2022

Route	West	% in Total	East	% in Total	Total
1	3	100%	0	0%	3
2	12	71%	5	29%	17
3	56	64%	32	36%	88
4	46	81%	11	19%	57
5	27	41%	39	59%	66
6	35	45%	43	55%	78
7	4	31%	9	69%	13
Composite	1	50%	1	50%	2
All routes	184	57%	140	43%	324

*Notes: Composite trip refers to trips that traverse using two water routes of the NWP.
Source: Headland (2022)

From the period 2010 to 2022, the number of voyages increased from 135 voyages by the end of 2009 to 324 voyages by the end of 2022 (Headland, 2022). The record saw a significant rise in number of registries (total 35 registries) and foreign-flagged vessels (other than Canadian-flagged) domination, with France as the leading registry in terms of trips. Canadian-flagged trips shared the fifth place with Bahamas-flagged and Cayman Islands-flagged trips (See Table 2.7).

From the NWP's shipping record over a century (1906 – 2022), there are three key findings that can be drawn: 1) shipping activity on the NWP has been increasing over time, 2) the majority of flag registry on the NWP is Canada-registered vessels for domestic transit, and 3) the number of international flag vessels is developing, indicating a growing interest of international transit voyages.

Table 2.7: Flag registry and trip counts on the NWP during 2010 – 2022

Registry	Trip counts	Percentage
France	26	13.47%
Netherlands	22	11.40%
Britain	18	9.33%
US	15	7.77%
Canada, Bahamas, Cayman Islands	13	6.74%
Germany	9	4.66%
New Zealand	6	3.11%
Finland, Austria, Norway, Russia, Australia, Sweden, Marshall Islands, Switzerland	5	2.59%
Belgium, Poland	3	1.55%
Antigua and Barbuda, Malta	2	1.04%
Israel, Cook Islands, Slovakia, Curacao, Panama, Czechia, Italy, Denmark, South Africa, China, Nouvelle Calédonie, Hungary, Greenland, Hongkong	1	0.52%
Grand Total	**193**	**100%**

Source: By author (compiled from Headland (2022))

This review has stressed the evolution of the international transit interest and the importance of the NWP. To facilitate this growth trend, a strategy to select critical investments that support international transit is of paramount importance. Griffiths (2005) quoted an expert in military and strategic studies – Canada's position is likened that of a strait state: "Singapore has demonstrated that with the proper planning, geographic location on an international strait can bring substantial economic benefits" (Huebert, 2011, p.396). According to Griffiths (2005), Canadian government should seize the opportunity proactively so that eventually, it could profit from it. Therefore, this research will tackle this problem in the literature and serve as a preparing step for future planning.

2.1.3 A comparison of shipping traffic between the NWP and the NSR

Both Canada and Russia claim sovereignty over the NWP and the NSR; however, there is a substantial difference in the validity of their claims and their execution on the passages. The Northeast Passage (NEP) is a set of shipping routes connecting the Atlantic and Pacific Oceans, along the Arctic coasts of Norway and Russia. The western route through Canadian Arctic is the Northwest Passage (NWP). The NWP rests almost entirely in Canadian-claimed internal waters (extending from Baffin Bay to the Beaufort Sea) (refer to further sovereignty discussion in Section 2.3.3), whereas the NSR, the Russian-claimed and Russian-administered route that connect Europe and Asia along the northern shores of Russia, is only a part of the NEP, (extending from Kara Gate and the Bering Strait). The NEP lies mostly outside Russian territorial waters, except for a few locations where NEP briefly crosses Russian straits thus Russian-claimed internal waters (Dawson et al., 2017). Since a part of the NEP lies within the Russian Exclusive Economic Zone (EEZ), Russia imposes regulations on shipping activities along the NSR based on Article 234 of the UNCLOS, obliging ships to comply with Russian's sovereignty within the Russia's EEZ; therefore, enforces ships to use mandatory, fee-required piloting and icebreaker escort services (Guy & Lasserre, 2016). Russia set up a special administration body to manage traffic and called this segment the NSR Administration (NSRA). The NSRA oversees applications for transit and collects the fee that Russia imposes in exchange for providing piloting or icebreaker escort services, as well as the vessel's ability to dock at one of the several small ports along the NSR in case of emergency (Arkhangelsk, Dudinka, Tiksi and so on), and accessibility to a network of Russian's search and rescue centers in the Arctic (Guy & Lasserre, 2016).

On the other side of the Arctic basin, Canada requires no mandatory transit fee in the NWP as Canada offers no similar services, except for basic navigation aid (seasonal buoys, frequent transmission of ice maps). Canada has not yet organized sufficient resources such as icebreakers to organize convoys and assistive commercial vessel piloting. Furthermore, there is no deep-water port along the NWP between Iqaluit and Point Barrow in Alaska (US) (Eger, 2010) until summer 2023; the nearest search and rescue (SAR) bases are located far south in Halifax, Cold Lake or Comox. Therefore, the infrastructure and associated services pales in comparison on the Canadian's Arctic.

There are different aspects that can be used to compare transit along the NWP and the NSR, in this thesis, two aspects of voyages on the NWP and NSR are considered: trip counts and ship types. For the first aspect (trip counts), the thesis will review the transit record on the NWP and the NSR during the period from 2011 to the latest shipping season of 2022.

For the NWP's statistics, the thesis employed records documented by R.K. Headland and his colleagues of the Scott Polar Research Institute at the University of Cambridge in England. Despite being an independent data source from NORDREG, Headland's data is frequently updated from multiple trusted advisors in US Coast Guards, Canadian Coast Guards departments (Headland, 2022). For the NSR's statistics, the thesis obtained the data straight from CHNL's statistics at Northern Sea Route Information office at https://arctic-lio.com. The traffic statistics is shown in Table 2.8.

The turning point of this database is the year of 2014: for the NSR, the number of transits in all origin – destination (OD) pairs dropped significantly while in contrast, on the NWP, 2014 marked a tipping point where all transits grew sharply. Industry experts attributed the decline in traffic on the NSR to three major reasons: the steep reduction in bunker prices reflecting the sharp decrease in fuel, as well as the decline of commodity price and presumably, the Western sanctions imposed on Russian military intervention in Crimea (Ukraine) (Lasserre et al., 2019) and the decision by Russian authorities to dedicate icebreakers primarily to offshore oil exploration, thus severely reducing their availability to transiting ships (Guy & Lasserre, 2016). Along the NWP, the traffic fluctuated from year to year after 2014, with a peak in 2019.

Table 2.8: Transit traffic statistics of the NWP and the NSR, period 2010 – 2022

Year	NWP	NSR
2011	14	41
2012	22	46
2013	21	71
2014	11	31
2015	20	18
2016	19	19
2017	33	27
2018	3	27
2019	25	37
2020	6	64
2021	5	85
2022	27	43
Total	**206**	**509**

Source: By author (NWP's data extracted from this link here and NSR's data extracted from this link here).

The turning point of this database is the year of 2014: for the NSR, the number of transits in all origin – destination (OD) pairs dropped significantly while in contrast, on the NWP, 2014 marked a tipping point where all transits grew sharply. Industry experts attributed the decline in traffic on the NSR to three major reasons: the steep reduction in bunker prices reflecting the sharp decrease in fuel, as well as the decline of commodity price and presumably, the Western sanctions imposed on Russian military intervention in Crimea (Ukraine) (Lasserre et al., 2019) and the decision by Russian authorities to dedicate icebreakers primarily to offshore oil exploration, thus severely reducing their availability to transiting ships (Guy & Lasserre, 2016). Along the NWP, the traffic fluctuated from year to year after 2014, with a peak in 2019.

To explain the gap why the traffic records on the NSR almost doubled the records on the NWP, many researchers have agreed on the fact that the NSR is more viable than the NWP in the short term, thanks to three main attributes: the sea-ice dynamics on the NSR is more stable and predictable than on the NWP, there are more make-ready port infrastructure as well as available maritime services and established insurance on the NSR than on the NWP, and the commercial opportunities are well utilized (Dawson et al., 2017). The unpredictable, constantly changing nature of sea ice on the NWP and the severely insufficient port and maritime infrastructure will be discussed further in Section 2.3, as the two major challenges posed (among other systematic challenges) for traffic development on the NWP. The commercial analysis between the NWP and traditional maritime routes will be tackled in Section 2.2.

The second comparison aspect is by different ship types of traffic in the Arctic area. During period 2005 – 2014, local or destination traffic for re-supply purpose is on the rise in both Arctic Canada and Russia (Guy & Lasserre, 2016). The data source for this comparison analysis is based on data collected by various maritime institutions of Canada and Norway/Russia. In the Canadian Arctic water region, commonly referred to as Northern Canada Vessel Traffic Services Zone (NORDREG), the Canadian Coast Guard's Marine Communications and Traffic Services (MCTS), located in Iqaluit, monitors marine traffic (Lasserre et al., 2019). On the NSR's side, the Centre for High North Logistics (CHNL), an international information hub providing information on shipping and logistics in the Euro-Russian Arctic, collaborated with Rosatomflot (Russia) to establish the online database ARCTIS (Arctic Resources and Transportation Information System) (Lasserre et al., 2019). Together, these two sources, NORDREG and CHNL (with a lesser precision than the data for the NWP) were processed towards a harmonized typology to perform statistics of the voyages via the NWP and the NSR. The breakdown of total trips is illustrated in Table 2.9.

One notable highlight is the "issues with data consistency", as explained by Lasserre et al. (2019, p. 77), the inconsistencies between datasets existed in the inconstant standard of the data input. The CHNL's data report counted both full transits and partial transits during the period 2011 to 2014, but they only counted full transit and excluded partial transit in 2015 and 2016. The NORDREG's data always counted both full and partial transits the whole time. The traffic on NWP outnumbered the transit on the NSR during 2011 – 2016, even when partial transits are presumably removed in 2015, 2016 on the NWP (the full transit counts on the NWP are 27 and 23 respectively in 2015 and 2016).

For Canada's high north, the most frequently observed ship types were commercial cargo ships supplying mining exploration and the local communities, fishing trawlers (grouped under "Pleasure boat" type), and tourist and cruising support ships ("Cruise ship or touristic icebreaker"). Transit remains poorly developed along the NWP (Guy & Lasserre, 2016): commercial cargo transit is minimal, and the data is mainly fueled by pleasure boats (See Table 2.9). This similarity corresponds to the France-flag registry in Headland's data during 2011 – 2022. The mechanism to consider partial transit contributed significantly to the usage of the NWP; therefore, the NWP's record outpaced NSR's data during 2015 – 2017 in the dataset by Guy & Lasserre (2016), Lasserre et al. (2019) and Lasserre (2022) (See Table 2.9).

Shipping activities on the NWP and on the NSR follow a clear trend of expansion, but with different growth phases between the two regions. Transit numbers on the NWP had been low at the beginning of the period from 2005 – 2011, experienced stable growth from 2012 – 2017 then dropped significantly during 2018 – 2020. On the contrary, along the NSR, shipping activities did not prosper during 2005 – 2011, then witnessed a booming effect in a short period from 2011 – 2014, then suddenly dropped (Western sanction on Russia for the Crimea invasion) during 2015 – 2017. But since then, traffic on the NSR is picking up and developing at a steady rate (Guy & Lasserre, 2016). NSR's traffic not only developed at a faster rate than NWP's during 2018 – 2020, but it also contained higher commercial transit ratio, a dimension largely absent in the NWP (Guy & Lasserre, 2016).

One notable highlight that the thesis recognized while performing trip counts on the NWP and trip count comparison between the NWP and the NSR, is the difference between two sets of data (Headland's record in Table 2.8 and NORDREG's record compiled by Guy & Lasserre (2016) and Lasserre et al. (2019) presented in Table 2.9). There are three major assumptions in the data collection mechanism that contributed to the different transit records in the same year between Headland's data and NORDREG's data, they are: 1) nature of the voyage's difference: Headland's data only counted full, complete journeys while NORDREG's data recorded both full transits and partial transits (delivery voyages for re-supply purposes for northern communities residing within the Canadian Arctic Archipelago), 2) territorial difference: Headland's data counted voyages traversing the NWP from/to the Atlantic Ocean to/from the Pacific Ocean while NORDREG's data recorded any voyages performed by any vessels operating within the Canadian Arctic waters, 3) ship category difference: Headland's data excluded small crafts traversing the Canadian Arctic archipelago but not entering the Pacific Ocean while NORDREG's data included these small crafts counts.

To compare transit between the NWP and the NSR, Lasserre et al. (2019) also considered other comparison metrics including cargo type and volume, transit volume by transit and cargo types. Cargo volume is also an important indicator in suggesting the business nature of the traffic on the passage. The comparison produced an interesting result, cargo volume on the NSR is not significantly larger than on the NWP in terms of transit volume – the main volume enabler on the NSR is the destination transit (Lasserre et al., 2019) (See Table 2.10), thanks to the denser population living along the NSR and the growth of various LNG plants and other natural resource extraction sites along the NSR (Pahl & Kaiser, 2018).

Table 2.9: Transit traffic on the NWP and NSR, period 2005 – 2020

Ship type	**Icebreaker**		**Cruise ship or touristic icebreaker**		**Government ship**		**Pleasure boat**		**Tug**		**Cargo ship**		**Research ship**		**Total transit**		**Source**
Route	NWP	NSR	NWP	NSR	NWP	NSR	NWP	NSR	NWP	NSR	NWP	NSR	NWP	NSR	NWP	NSR	
2005	2		2										3		**7**	**0**	Guy and Lasserre (2016)
2006	2		2						1				1		**6**	**0**	
2007	2		3				2			1		1			**7**	**2**	
2008	1		2				7			1	4	2	1		**15**	**3**	
2009	2		3				10		2		1	5			**18**	**5**	
2010	2		6	1			12		1	4	4	6		2	**25**	**13**	
2011	2	2	4	1		1	13			4	7	31	1	0	**27**	**41**	
2012	2	3	6	0		0	22		2	5	7	38	1	2	**40**	**46**	
2013	2	1	4	1		1	14				1	66	1	2	**22**	**71**	
2014	4	2	2	3		1	10			1	1	24			**17**	**31**	
2015		1		1	6	3	27		0	4	10	15	0	0	**43**	**24**	Lasserre et al. (2019)
2016		2		1	3	1	28		0	4	13	11	3	0	**47**	**19**	
2017	2	1	3	0		0	22	1	3	2	2	23	5	0	**37**	**27**	Lasserre (2022), CHNL's website
2018	2	1	0	0		0	2	1	1	2		23		0	**5**	**27**	
2019	1	11	5				13	4	1		3	22			**23**	**37**	
2020	1	7	0	1			1	5	5			56			**7**	**64**	

Note: Partial transits are counted on the NWP during 2005 – 2020 and NSR during 2005 – 2014); "Icebreaker" on the NSR in 2020 is grouped as "Icebreaker/ Supply/ Tug"; "Pleasure boat" on the NWP included Passenger ship and Pleasure craft, "Pleasure boat" on the NSR included Fishing; "Cargo ship" on the NWP included Tankers, "Cargo ship" on the NSR included General cargo, Heavy Load, Tanker, Reefer, Container, Bulk; "Research ship" on the NWP included Others.

Source: By author (adapted from Guy & Lasserre (2016) for period 2005 – 2014; Lasserre et al. (2019) for period 2015 – 2016; Lasserre (2022) for NWP's transit and CHNL's data for NSR during period 2017 – 2022).

Table 2.10: Total transit cargo volume (metric tons) along the NSR and the NWP, 2011–2016

Year	NWP total tonnage	NSR transit tonnage	NSR total tonnage
2010	-	110,000	110,000
2011	331,591	820,789	3,225,000
2012	209,400	1,261,545	3,750,000
2013	261,220	1,176,454	3,914,000
2014	299,654	274,103	3,982,000
2015	429,461	39,586	5,432,000
2016	403,225	214,513	6,060,000
2017			9,700,000
2018			18,000,000

Source: Lasserre (2022).

Since the 1980s, global average surface temperatures during a given decade have always been higher than the average temperature in the preceding decade, suggesting that global warming effect had been taken place. For the ice-free Arctic prediction, it has been more than 30 years since the foundation of IPCC that gathered consensus among scientists. However, in September 2022, there was still almost 5 million square kilometers of sea ice in the Arctic Ocean in the lowest point during September (NSIDC, 2022). In other words, the ocean is never entirely ice-free, and forecast has fluctuated significantly from year to year. It is undeniable at the margins that there is an extended period of open water during the swift shipping season in summer, but the sea ice dynamics vary substantially among different regions and among years (See further discussion on the constant changing nature of sea ice in Section 2.1.3). In the case of the NSR, the shipping season is a bit longer in comparison, thanks to the lesser density of islands north of the coast and the entry of warmer water from the Northeast Atlantic currents. In contrast, the

NWP is gifted with the complexity geographic nature of the Canadian Arctic Archipelago, involving its water channels through Canada's Arctic islands that are easily prone to ice formation. Therefore, the transit records through quantity (trip counts and ship types) and quality (transit volume) analysis concludes that there is a lesser traffic pattern on the NWP than on the NSR. Navigating the NWP is more difficult than the NSR due to many challenges, which are: 1) the sea ice dynamics (Guy & Lasserre, 2016; Pizzolato et al., 2014, 2016)), 2) the navigational conditions of the archipelago (Giguère et al., 2017), 3) the availability of maritime market and (Lasserre & Pelletier, 2011; Lasserre et al., 2016; Meng et al., 2017), 4) the absence of affordable, sufficient insurance and premiums for NWP's voyages (Mikkola & Käpylä, 2013; Giguère et al., 2017)) and 5) the absence of available port structure (Giguère et al., 2017; Guy & Lasserre, 2016; Lasserre & Pelletier, 2011; Mussells et al., 2017; Pahl & Kaiser, 2018). While the NWP may never be able to compete with the NSR in the short term; nonetheless, there is room for significant potential for growth along Canada's NWP, through various federal and local policy positions to facilitate and drive additional traffic in the future. These policies will initially take multiple generic forms of strategic investments to improve the status-quo of navigating the NWP, which also is the major objective of this research.

2.2 Commercial viability of the NWP

Arctic shipping is an emerging topic in maritime transport research, expressing an exponential interest in publications in the last decade (Theocharis et al., 2018). Lasserre (2014) and Lasserre (2015) reviewed 26 comparative studies on Arctic versus traditional routes from 1991 to 2013, Meng et al. (2017) assessed 25 publications on commercial viability from 1992 to 2014 and Theocharis et al. (2018) systematically reviewed 33 studies on Arctic shipping from 1980 to 2017. Lasserre (2014) concluded that among published models assessing the potential profitability of commercial transit shipping along Arctic routes, a majority concluded that Arctic routes are profitable. Lasserre (2014) grouped the studies into two categories: 12 studies with conclusions of simulations that Arctic routes are profitable in comparison with traditional routes and 11 studies with conclusions that Arctic routes are not or may not be profitable. In Lasserre (2014), he performed four simulations on two OD pairs, in summer shipping season scenarios, comparing two Arctic routes with the Suez canal route and in Lasserre (2015), he expanded to eight simulations based on Lasserre (2014) and added year-round shipping scenarios. Lasserre (2015) concluded that only transits to Yokohama are more profitable in both Arctic routes despite lower load factors, and year-round liner service is never profitable, even to Yokohama. Meng et al. (2017) concluded that there is diversity in conclusions of 25 publications: 12 models concluded that trans-Arctic shipping routes were commercially viable; 11 presented results that the routes were only economically viable in special scenarios; and two argued that Arctic routes were not profitable in the short term. Theocharis et al. (2018) found that 13 of 31 papers considered Arctic routes to be more competitive than their traditional rivals, five projected that they will be competitive in the long term while, on the contrary, six papers concluded they were uncompetitive and seven reported mixed results. In summary, these publications reviewing models based on multiple assumptions and simplifications, all came to the same conclusion that in most scenarios, Arctic routes are commercially viable but under certain conditions. The publications also concluded that competitiveness of Arctic routes declined upon moving towards year-round shipping.

The literature studying the viability of the NWP covers multi-dimensional aspects including navigational, sovereignty and commercial viability of the passage, and produces both positive and negative conclusions on the question that whether it is beneficial for shipping firms to use the NWP. In order to attract attention and investment in building port infrastructure, commercial viability of the route is a key element in the research and thus, a key factor to analyze.

Based on the literature review in the four studies mentioned (Lasserre, 2014, 2015; Meng et al., 2017; Theocharis et al., 2018), there are 16 publications studying the NWP. To prove the NWP's dominance in commercial viability compared with traditional routes, various authors have used multiple methodologies and ultimately arrived at three distinctive results: nine studies concluded that the NWP is more competitive economically than traditional routes (hereby renamed as Group A), three studies inferred that NWP is not more profitable than traditional routes (Group B) and four studies arrived at the conclusion that NWP has mixed results when compared with traditional routes in different scenarios (Group C). Therefore, we expect to see the advantages outweigh the disadvantages, since the number of studies in Group A exceeds that of Group B.

Østreng et al. (2013) suggested that there are three main approaches to compare shipping costs between the trans-Arctic shipping routes and traditional maritime routes. Meng et al. (2017) named these methods as: 1) single voyage-based method: to estimate the shipping cost per ton for a target shipping route by calculating the total transportation cost on a specific route, 2) regular service-based method: to calculate the total cost of setting up a regular shipping service based on an assumed yearly quantity of trips performed and 3) cost difference-based method: to specify the shipping cost differences for particular components among the target route alternatives. Table 2.11 lists all publications studying the NWP, comparison methods applied and their conclusions, in the four publications reviewing Arctic routes' commercial viability.

Table 2.11: Literature review on commercial viability of the NWP

Number	**Lasserre (2014), Lasserre (2015)**	**Meng et al. (2017)**	**Theocharis et al. (2018)**	**Method**	**Group**
1	Griffiths (2005)			1	B
2	Guy (2006)	Guy (2006)	Guy (2006)	3	A
3	Somanathan et al. (2007)	Somanathan et al. (2007)	Somanathan et al. (2007)	2	C
4	Borgerson (2008)	Borgerson (2008)		3	A
5	Somanathan et al. (2009)	Somanathan et al. (2009)	Somanathan et al. (2009)	2	C
6		Dvorak (2009)		3	B
7	Srinath (2010)	Srinath (2010)		1, 2	A
8	Paterson (2011)			1	B
9			Tavasszy et al. (2011)	3	A
10			Fan et al. (2012)	1	A
11	Østreng et al. (2013)	Østreng et al. (2013)		3	A
12		Lasserre (2014)	Lasserre (2014)	2	C
13			Lu et al. (2014)	3	A
14			Lasserre (2015)	3	C
15			Fan et al. (2015)	1	A
16			Wang et al. (2016)	2	A

Source: By author (adapted from Lasserre (2014), Lasserre (2015), Meng et al. (2017) and Theocharis et al. (2018))

For studies with conclusions that the NWP is more competitive than traditional maritime routes, Guy (2006) studied the NWP in several scenarios (charter cost of the ship, transit duration and possible transit fees) in comparison with Suez and discovered that savings by the NWP over Suez vary from 33% (most optimistic case) to 14.2%. However, he underlined optimal conditions must be met to achieve profitability: rapid transit speed; low transit fees and limited premiums for Arctic shipping costs (ice-class ship; crew; insurance; maintenance) (Guy, 2006, p.13). Borgerson (2008) compared the NWP with the Panama route on a voyage from Seattle to Rotterdam; he commented that the NWP reduced the distance by 2,000 nm (approximately 25% shorter). He factored canal fees, fuel cost and freight determinants variables into his model: single voyage on the NWP (large container ship) saved between \$14 million to \$17.5 million per trip (as much as 20% of trip's total cost), translating to billions of dollars savings per year, based on the assumption that the shipping lines used the NWP in multiple voyages, as an alternative for the Panama Canal. Srinath (2010) performed a single voyage-based and year-round total trips comparison between NWP and Suez route, stating that the NWP presented better profit margins in all three scenarios (year round operation, semi-year operation: NWP open for 4 months or 6 months) – NWP allowed ship owners to perform higher turnover (more trips), thus leading to inferior cost and higher revenue. Tavasszy et al. (2011) found that the competitiveness of the NWP increases for year-round liner shipping operations only in the long term by forecasting future cargo flows based on transport cost of alternative routes. Fan et al. (2012) did not consider the NWP in respect with a specific targeting route, the authors performed simulations that allow for containerized import shipments to the US through the Northwest Passage, Prince Rupert, Mexican ports and an expanded Panama Canal. Fan et al. (2012) and Fan et al. (2015) concluded that usage of the NWP had the advantage of reduced distance over Panama; therefore, the NWP would attract 0.37 million TEU (Twenty Equipment Unit) volume, equal to \$105.45 million in dollar terms (based on the assumed terminal handling charges savings at \$285/TEU which was adjusted for differences in wharfage costs by all ports studied in the said paper).

Østreng et al. (2013) assessed cost differences between the NWP versus Suez route in two scenarios: 1) General cargo ship on route Yokohama – Hamburg using the NWP could reduce sailing days from 33 to 25, generating a total saving of \$178,100 or about \$14 per dwt (dead-weight tonnage) per trip, 2) Container ship on route Shanghai –

Hamburg, using the NWP only saved one sailing day but total savings are about $710,000, or approximately $167 per TEU (both assumed fuel price at $465 per ton). Lu et al. (2014) ran a simulation of container ships of 4,500 – 15,000 TEU between Busan and New York, benchmarked with Panama Canal: the NWP (specially Route 3) is a far more advantageous by at least $600,000 (no transit fee on the NWP as current status). Wang et al. (2016) pointed out that although Lasserre (2014) highlighted that transport time was shortened via Arctic routes but the said study had neglected cargo time value. Wang et al. (2016) re-computed the freight rate: the unit comparison cost (USD/TEU) of the Rotterdam – Shanghai route is $277/TEU via the NWP, lower than via the Suez of $802/TEU and the unit comparison cost (USD/TEU) of Rotterdam – Yokohama is $139/TEU via the NWP, lower than via Suez of $934/TEU.

On the other hand, Griffiths (2005) performed a cost comparison between the NWP and Suez Canal and the NWP's saving amount was only $83,000 per trip. This saving was too minimal for reputable ship owners and operators to consider risking their high-value vessels for a single Arctic voyage. Dvorak (2009) considered that a trip from Shanghai to New York using the NWP can save 4,000km in distance but harsh weather, growlers and high insurance premiums would wipe out any savings made from the Panama Canal fees. Paterson (2011) concluded in the non-competitiveness of the NWP when he presented FEDNAV's simulation over a single voyage New York – Shanghai using the NWP and stated that, apart from consuming "more fuel than any other voyage" (Paterson presentation's keynote), additional insurance premiums being twice the cost of Panama toll fee, together with possibility of damage and associated unknown costs would make the NWP uneconomically viable anytime soon.

The last group is the mixed result group which arrived at the conclusion that, some scenarios produced satisfactory conclusion that the NWP is more profitable than traditional routes while in certain other scenarios, NWP's usage proved otherwise. Somanathan et al. (2007) computed shipping cost (USD/TEU) for the base case assuming 30% premium cost (CAC3 ship), considering two routes Yokohama to St John's and to New York. The results show that the NWP route would be more economical for freight between St John's Newfoundland and Yokohama as it "offers a saving of almost 10% relative to the Panama Canal for freight from St John's" (Somanathan et al., 2007, p.330) but less economic for New York and Yokohama (8% more costly). Somanathan et al. (2009) revisited the simulation in Somanathan et al. (2007) but the authors analyzed two different metrics: number of maximum trips travelled annually and required freight rate (RFR) per trip. Results indicated higher theoretical maximum round trips by the NWP, thus generating more revenue per year on both target routes than using Panama Canal: 38% more from St. Johns to Yokohama, 13% on the New York to Yokohama route. Regarding the RFR metrics, Somanathan et al. (2009) highlighted that RFR is slightly lower for the St. Johns to Yokohama transit via the NWP, but higher for the New York to Yokohama route, as compared to the Panama Canal. The authors commented that the difference ($13/TEU) in case that the NWP's RFR is cheaper than the Panama's RFR, is not convincing to ship owners considering the uncertainty and operating risk associated with the NWP. Lasserre (2014) conducted simulations on cost per TEU in summer transit across the NWP, both originating from Rotterdam port. He concluded that using the NWP to Yokohama is more economic (20% cheaper) while Shanghai route is not (10% more expensive), in comparison with a base case using Suez. Lasserre (2015) re-examined the same simulations and came to the same conclusion but presented different gaps: Yokohama is more economic (15% cheaper) while Shanghai route is uncompetitive (14% more expensive). Furthermore, Lasserre (2015) extended the simulation to cover all-year scenario for the superior route to Yokohama and concluded the opposite: year-round transit across the NWP has higher cost (33% more expensive) than Suez option.

Unlike the common belief that the Panama Canal route is the sole alternative to the NWP, there is a repetitive pattern that the NWP is competitive with the Suez Canal route as well. The author of this thesis analyzed the studies based on their comparison against the two traditional routes (between the Panama or Suez Canal) and performed groupings in terms of OD pair (not differentiating/respecting eastwards or westward direction to standardize into the same route) to study the winning pattern of the NWP. The result is a list of 23 OD pairs. The route Yokohama/Shanghai – Rotterdam/Hamburg is the most popular (10 models over a total of 23 models), they altogether put the NWP in comparison with the Suez Canal route. In this subset of ten models, six models have conclusions belonging to Group A, and four models belong to group B. Second place goes to Yokohama/Shanghai – New York/St John (6 models over a total of 23 models).

One model studied, Busan – New York, was generalized into Yokohama/Shanghai/Busan – New York/St John for a total of 7 models, and they altogether put the NWP in comparison with Panama Canal route. In this subset of seven models, only three models have conclusions belonging to Group A, and four models have conclusions belonging to Group B. The remaining models form a group of generic comparison irrespective of OD (5 models over a total of 23 models), with one exception study reviewing the route Seattle – Rotterdam. They compared the NWP with both Suez and Panama, but they always have a conclusion belonging to Group A.

There are three conclusions from this analysis: 1) The NWP only proves its commercial viability in the long term; 2) For studies comparing the use of NWP on OD routes from Asia to Europe (Yokohama/Shanghai – Rotterdam/Hamburg) compared with Suez, the NWP is more profitable in most cases, 3) Contrary to conventional assumptions, the Panama Canal route continues to be the optimal passage for Asia – North America (East Coast) transit compared to using the NWP.

CASA (2007) concluded on the comparative advantages of the NWP, in open water conditions, on the three following routes: 1) Between the East and West coasts of North America for a narrow range of port pairs, 2) Between Eastern Asia (north of Singapore) and the entire East coast of North America and 3) Between Northeast Asia and the western Mediterranean (including the Iberia Peninsula). There are three implications from these conclusions: 1) While summer-transit using the NWP is profitable, year-round transit is not; 2) The NWP is highly competitive with Suez Canal route for Asia – Europe transit; 3) In contrast with conventional assumption that the NWP is more competitive against Panama on Asia – North America East Coast traffic, the Panama Canal route is still the optimal transit.

2.3 Challenges of navigating the NWP

The Arctic climate is changing faster than anticipated in the IPCC 4th Assessment Report (IPCC, 2007; Serreze & Francis, 2006; Stroeve et al., 2007), climatic studies confirmed the perennial sea ice cover in the Arctic Ocean is declining rapidly (Comiso, 2002; Flato & Boer, 2001; Parkinson et al., 1999) with several simulation models predicting an ice-free summer Arctic by 2037 (M. Wang & Overland, 2009). However, dramatic climate changes, giving way to more accessible Arctic Ocean and easier connection to Arctic passages, will not inevitably result in an instant boom of Arctic trade flows, let alone becoming the major competitor for traditional trading routes (Mikkola & Käpylä, 2013). There are particularly immense challenges for navigating the Arctic (Guy & Lasserre, 2016; Hansen et al., 2016; Mikkola & Käpylä, 2013; Pahl & Kaiser, 2018).

An ice-free summer Arctic Ocean will remove the presence of thick multi-year ice, but the winter ice cover is not expected to disappear within at least this century (Arctic Council, 2009). While navigation during summer months is affected by mild currents and wind conditions, drastic weather pattern changes in autumn and winter persist with virulent wind systems, temperature descending to -50ºC causing sea sprays created by vessel motion to instantly freeze and damage vessel's hull, total darkness from short daylight hours in winter and so on (Arctic Council, 2009).

The challenges

Mikkola & Käpylä (2013) compiled a comprehensive list of six challenging factors of navigating polar waters, which are: 1) climatic factors (low temperature, physical obstacles generated by ice); 2) geography and bathymetry factors (broad and shallow continental shelves as grave dangers to Arctic-travelling vessels); 3) economic factors (high cost of minimum requirement of ice-strengthened Polar Class carrier fleets – a classification system regulated by the International Association of Classification Societies (IACS) to categorize ships with special hull design that can resist collisions with, and pressure from, sea ice and permit it to navigate into ice-infested waters (Engler & Pelot, 2013); 4) expensive maritime insurance premium); 5) technical factors (insufficient, unavailable hydrographic, bathymetric maps and ice charts for several areas); 6) infrastructure factors (lack SAR and salvage point facilities, ice-management cap, ports and harbor, lack of communication infrastructure and experienced staff to operate in icy waters). Hansen et al. (2016) named the severely underdeveloped SAR infrastructure (whereas the "nearest assets may easily be located more than a thousand kilometers away from potential emergencies" (p.16)), technological challenges (insufficient local understanding, satellite communication and navigating support), the void of relevant legislation regulating Arctic waterways, resources and natural environment. Guy & Lasserre (2016) listed climatic and geography factors (persistent ice and extreme temperature during winter, polar night, low water levels, uncertainty of varying weather from year to year, drifting growlers and icebergs), economic factors (expensive fleet investment to equip “strengthened hull, powerful night ice spotting radars, an experienced crew, and equipment to cope with icing, protect cargo from frost, insurance premium” (p.8)) and technical challenges (inadequate of Arctic mapping). Pahl & Kaiser (2018) stated the absence of access to reliable environmental observations and forecast, lack of in-time provision of SAR services, insufficiency of navigation technology support and absence of integrated governance and regulatory framework.

As the NWP resides within the Arctic, navigating the NWP will face the same challenges with navigating the Arctic, plus the distinctive challenges posted by the characteristics of the Canadian Archipelago. Bourbonnais & Lasserre (2015) combined existing literature and empirical accounts from Canadian Coast Guard and shipping companies (NEAS, Fednav) to conclude that, physical constraints including extreme cold and darkness, weak economic rationale with no large cities, industries, and economic centers upstream, as well as network of navigation aids and maritime infrastructure are hindering the development of the NWP in Canadian Arctic. Giguère et al. (2017) investigated vessel traffic in Canadian Arctic during 2002 – 2013 and concluded that, market changes, regulatory regime and technical risk (lack of infrastructures, poor navigation aids and costs of insurance) to be the main challenges. Dawson et al. (2017) performed a semi-structured interview approach with 57 interviews (N = 57) and a follow-up survey (n = 30), whose respondents are a mix of government representatives, shipping operator stakeholders, ship captains, ship insurers, scholars, and representatives from relevant non-governmental and not-for-profit agencies, to identify challenges for the use of the NWP and the waters of the Canadian Arctic to be in most important order: 1) Economic factors, 2) Infrastructure factors, 3) Climate changes, 4) Political factors, 5) Social factors and 6) Technological factors.

As Section 2.2 proved the commercial advantages of the NWP through economic evaluation, the remaining challenges are considered ample constraints preventing regularly Arctic shipping and specifically, the usage of the NWP. Throughout the literature, these challenges can be grouped into three major categories: climate, technical and legal.

2.3.1 Climate

Throughout the literature review on climate issues of the Canadian Arctic including the NWP, uncertainty is frequently referenced.

Past records

Canadian Ice Service completed the most extensive work on ice condition during 1969 – 2001 in the context of Canadian North, and concluded that sea ice cover in the Canadian Arctic decreased by around 15% with considerable variation between regions due to the complexity of the Canadian Archipelago (Falkingham et al., 2001). Kubat et al., (2006) indicated that a three decades archive is an extremely short time to draw any conclusions in the climatological sense. Crocker et al. (2002) who analyzed the same dataset (1969 – 2001), demonstrated that large variability in sea ice condition (ice cover in cold years can almost double median level, while in warm year, it can decrease by 50%). The authors also arrived at the same conclusion that the short length of the dataset and the high natural variability make it difficult to extract patterns. Howell & Yackel (2004) examined ship navigation variability for the western part of the NWP during the same period (1969 – 2001), they suggested that the major drawback of future navigation in the NWP will be the invasion of multi-year ice into the NWP routes as a result of increased first-year ice melt. Falkingham et al. (2001) also supported the argument that the same invasion phenomenon will make shipping on the NWP more unpredictable and hazardous.

Future prediction

Maurette (2010) presented a summary based on comprehensive literature review of projected ice conditions in the Arctic, and the study shows a wide range of projections with significant degree of uncertainty (Engler & Pelot, 2013). Unknown GHG and aerosol emissions, differences in the regional pattern of climate change simulated by individual climatic projection models are the main sources of uncertainties when projecting the future climate changes for the NWP and Canadian Arctic area (Prowse et al., 2009).

The six water routes of the NWP are projected to have different, fluctuating sea ice condition trends according to Stewart et al. (2010), CASA (2007) and Statistics Canada (2011). In summary, these report forecasted that by 2020, frequency of Route 1 and 2 during summer will be expanded (CASA, 2007) while Route 2 and 3 will remain ice congested for more years (CASA, 2007; Statistics Canada, 2011). The multi-year ice condition remains for Route 1, 3, 4 and 6 (CASA, 2007; Stewart et al., 2010), large interannual variability for Route 1 and 3 (CASA, 2007) and the multi-year ice drifting persists for Route 1, the most feasible route of the NWP (Stewart et al., 2010).

Drifting ice, extreme cold (that supports ice blockage) and inter-annual variability of ice extent despite the trend in melting (Lasserre & Pelletier, 2011) are the major climate causes for the uncertainty on the route.

2.3.2 Technical

The technical challenges of navigating Arctic waters and the NWP lie in multiple aspects, including vessel fleet's technical standards, crew and ice navigator's training and operational requirements, satellite communication and navigational charts to support safe voyages, port infrastructure as well as port services and risk evaluation for Arctic shipping insurance (Østreng et al., 2013a). Section 2.2 already incorporated the cost of insurance in the commercial analysis of NWP's voyages; therefore, this sub-section will review the port infrastructure, fleet operations, crew requirements and information infrastructure.

Port infrastructure

Lavissière et al. (2020) reviewed a corpus composed of 386 articles about Arctic transportation systems during a review period of 30 years (from 1990 to 2019), which included two academic books with studies of most recent Canadian ports on the NWP. To ensure a complete collection of ongoing and current NWP's ports, this thesis performed an extensive search and incorporated literature review based on Østreng et al. (2013) and Ircha & Higginbotham (2016).

Østreng et al. (2013) stated that, in contrast to the NSR, there were very few Canadian ports and no deep-water ports along the NWP. The author listed Port of Churchill, two plans to build deep-water ports in Iqaluit and Nanisivik, and three on-going development projects in Steensby Inlet, Roche Bay and Bathurst Inlet (See Figure 2.5).

Figure 2.5: On-going projects locations on the NWP corridor
Source: Østreng et al. (2013, p. 219)

Ircha & Higginbotham (2016) identified seven existing Arctic facilities which have the potential to develop as NWP deep-water ports. Their list contains: Tuktoyaktuk, Cambridge Bay, Bathurst Inlet, Resolute Bay, Nanisivik, Iqaluit and Churchill. A summary of these locations and their characteristics are listed in Table 2.12.

Table 2.12: Potential Northwest Passage deep-water ports

No.	Port	Region	Depth	Characteristics
1	Tuktoyaktuk	Beaufort Sea	4–6 m	New road link; hub for oil and gas exploration; airport; small shallow harbor.
2	Cambridge Bay	Queen Maud Gulf	Anchorage: 4m	Sheltered water; airport.
3	Bathurst Inlet	Bathurst Inlet	Serve ships up to 50,000 tons	Proposed private port for mining; sheltered water; airport.
4	Resolute Bay	Barrow Strait	Anchorage: 5–6m	Central portion of NWP; sheltered water, airport.
5	Nanisivik	Baffin Island	10+ m	Royal Canadian Navy vessel supply facility; place of refuge; airport.
6	Iqaluit	Baffin Island	11m with development	Capital city of Nunavut; plans for deep-water port; high tidal range; airport.
7	Churchill	Hudson Bay	10m	Rail link south; major port; place of refuge

Source: Ircha & Higginbotham (2016)

In May 2017, after a massive flood followed by washout conditions (CNW, 2017), OmniTRAX Inc., the owner and operator of the Hudson Bay Railway (HBR) and port of Churchill, announced that the HBR was destroyed in at least 19 locations and they had to suspend indefinitely service of the HBR from Amery to Churchill until one year later

(Afenyo et al., 2020). This event further distressed the railway connection to Churchill and impaired the port capabilities.

Pahl & Kaiser (2018) updated the list of current and planned ports in Canada Arctic and summarized 21 port projects (See Table 2.13).

Table 2.13: Current and planned ports in Canada Arctic region

No	Port	Region	Harbor size	No	Port	Region	Harbor size
1	Iqaluit	Davis Strait		**12**	Saches Harbor	Out in Beaufort Sea	V
2	Nanisivik	Lancaster Sound		**13**	Cape Young	Amundsen Gulf	V
3	Pangnirtung	Davis Strait	V	**14**	Lady Franklin Port	Amundsen Gulf	V
4	Pond Inlet	Lancaster Sound	M	**15**	Coppermine (Kugluktuk)	Coronation Gulf	V
5	Churchill	Hudson Bay	S	**16**	Cambridge Bay	Queen Maud Gulf	V
6	Paulatuk	Amundsen Gulf	S	**17**	Resolute Bay	Lancaster Sound, Peel Sound	V
7	Bernard Harbor	Dolphin and Union Strait	V	**18**	Padloping Island	Davis Strait	V
8	Tuktoyaktuk	Out in Beaufort Sea	V	**19**	Saglek Bay	Out in Labrador Sea	V
9	Police Point	Amundsen Gulf	V	**20**	Kangiqsujuaq (Maricourt)	Hudson Strait	V
10	Pearce Point	Out in Beaufort Sea	V	**21**	Bathurst Inlet	Amundsen Gulf	
11	Tysoe Point	Amundsen Gulf	V				

Legend: Harbor size: Very small (V), Small (S), Medium (M).
Source: By author (adapted from Pahl & Kaiser (2018, p. 155-156)

Several studies on the container port competitiveness have endorsed strategic and competitive assets belonging to a port to be vital factors, including port performance, port effectiveness and port facility (Guy & Urli, 2006; Nir et al., 2003; Song & Yeo, 2004; S. Tiwari et al., 2018; Ugboma et al., 2006). However, upon reviewing the literature, the major current ports in Canadian Arctic are in a planning phase or are small to medium size only. Until this year, there was no operational deep-water port in the Canadian Arctic waters yet. The most advanced plan was the deep-water port project plan in Iqaluit that is supposed to operate in summer 2023. For vessels navigating the NWP, the absence of port means no calls for refueling, emergency or changes of crew.

Fleet

To navigate in Arctic waters in general and on specific Arctic routes (NSR, NWP, TPP, etc.), vessels are required to comply with international and national technical requirements. Driven by the disaster of Exxon Valdez off the coast of Alaska in 1989 (Jensen, 2007), in 2002, the International Maritime Organization (IMO) published the Guidelines for Ships Operating in Arctic Ice-Covered Waters (in short, the IMO Guidelines) to provide ship owners, ship designers, ship builders, ship repairers, equipment manufacturers, installers and all other parties concerned with the operation of ships in Arctic ice-covered waters with safety recommendations (Østreng et al., 2013a). From a set of voluntary safety guidelines, after two decades, the IMO Guidelines gradually developed into today's sophisticated, legally binding catalogue of rules – the Polar Code, requesting "mandatory standards that cover the full range of design, construction, equipment, operational, training and environmental protection matters that apply to ships operating in the inhospitable waters surrounding the two poles" (IMO, 2017).

Upon navigating on the NWP, vessels are compelled to comply with the Canadian Arctic Shipping Pollution Prevention Regulations (ASPPR) and register in advance with NORDREG, the Canadian Coast Guard bureau responsible for the supervision of marine transportation in the Arctic. The ASPPR aligned Canada's domestic law with the Polar Code and complemented it with "Canadian modifications": more stringent discharge restrictions, extended application to smaller vessels that do not fall under the Polar Code requirements, and effective for both Canadian-flagged and foreign vessels navigating in Canadian's Arctic waters (Pic et al., 2021).

Crew

In harmony with fleet's technical requirements, crew training and competence standards for NWP transits are required to comply with the IMO Guidelines and the ASPPR. Ship owners and masters proposing to navigate the NWP must apply for an Arctic Pollution Prevention Certificate from a Canadian marine inspector or from an examiner of classification society outside Canada (Østreng et al., 2013a). The structure of ice navigation training that follows the requirements expressed in STCW (International Convention of Standards of Training, Certifications and Watchkeeping for Seafarers), the

IMO Guidelines, the Canadian ASPPR usually comprises four main categories: theoretical training, practical training, on-the-job experience and simulator training (Østreng et al., 2013a). From a survey carried out with data collected from well-known seafaring countries including Finland, Russia, Germany, Sweden, Canada, and the Netherlands, theoretical courses in ice navigation, lasting between 1 and 10 days, are priced at between $300 and $2,000 and practical training courses lasting between 3 and 30 days cost around $2,000 (Arctic Council, 2009). In another recent survey with 99 completed questionnaires provided by shipping companies both active and inactive in Arctic, respondents were mostly unaware of Canadian regulatory schemes on Arctic shipping, with the exception of Canadian companies and a few foreign companies and felt that Canadian regulations were stricter than the Polar Code (Pic et al., 2021). Compared with the NSR, the stricter rules on navigating the NWP are challenging limiting the commercial attractiveness of the route, as reflected in company surveys and traffic statistics (Pic et al., 2021).

Information

Most parts of the Arctic, which have only recently opened up to modern commercial vessel traffic, do not have risk-mitigating capabilities including basic facilities like lighthouses, buoys, navigational systems equipped with pilotage requirements, radio communications systems and radar equipped Vessel Traffic Systems (VTS) in place (Ocean Conservancy, 2017). It is estimated that only 6% of the Arctic waters are charted and 11% is mapped to international standards (Giguère et al., 2017), while in the Canadian Arctic, 12% of Canada's Arctic waters have been charted to international standards. Nevertheless, navigation support services (navigational, hydrographic, meteorological, communication) are not commensurate with increasing shipping activities (Giguère et al., 2017; Ocean Conservancy, 2017).

2.3.3 Legal

Maritime navigation on any water routes, depending on either geographical location or both international and national governance of that shipping pass, is subjected to the legal regimes regulating the passage and the geopolitical factors within those waters impacting the international shipping community (Rothwell, 2012). A large majority of academic studies debate the legal stand of Canada's sovereignty over the NWP based on the interpretation of Article 234 in the UNCLOS (which will be addressed later in this section); however, given the focus of this research to be on operational aspects, the stand for this research is to agree with and honor this claim. The legal challenges discussed here are those faced by ship owners and operators when navigating the route. Despite the relatively small traffic size on the NWP, it is indeed of growing significance to have a more harmonized legal/regulatory framework to facilitate traffic growth and to ensure safety, security and environmental protection.

There is a wide variety of existing regulatory and non-regulatory measures influencing Arctic vessel traffic activities, in general, and navigation on the NWP, more specifically.

On the global basis, maritime operation is governed by an overarching legal framework established by customary international law and the 1982 UNCLOS, the first ratified global maritime regulation (Ocean Conservancy, 2017). Additionally, ship operators are accountable to comply with the mandated IMO as mentioned in technical challenges part, as well as IMO's instrument, which are the International Convention for the Safety of Life At Sea (SOLAS), the International Convention for the Prevention of Pollution from Ships (MARPOL) and the Polar Code (Hansen et al., 2016; Ocean Conservancy, 2017)

On a regional basis, the Arctic Council, established in 1996, carries the mission to promote cooperation, coordination, and interaction among the Arctic States, with the involvement of the Arctic indigenous communities and other Arctic inhabitants. Despite their non-binding nature, Arctic Council projects and initiatives provide policy-making recommendations to member states by addressing science, ecology, social and cultural issues.

The most well-known clause that raises debates and shapes responses of Arctic states and other Arctic stakeholders is Article 234 in the UNCLOS, stating that coastal states may adopt and enforce non-discriminatory laws and regulations designed to prevent, reduce and control vessel pollution in ice-covered waters within a nation's EEZ. Based on their understanding of the article, Russia claimed their sovereignty over the NSR and Canada over the NWP, thus denying the interpretation put forward by the US and the European Union (EU), that the NWP is an international strait open to international shipping (Bartenstein, 2011; Lalonde & Lasserre, 2013). Canada places an environmental protective orientation to its assertion of sovereignty in Arctic waters, with good reasons: the Arctic ecosystem is fragile and a major oil spill from a poorly-suited vessel to Arctic navigation would prove disastrous (Guy & Lasserre, 2016). Therefore, prior to entry of the NWP, vessels are required to enforce their compliance with Canada's ASPPR and registration with NORDREG.

There are enforcements to ensure compliance with ratified regulations like the UNCLOS and IMO, where non-compliance can lead to negative consequences and may result in settlements in international courts. However, recognizing Canadian sovereignty would not entail any additional cost or difficulties. Therefore, it seems unlikely that shipping industry would find it productive to challenge the government's position (Lajeunesse, 2012).

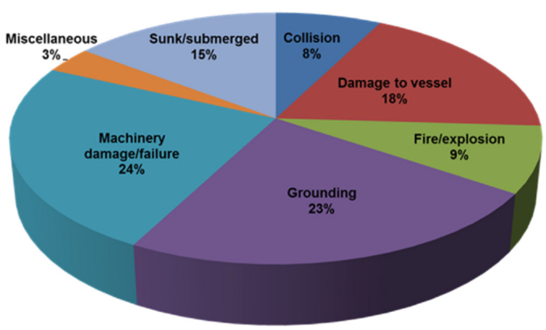


Figure 2.6. Maritime accidents in the Canadian Arctic, 1994 – 2005.
Source: Giguère et al. (2017).

Various types of marine accidents (293 records) occurred in the Canadian Arctic according to the archives of the Canadian Coast Guard between 1995 and 2004 (Giguère et al., 2017). Many of these events were minor: damage to ships, mechanical breakdown and vessels stuck in ice (Figure 2.6). As a rule of cause and effect, the three challenges reported above, namely climate, technical and legal challenges, are inter-related. For instance, unpredictable climate conditions contribute to vessel's technical failure and thus, result in pollution accidents that make ship owners prone to legal accusations. Therefore, apart from supporting commercial benefits, potential port locations should provide safety for vessels and its crew, as well as protect the Arctic environment.

Overall, based on the myriad literature on the challenges of navigating the NWP reported in this Section 2.3, numerous potential investment criteria can be drawn and they are organized and grouped in Table 2.14a-f.

Table 2.14a: Challenges in the literature and their associated investment domain (climatic)

Challenge group	Challenges description	Associated Investment	Literature
Climatic factors	*Increased ice hazards; Increased instability and unpredictability of safe ice conditions*	Climatic forecast	Dawson et al. (2017)
Climatic factors	*Low temperature, physical obstacles generated by ice*	Climatic forecast	Mikkola & Käpylä (2013)
Climatic factors	*Low water levels, uncertainty of varying weather from year to year, drifting growlers and icebergs*	Climatic forecast	Guy & Lasserre (2016)

Source: By author, compiled from literature as referenced above.

Table 2.14b: Challenges in the literature and their associated investment domain (economics)

Challenge group	Challenges description	Associated Investment	Literature
Economic factors	*High cost of minimum requirement for ice-strengthened Polar Class carrier fleets*	Ice-class fleet	Mikkola & Käpylä (2013)
Economic factors	*Expensive maritime insurance premium*	Insurance	Mikkola & Käpylä (2013)
Economic factors	*Expensive fleet investment to equip "strengthened" hull*	Ice-class fleet	Guy & Lasserre (2016)
Economic factors	*Powerful night ice spotting radars, and equipment to cope with icing, protect cargo from frost*	Communication infrastructure	Guy & Lasserre (2016)
Economic factors	*Experienced crew*	Crew competency	Guy & Lasserre (2016)
Economic factors	*Insurance premium (*)*	Insurance	Guy & Lasserre (2016)
Economic factors	*Navigation difficulties and greater potential for hull strikes, sinkings*	Ice-class fleet	Dawson et al. (2017)
Economic factors	*Vessel fleet's technical standards*	Ice-class fleet	Østreng et al., 2013
Economic factors	*Risk evaluation for Arctic shipping*	Insurance	Østreng et al., 2013

Note: (*) The insurance premium challenge under Economic factor does not appear in the final criteria of the model since it is a market element depending on supply and demand pricing mechanism. It is already incorporated in commercial viability analyses in Section 2.2 to arrive with a different conclusion to the question that, whether the usage of the NWP is more beneficial compared with traditional maritime routes.

Table 2.14c: Challenges in the literature and their associated investment domain (geography and bathymetry)

Challenge group	Challenges description	Associated Investment	Literature
Geography and bathymetry factors	*Broad and shallow continental shelves as grave dangers to Arctic-travelling vessels*	Climatic forecast	Mikkola & Käpylä (2013)
Geography and bathymetry factors	*Persistent ice and extreme temperature during winter, polar night,*	Climatic forecast	Guy & Lasserre (2016)
Geography and bathymetry factors	*Extreme cold and darkness*	Climatic forecast	Bourbonnais & Lasserre (2015
Geography and bathymetry factors	*Extreme cold (that supports ice blockage)*	Climatic forecast	Lasserre & Pelletier, 2011)
Geography and bathymetry factors	*Interannual variability of ice extent*	Climatic forecast	Lasserre & Pelletier, 2011)

Source: By author, compiled from literature as referenced above.

Table 2.14d: Challenges in the literature and their associated investment domain (legislation)

Challenge group	Challenges description	Associated Investment	Literature
Legislation	*Lack of relevant legislation regulating Arctic waterways, resources and natural environment.*	Legal stand	Hansen et al. (2016)
Legislation	*Absence of integrated governance and regulatory framework.*	Legal stand	Pahl & Kaiser (2018)
Legislation	*Regulatory regime*	Legal stand	Giguère et al. (2017)
Legislation	*Question sovereignty over Arctic waterways; Improved access increases potential for illegal entry, human and substance trafficking*	Legal stand	Dawson et al. (2017) listed as "Political factors"
Legislation	*Increases potential for environmental degradation; Impacts on health of individual residents and communities through shipping*	Legal stand	Dawson et al. (2017) listed as "Social factors"

Source: By author, compiled from literature as referenced above.

Table 2.14e: Challenges in the literature and their associated investment domain (infrastructure)

Challenge group	Challenges description	Associated Investment	Literature
Infrastructure factors	*Extreme events and erosion led to destruction of shipping infrastructure*	Refuge ports	Dawson et al. (2017)
Infrastructure factors	*Satellite communication*	Communication infrastructure	Østreng et al., 2013
Infrastructure factors	*Navigational charts*	Climatic forecast, Communication infrastructure	Østreng et al., 2013
Infrastructure factors	*Port infrastructure as well as port services*	Refuge ports	Østreng et al., 2013
Infrastructure factors	*Lack of Search and Rescue (SAR) capability*	SAR capabilities	Mikkola & Käpylä (2013)
Infrastructure factors	*Lack of salvage points*	Refuge ports	Mikkola & Käpylä (2013)
Infrastructure factors	*Communication infrastructure*	Communication infrastructure	Mikkola & Käpylä (2013)
Infrastructure factors	*Inexperienced staff*	Crew compentency	Mikkola & Käpylä (2013)
Infrastructure factors	*Lack of SAR*	SAR capabilities	Hansen et al. (2016)
Infrastructure factors	*Lack of in-time provision of SAR services*	SAR capabilities	Pahl & Kaiser (2018)
Infrastructure factors	*Network of navigation aids*	Communication infrastructure	Bourbonnais & Lasserre (2015
Infrastructure factors	*Maritime infrastructure*	Refuge ports	Bourbonnais & Lasserre (2015

Source: By author, compiled from literature as referenced above.

Table 2.14f: Challenges in the literature and their associated investment domain (technical)

Challenge group	Challenges description	Associated Investment	Literature
Technical factors	*Prevalence of wind, fog, and extreme weather events has implications for safety of local vessels and all shipping activities*	Crew compentency	Dawson et al. (2017)
Technical factors	*Insufficient, unavailable hydrographic, bathymetric maps and ice charts for several areas*	Climatic forecast	Mikkola & Käpylä (2013)
Technical factors	*Insufficient local understanding*	Crew compentency	Hansen et al. (2016)
Technical factors	*Satellite communication and navigating support*	Communication infrastructure	Hansen et al. (2016)
Technical factors	*Inadequate of Arctic mapping*	Climatic forecast	Guy & Lasserre (2016)
Technical factors	*Absence of access to reliable environmental observations and forecast*	Climatic forecast	Pahl & Kaiser (2018)
Technical factors	*Insufficiency of navigation technology support*	Communication infrastructure	Pahl & Kaiser (2018)
Technical factors	*Lack of infrastructures*	Refuge ports	Giguère et al. (2017)
Technical factors	*Costs of insurance*	Insurance	Giguère et al. (2017)
Technical factors	*Increased prevalence of wind, fog, and extreme weather events*	Communication infrastructure	Dawson et al. (2017)
Technical factors	*Alter species distribution, migration patterns, and population health of flora and fauna;*	Legal stand	Dawson et al. (2017)
Technical factors	*Crew and ice navigator's training*	Crew compentency	Østreng et al., 2013

Source: By author, compiled from literature as referenced above.

2.4 The need for strategic investments for the NWP

In this section, we will find that the drivers for increased demand for the NWP traffic include systematic factors such as better infrastructure, better regulatory framework, better weather forecasting tools, besides ice retraction. We will look at the reasons why Canada should consider the strategic investments required for the NWP. Our argument is the investment is essential for a better future for Canadian North. These investments, in the short term, will strengthen the supply chain network for Northern

Canada and support Indigenous people's livelihood. In the long term, they will continue to support Canada's Northern strategies and act as preparation for the "Arctic Saga" scenario.

2.4.1 Sea ice retraction as an enabler

There is a high consensus among scientists that the sea ice extent and volume is declining during all months of the the year (Comiso, 2002; Falkingham et al., 2001; Serreze et al., 2007; Stroeve et al., 2007). In Canadian Arctic, the sea ice pattern follows the same declining trend, with the strongest reduction observed in Hudson Bay and Baffin Bay (Derksen et al., 2012; Tivy et al., 2011). The continuous reduction of sea ice based on different future global climate model projections has attracted significant attention, and as conventional logic, this decline would open significant opportunities for increasing accessibility for Arctic marine shipping activities (Stephenson et al., 2011, 2013). Optimistic models even projected that the Arctic could be ice-free in September as early as 2030 (Arctic Council, 2009; Wang & Overland, 2009). However, as Pizzolato et al. (2014) pointed out, when model simulations predict sea ice-free conditions as early as 2030, "they are referring to sea ice extent not exceeding 1 million km^2" (Pizzolato et al., 2014, p.162). In their two successive papers, Pizzolato et al. (2014, 2016) verified the findings by investigating ship activity patterns in the Canadian Arctic in relation to changes in sea ice area from 1990 to 2015. The authors crossed the NORDREG's shipping dataset with sea-ice data from Canadian Ice Service Digital Archive's (CISDA) mix of surface, aerial and satellite observations and surface air temperature (SAT) from National Centers for Environmental Prediction – National Center for Atmospheric Research (NCEP – NCAR) and surprisingly, their conclusion contradicted the common belief: there was a significant *negative* correlation between sea-ice concentration and shipping activity in the Canadian Arctic (Pizzolato et al., 2014). Moreover, the authors pointed out that, despite there being a correlation between the two, sea ice retraction may not be the primary driver in growing shipping activity in Canadian Arctic, but merely an enabler and therefore, it raises open questions as whether external factors including infrastructure development, economic activities, and resource extraction should be considered to be the driving factors in traffic development (Pizzolato et al., 2014, 2016). Moreover, Maurette

(2010) added that there was uncertainty in projecting the ice conditions in the Canadian Arctic, which further complicates forecasting efforts. The poor sea ice forecasting systems and charting available also contributed substantially to adding risk and raising premiums in maritime insurance, together with the high operational cost associated with salvage, lack of infrastructure for repair and mooring, unstable communication and so on (Sarrabezoles et al., 2016). Therefore, to prepare for the increased use of the NWP, Canada cannot simply rely on the sea ice to essentially retreat. Major investments to improve access to reliable environment observations have to be made to facilitate vessels operating in the Arctic, including sea ice, wind, and ocean condition and their forecasts (Pahl & Kaiser, 2018). This conclusion is aligned with Giguère et al. (2017) and Eguíluz et al. (2016), who postulate that the influence of a solid regulatory framework, shipping lines' interest and infrastructure developments contributed more to shipping activity than sea ice trend.

From a different perspective, the sea (ice), rather than being a bounded space and obstacle to transit, is the living environment for Inuit's life in three major aspects: 1) it changes considerably throughout the seasons; 2) it supports animals' livelihood and shelters and 3) it accommodates Inuit's commerce and travel (Aporta et al., 2018). Sea ice fluctuation creates open water for Inuit to hunt walrus, narwhal, and seals (their main protein sources) during harvesting seasons and collect bird eggs during summers; their caribou herds make use of sea ice as moving path during fall (Aporta et al., 2018). The land-sea continuum is an integral part to the Inuit worldview, because it is strongly connected with them. The Inuits associate this continuum and their marine use with their coastal place names, camping sites, and well-established routes (Aporta et al., 2018). In a previous section, we already realized how maritime industry's and Inuit's conceptions of sea ice, clash against each other, and how their convergence may impact its governance. Perceptible tensions have manifested with two major developments in international laws: the first one is the 2007 United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) (especially Article 3 – the right to self-determination that Canadian signed as full supporter, without qualification in May 2016) and the second, the international regulation of Arctic shipping by the International Maritime Organization (especially the International Code for Ships Operating in Polar Waters, effective January 2017) (Aporta et al., 2018). We will investigate this further in the next section, how they contradict each other and what are the possible consequences in the future.

2.4.2 Strengthening the supply chain network of Northern Canada

The Arctic reserve is similar to a treasure chest for the owning state, with extensive reserve of natural resources, ranging from oil and gas, base metals, precious metals, rare earth elements, together with smokeless industries' reserves for fisheries and tourism (Buixadé Farré et al., 2014). The Canadian Arctic holds large quantities of minerals, including nickel, iron ore, copper, zinc, rare earth elements like uranium and lithium, as well as other precious metal stones, including silver, gold, diamond (Engler & Pelot, 2013). According to NRTEE's report (2009), there are 215 potential sites under exploration phases, along with six operating sites, just within the three territories: Yukon (150 exploration phase sites and 1 operating site), Northwest Territories (45 exploration phase sites and 4 operating sites) and Nunavut (20 exploration phase sites – 1 operating site) (National Round Table on the Environment and the Economy (Canada), 2009).

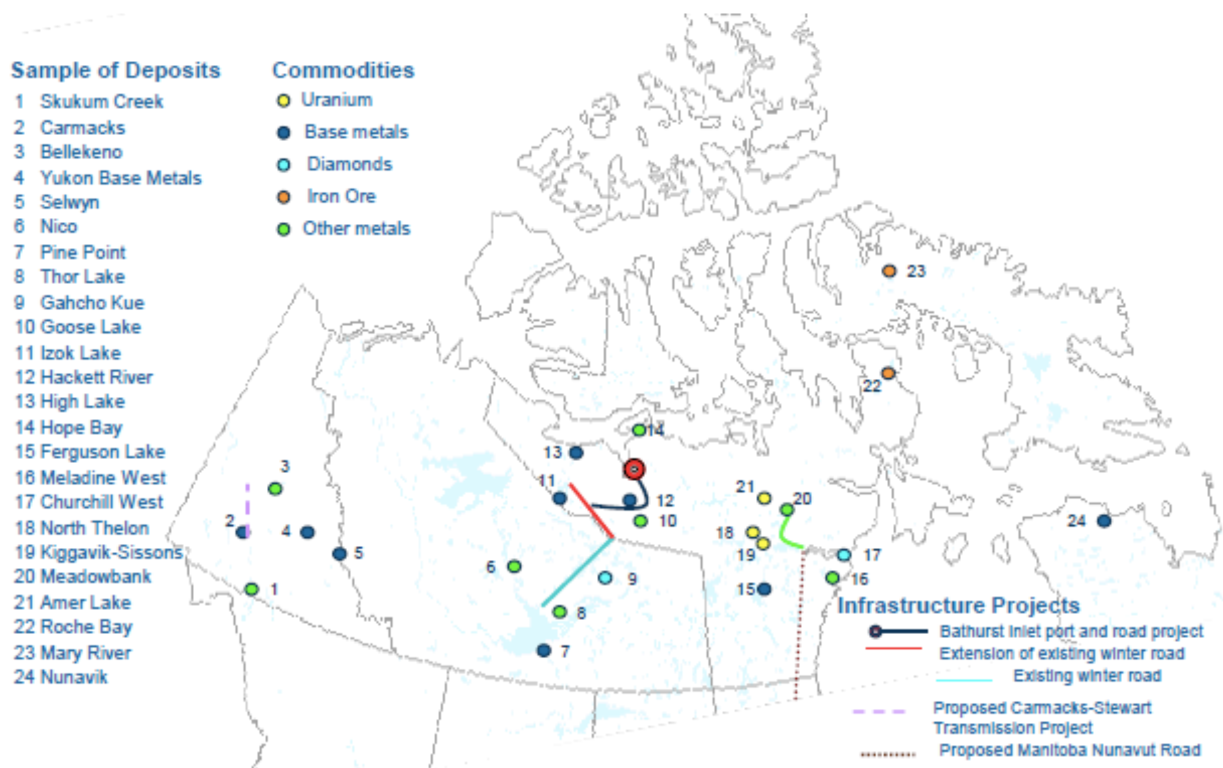


Figure 2.7: Mineral exploration and mining locations in Canada's North.
Source: Arseneau (2010)

Figure 2.7 describes the spatial distribution of the mines and their on-going supporting infrastructure projects.

Canada's North faces a unique gap between myth and reality, a stark difference between southern perception of the North and the harsh reality of northern circumstances. Canadian North is depicted as "the True North, Strong and Free" with the romantic perceptions of northern communities, the vision of pristine wilderness, popular images of polar wildlife and limitless possibilities of rich natural resources to be found (NRTEE, 2009). However, the reality is where the land, sea, communities and people continuously face lingering and new pressures on stagnant economic growth, depleted social development conditions and eroding environmental integrity. The current transportation infrastructure is not supportive enough of a complete supply chain network for Northern economic activities. Mining activities and the community re-supply segment rely heavily on air and winter roads. However, studies show that there are increasing challenges to construct and operate winter roads during shorter operational seasons as a result of climate change (Engler & Pelot, 2013). Stephenson et al. (2011) estimated that inland and maritime transportation accessibility will experience a 13% decline in annually averaged changes by 2045 – 2059 when compared with the baseline period (2000 – 2014). The authors exemplified the case of the Tibbitt - Contwoyto winter road, the Northwest Territories' longest winter road and an important service road for diamond mines, to lose around 17% of its operating season between 2008 – 2020 (Stephenson et al., 2011). This potential loss of inland transport roads will have an impact on the mine transportation systems, which in turn, will increase the demand for Arctic maritime shipping. Alternatively, airlift can replace roads as a transport system for some demand segments with urgent needs, but sealift offers a solution as a much more economical and sustainable means of transport for the north. Therefore, supporting the development of the NWP will empower not only the economic but also the wellness of Canadian Arctic.

2.4.3 Supporting the local communites

In the beginning of December 2022, there was a widespread video shared on social media about the groceries prices in Arctic Bay (an Inuit hamlet located in the northern tip of Baffin Island, Qikiqtaaluk Region of Nunavut, Canada), with a price tag of CAD

$60.49 for a 2 kilogram bag of frozen chicken (Nabulsi, 2022). The comment section outburst with the mass calling Arctic Bay's groceries prices "illegal" and "outrageous", but it has always been the inevitable reality for the Northerners. To this day, thousands of Northerners are leading in high-cost-low-quality living conditions, lacking the infrastructure and services to support their livelihood, wellbeing, safety and environmental priorities in the region (Coates & Poelzer, 2010). The three territories that the NWP passes by are Yukon, Northwest Territories and Nunavut, the home to a growing population of over 130,000 Canadians (Statistics Canada, 2021). The communities have long, rich social and cultural histories, some of them are over 100 years or older (Coates & Poelzer, 2010). These three territories are also home to various natural resources industries and extraction sites, including mining and energy industry, together with manufacturing, fisheries and tourism centers (Coates & Poelzer, 2010). Canadians in these three North provinces contributed approximately $12 billion to the Canadian economy in 2021 (Wikipedia, 2021). However, there exists a striking difference in the available infrastructures and investments for them, as Coates & Poelzer (2010) criticized, the lack of long term investment and inconsistent policies cast the most destructive effects in Canadian North.

Infrastructure gap in the North

The territory with the largest intersection with the NWP, Nunavut, is the only jurisdiction in Canada that cannot be reached by road. Nunavut lacks road connection to other parts of the country and there are also no roads connecting communities together (NTI, 2020). It is not possible to drive between population sites as roads only exist within communities; thus, air travel is the only practical way to commute between communities and the rest of Canada (NTI, 2020). Only during summer, can communities be accessed by boat (sealift) when shipping waterways are clear of ice. All 25 separate communities in Nunavut depend on sealifts during summer shipping seasons for all-year supply; hence, safe operational waterways is crucial to support the life-line of communities and strengthen Inuit food sovereignty (NTI, 2020).

Sharing the same situation, many communities in the Northwest Territories also have no all-weather road connections to the southern Canadian highway system (Prolog Canada Inc., 2011). There are plans for public investment proposals for the Mackenzie

Valley highway and for the Nunavut – Manitoba road to connect with existing resources access roads. However, the current Tibbitt to Contwoyto winter road, is exclusively a resource access road which is constructed and repaired each year with private sector spending (Prolog Canada Inc., 2011).

The province with the most well-developed infrastructure is Yukon, they have “the most extensive highway system in Northern Canada, embracing Alaska highway, Klondike Highway and Dempster Highway connections to both Inside Passage and Arctic Ports” (Prolog Canada Inc., 2011, p.57).

Food insecurity

With climate change, indigenous communities are heavily affected. Their traditional food sources (also called country foods) including seals, chars, caribou, walrus, muktuk (whale skin and blubber) (Derksen et al., 2012) are greatly reduced. Sea ice conditions become unpredictable and pose dangers to hunters when they travel using traditional dogsleds or snowmobiles. Rising sea levels “expose communities to destructive coastal erosion and costly damage to infrastructure” (Government of Canada, 2019, p.5) Therefore, one of the most urgent and critical objectives is to improve the port infrastructure and refuge facilities in the Canadian North, as this infrastructure, designed to meet marine security and safety demands, will eventually also serve as stimulus for future economic and community development, thus facilitating and augmenting transport demand (Giguère et al., 2017). Another overflowing benefit from investing in infrastructure and SAR capabilities is the idea proposed in Benz et al. (2021) to utilize and integrate the resources of local indigenous people into SAR activities. This solution improves SAR capacities and ensures quick and efficient responses in case of emergencies (Benz et al., 2021). Benz et al. (2021) suggested that local personnel have the immediate resources to be deployed instantly (e.g., ships, snowmobiles, barges), and their major advantage lies in their knowledge of the local conditions (e.g. currents, winds, draft, ice condition). The systematic involvement of the locals will lead to the formation of a local workforce (e.g. Canadian Coast Guard Auxiliary), who can significantly relieve and support SAR agencies, especially in remote locations or in case of minor incidents (Byers & Covey, 2019). On the other hand, comprehensive training is necessary to equip local forces in various SAR training areas: first aid, emergency management, multi-stakeholder and multi-agency responses (Ford & Clark, 2019). Therefore, this process will fuel direct employment for the local communities and create knowledge spillover for the government institutions that participate in it.

2.4.4 Future Arctic scenarios

To sketch the possible outcomes of future Arctic marine operations, Arctic Council held a scenario workshop seeking perspectives of the Arctic states, indigenous residents, non-Arctic and maritime industry stakeholders to create a framework of plausible futures for Arctic marine navigation to 2050. Workshop participants incorporated different uncertainties in (legal) Stability and Demand with two factors – Governance and Resource & Trade – to form a matrix containing four different scenarios (Arctic Council, 2009). The four relevant scenarios are Arctic Race, Polar Lows, Polar Preserve and Arctic Saga, their descriptions are depicted in Figure 2.8.

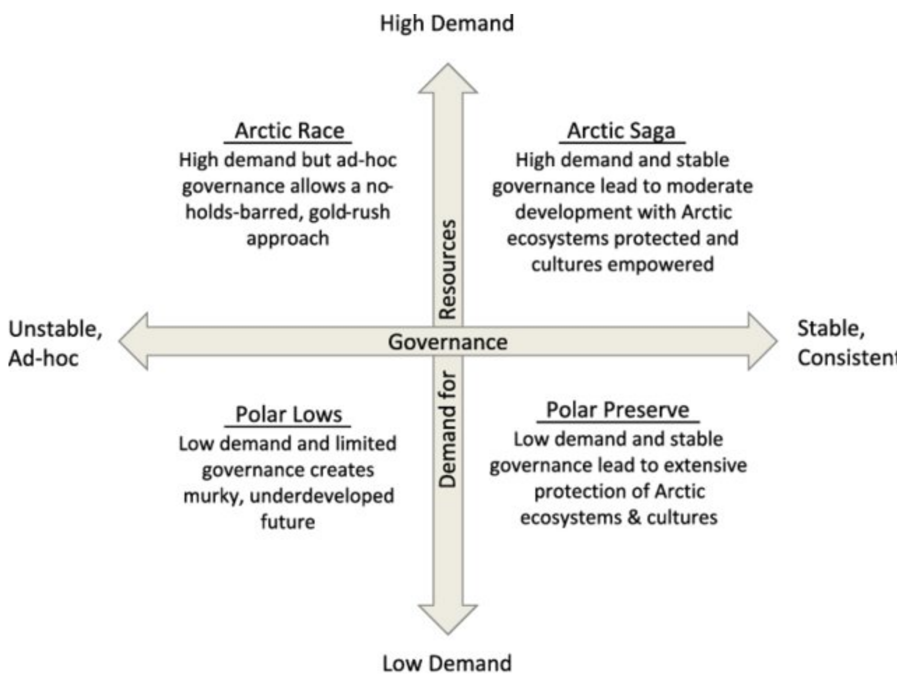


Figure 2.8 Four scenarios for the future of the Arctic.
Source: Adapted from Arctic Council (2009)

According to Arctic Council (2009), the Arctic Race scenario, or the least wished for scenario, is when an "economic rush" took place without the proper governance: commodity prices, demand Arctic resource extraction and marine tourism Preserve soared without the sufficient infrastructure and legal framework to support the development.

Polar Lows is the possibility of both low demand and unstable governance – a gloomy and undeveloped future for the Arctic where Polar Preserve is the opposite – low demand accompanied with stable and developed governance of marine use that fuels a systematic preservation, where environment concerns balance with geopolitical and economic interests. The final scenario is the ideal one, known as the Arctic Saga, where we have “high demand for resources and trade coupled with a stable governance of marine use”, leading to “a healthy rate of Arctic development that includes concern for the preservation of Arctic ecosystems and cultures, and shared economic and political interests of the Arctic states” (Arctic Council, 2009, p.96)

In any scenario, the challenges of all the Arctic states are multiple, some key issues among many are: the strong growth of destination marine traffic; the arrival of the global maritime industry through the presence of large tankers, cruise ships, bulk carriers; the lack of international policy in form of harmonized maritime governance; the lack of adequate maritime infrastructure to cope with current and future levels (Arctic Council, 2009; Hreinsson, 2020). To enhance marine safety and environment preservation, the Arctic states, including Canada, are recommended to liaise closely with the IMO to develop a systematic set of rules and regulations governing Arctic marine activity. Alongside, in the current era of reconciliation and commitment to the UNDRIP, Canada should embrace and fully supports the Indigenous government to “operationalize Indigenous rights, sovereignty, and reconciliation through already-existing structures and frameworks” (Snook et al., 2018, p. 69).

Legal stand

The two commitments – UNDRIP and the Polar Code mobilities, in the context of an evolving Arctic, are the guiding frameworks for Arctic governance, as it demands recognition and inclusion for Inuit’s livelihood and welfare as per the stipulations in UNDRIP as well as compliance and development of Polar Codes for shipping industry (Aporta et al., 2018). Canada, as a leading and active Arctic state, must continue to engage with both Arctic, non-Arctic states and global institutions to enforce universal acknowledgement of sovereignty and enhance cooperation in maritime affairs in Canadian Arctic waters. These two imperatives will provide guidelines to address complex, evolving marine issues in an uncertain future.

2.4.5 The Northern Strategy

In view of a changing global and continental trade environment, Canada needs a public policy strategy supported by efforts made by all levels of government to sustain shipping and enhance resource development and the indigenous wellbeing brought by climate change in the Arctic. Among these coordinated efforts, on the provincial level, are the "Over-the-top" shipping route, the Arctic Gateway program, and the Plan Nord. In 2007, the Government of Northwest Territories presented the "Over-the-top" shipping route whose development advocates for northern marine connectivity, creating direct employment, transportation competition and backhaul opportunities (Government of the Northwest Territories, 2011). In 2010, the Government of Manitoba and OmniTRAX Inc., the American firm also owner and operator of the Hudson Bay Railway (HBR) and Port of Churchill until 2018 (they sold the port and railway to the first version of the Arctic Gateway Group – a partnership between First Nations and other northern communities), announced the Arctic Bridge and Arctic Gateway strategy. The plan proposed a possible gateway to serve the NWP based on an intermodal marine and land transport network model, using Churchill port, Winnipeg road system and near-completion Iqaluit port infrastructure (Giguère et al., 2017). In 2011, the Québec government unveiled the "Plan Nord" which promoted the potential of mining, energy, tourism, cultural and social development for the Québec north territory above the 49th degree latitude (Giguère et al., 2017). At the federal level, the Northern Strategy, constructed by the Government of Canada (2009), was aiming at "asserting Canada's Arctic sovereignty, protecting the northern environment, promoting social and economic development and improving northern governance" (Giguère et al., 2017, p.358). In 2019, under Prime Minister Justin Trudeau's office, Ottawa superseded the Northern Strategy with the Canada's Arctic and Northern Policy Framework. In this Northern Strategy Framework, the federal government, the Indigenous people, the Inuit, the First Nations and Métis, together with six territorial and provincial governments (Yukon, Northwest Territories, Nunavut, Newfoundland and Labrador, Québec, and Manitoba) synergized common objectives and concerns to design the target for this policy.

The investments needed for the North and the NWP

The Northern Strategy (2009) committed to allocate CAD $2.3 billion for the construction of a maximum of six ice breaking-capacity patrol vessels and an additional CAD $1.2 billion for ports and transport supporting infrastructures (Giguère et al., 2017). These investments would go into the spending budget for Canadian's Coast Guards and the provincial authorities to support their procurement process for better, newer equipment and infrastructure. From the ship owners and operators' perspective, according to Guy & Lasserre (2016), few carriers have specialized fleet as they are considered expensive fleet investment and an economic challenge. In their report that analyzed marine traffic and their drivers along Canada's Coast (Engler and Pelot 2013b), the authors listed several hindering factors that influence the traffic demand, with remarkable stress on importance of investing for an ice-class fleet. The cost of building ice-class vessels, cost of operating ice-class vessels (e.g. use of icebreakers; insurance premium), cost of performing maintenance of ice-class vessels in open waters and cost of building supporting infrastructure (e.g. staging ports and transitional equipment to transfer cargo from ice-strengthened to non-ice- strengthened ships) are considered financial obstacles to achieve a higher traffic usage of the NWP (Engler and Pelot 2013b). Therefore, the allocation from the policy budget should not only restrict to SAR and patrol's use, but also extend to support the ultimate users of the NWP – the shipping lines, ship owners and operators.The Northern Policy Framework (2019) has multiple objectives to achieve in its allocation of budget, the framework's generic spending priorities in 2019 are affordable housing, food security, employment and social development for northern communities. For the year 2021, the framework's priorities are national defense, disaster mitigation, health and northern affairs enhancements (Government of Canada 2022b). Even though the plans might have different objectives, the shared common goal among them is that maritime transportation and the intermodal connectivity with shipping will play a key role and there is an obvious shift to focus more on northern communities' well-being and development in Canadian Arctic strategies throughout the years.

2.5 The use of multi-criteria decision analysis in strategic decisions

Decision making and analysis is an important part of management sciences, public policy and urban studies. In real-world with multi-stakeholder management problems, decision makers are likely to pursue multiple objectives while considering multiple factors and constraints (Farahani, SteadieSeifi, and Asgari 2010). Such mission transforms the decision making problem into a multi-objective decision making (MODM) problem, or a multi-attribute decision making (MADM) problem (Farahani et al. 2010). These types of problems fall under one category named multi-criteria decision making (MCDM) problems, which undergoes the multi-criteria decision analysis (MCDA) to search for the outcome. In several contexts, the two definitions MCDM and MCDA are used interchangeably. Multi-criteria decision making or multi-criteria decision analysis is a sub-discipline of operations research, commonly used in daily life, in various settings such as business and government, in particular relation to economics decisions such as welfare economics, utility theory and voting-oriented social choice theory and so on (Greco, Ehrgott, and Figueira 2016). There are multiple methods of MCDM, many of which are implemented and supported by specialized decision-making software, including Analytic hierarchy process (AHP), Analytic network process (ANP), Data envelopment analysis (DEA), Goal programming (GP), Evolutionary multi-objective optimization (EMO) and so on.

AHP for the research's problem

The goal of this thesis is to find the top strategic investments and the rankings among multiple investment perspectives to support the traffic development of the NWP. We need a priority order of the criteria so that recommendations to policy makers can be made, based on the criticality and urgency of the criteria's importance. The criteria and sub-criteria will be proposed based on a literature review of several studies identifying challenges to the use of the NWP (See Section 3.1). In this problem, the author wishes to establish the ranking of all the criteria and sub-criteria, and how they compare against each other. The author will gather qualitative input from key stakeholders with direct and significant involvement in the Arctic shipping field: leading professors in Arctic shipping field, representatives from Arctic shipping companies, and government officials in Arctic infrastructure development projects. The research question is: *"What investments are required and should be prioritized to facilitate navigation in the NWP?",* and the objective of this study is to identify the potentiality, in terms of ranking, for the strategic investments required, from a Canadian perspective, to support the development of the

NWP's traffic. Therefore, the AHP is a suitable methodology to tackle this type of problem and produce the desired outcome. The result will provide a ranking table and the weights of each criteria. The higher the rank, the more important role the investment (represented as the criteria in the model) will play. It means that top-ranked criteria are highly regarded compared to the low-ranked ones. In preliminary design, the problem can be sketched as a hierarchy using AHP method as below (See Figure 2.9). Figure 2.9 illustrates the problem analyzed as a hierarchical structure for the AHP methodology, with the final goal in the first level, the criteria in the second level and sub-criteria (if any) in the third level. The previous section (Section 2.4) has listed the needs and linked them to some initial solutions that are potential investment criteria, including legal stand, climatic forecast, infrastructure and people aspects. We will reconfirm the importance of these investments and finalize the selection of criteria in Chapter 3 – Methodology.

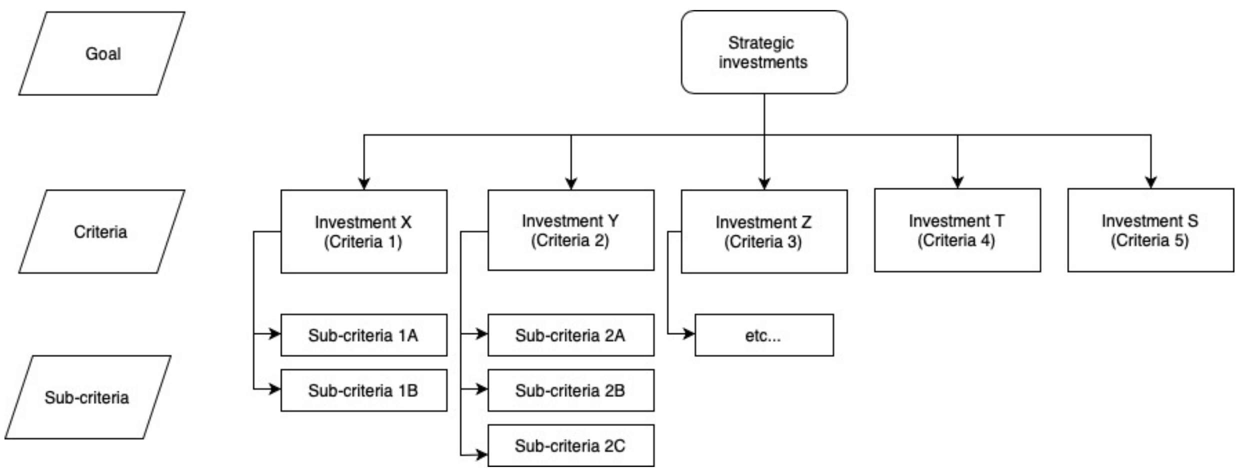


Figure 2.9: Preliminary design of the AHP model for this research's problem.
Source: By author

The rationale behind the choice of the AHP as the preferred MCDM method originates from the nature of the research question itself. The primary objective of this study is to determine the nature of investments and their hierarchical ranking. Other more technical in-depth studies with different aims, such as to quantify the exact financial requirements or to identify the specific locations for deep-water sea ports considering all given constraints, are better suited to methods like DEA or GP. AHP, with its distinctive capacity to quantitatively capture experts' qualitative inputs and to structure the research question, is the optimal choice, potentially paving the way for future endeavors to broaden the scope of advanced investigations. Nonetheless, the AHP method has its own shortcomings, which will be disscussed in Section 5.1.

2.6 Concluding remarks on the literature review

Within the realm of Arctic transportation scholarship, increasing popularity of the NWP as an emergent domain is steadily gaining greater prominence, establishing itself as an autonomous field of research (Lavissière et al., 2020). The commercial viability of the NWP has been addressed and affirmed in the literature, as well as straightforward challenges. Nonetheless, this status is expected not to persist. The investments in the NWP clearly do not yield immediate, short-term dividends akin to the expeditious construction of transportation infrastructure such as a metro system; rather, such investments for future benefits of the NWP and Canadian North will only become visbile over the course of the following decades or century.

In the process of crafting this thesis, the author collected a corpus of 276 source materials, consisting of a wide spectrum of genres, including articles, books, book chapters, reports, master's theses, Ph.D. dissertations, presentations, blog posts, magazine articles, and newspaper articles. Subsequently, 156 sources were reviewed and cited as literature. During the literature review process, the author attempted to identify studies leveraging the three principal keywords:, including “NWP” (“North west Passage”), “AHP” (“Analytical Hierarchy Process”), and “investment”. However, there has been no antecedent studies covering this aspect using AHP methodology, or any studies with similar or comparable research question of the investment’s priority that this thesis is working on. Therefore, the author is confident that the research question is pioneering, and the thesis is an original work and the first to tackle the issue.

3. Methodology

Saaty (1990) initially developed the analytic hierarchy process (AHP) for solving multiple criteria decision-making problems. AHP analyzes the decision by decomposing a complex problem into a multi-level, hierarchical structure which includes objectives, criteria and alternatives (Saaty 1985). AHP can be used in making decisions that are complex, unstructured, and contain multiple attributes, which include both physical and psychological elements (Saaty 1994). For an example problem, Lirn et al. (2004) used AHP to identify a location for a transshipment port, their problem is structured into a three-level hierarchy. The decision hierarchy for the selection of a transshipment port, based on seven criteria and four port alternatives, is illustrated in Figure 3.1.

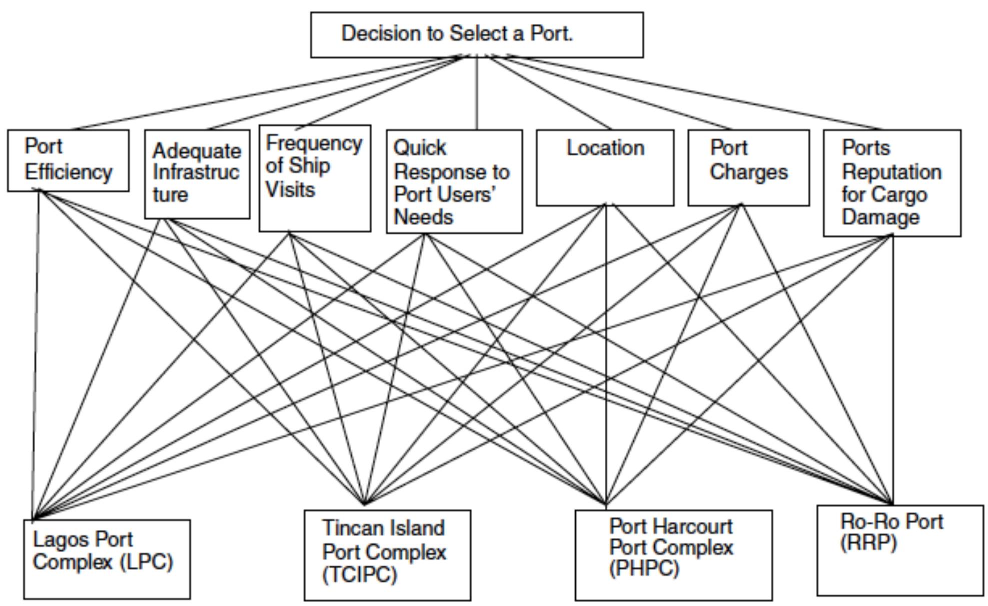


Figure 3.1: Decision Hierarchy to select a port.
Source: Lirn et al. (2004)

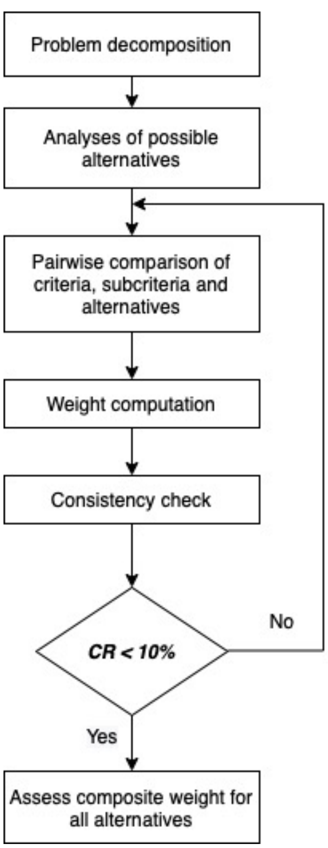
In this problem, the ultimate goal is to select a port, as shown on the top level of the hierarchy. On the second level are seven criteria and the authors performed pairwise calculations to identify which criteria is prioritized. Finally, on the third level, the AHP will provide the framework to rank the port candidates. The result is shown in Table 3.1. Interpreting the result, the criteria, "Port Efficiency" (with the highest priorities – 0.197) is considered the most important criteria, while "Frequency of Ship Visits" and "Adequate

Infrastructure" ranked second and third respectively in importance. For the final goal, the LPC (Lagos Port Complex) has the highest global synthesized priority (0.215), thus it is the best choice for the transshipment port, although with a very thin margin over the second choice, TIPC. The Consistency Ratio is calculated to verify the consistency of the criteria and alternatives in the model, and is required to be no more than 10% (or 0.1) (Saaty 1990).

Table 3.1: Priority vectors for the decision hierarchy

Attributes	**Level 2 Priorities**	**Port candidates**	**Level 3 Priorities**
Efficiency	*0.197*	*Lagos Port Complex (LPC)*	*0.215*
Frequency of Ship visits	0.124	Tincan Island Port Complex (TCIPC)	0.214
Adequate Infrastructure	0.120	Port Harcourt Port Complex (PHPC)	0.170
Location	0.117	Ro-Ro Port (RRP)	0.138
Port Charges	0.115		
Ports Reputation for Cargo Damage	0.110		
Quick Response to Port Users' Needs	0.081		
Consistency Ratio	0.02		

Source: Lirn et al. (2004)



The AHP is based on three principles: *decomposition, establishment of priorities* and *logical consistency* (Atthirawong and MacCarthy 2002; Yang and Lee 1997). The *decomposition* is performed by breaking down the complex problem into several components, based on a hierarchical structure including the goal, criteria, sub-criteria, and alternatives (Saaty 1990). The phase of *establishment of priorities* aims at determining the relative importance of each component, throughout each echelon of the hierarchy using pairwise comparison (Saaty 1990). Then, the synthesis of priorities is conducted to assess the composite weight of each decision alternative, thus producing the final ranking. To achieve the *logical consistency*, AHP requires the

Figure 3.2: The analytic hierarchy process algorithm
Source: Illustrated by Opasanon & Lertsanti (2013)

computation of the consistency ratio to be conducted to ensure that all inferences made from the AHP are indeed consistent and valid (Saaty 1990). The general procedural steps of the AHP are portrayed in Figure 3.2 (Saaty 2008).

The start of the process begins with the first step: to decompose the problem. In this step, the problem is analyzed to identify the criteria and alternatives. The model analysts conventionally perform extensive literature review to identify the criteria relevant to the problem. In the second step, the analysts conduct in-depth interviews with experts to obtain essential input on the candidate list. The next step requires experts' evaluation of multiple pairs comparison between different criteria and alternatives. The number of comparison pairs is equal to $\frac{n(n-1)}{2}$, where *n* represents the number of criteria in the problem. The analysts will then distribute two-part questionnaires to the respondents, where the first part acquires the judgement on the comparison of the criteria with respect to the goal while the second part questions the importance of alternatives with respect to the criteria. In both sections, pairwise comparisons are conducted based on the question in the form of: *"Which is more important, the first criteria/alternative, or the second criteria/alternative, and by how much, numerically?"* The numerical denotation of the relative importance is based on a nine-point scale and is presented in Table 3.2.

Table 3.2: Nine-point rating scale

Intensity of importance	***Definition***	***Explanation***
1	Equal importance	Two factors contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one over the other.
5	Strong importance	Experience and judgement strongly favor one over the other.
7	Very strong importance	Experience and judgement very strongly favor one over the other.
9	Extreme importance	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed.
Reciprocals	Reciprocals for inverse comparison	If attribute i has value n assigned when compared with attribute j, then j has reciprocal value $1/_n$ when compared with i.

Source: Saaty (1990, 2008)

The pairwise comparisons generate a matrix of relative importance between each criteria and alternatives at each level (Saaty 1990). After all the pairwise comparisons are obtained and all the matrices are developed, the degree of relative importance amongst the elements, referred to as the *eigenvectors* or the relative weights are computed, as well as the global weights and the maximum *eigenvalue* (λ_{max}) for each matrix. There are multiple useful tools to support this process, the analysts can choose from different options including software like Expert Choice, XLSTAT add-in tool in Excel, or free tools like Excel, BPMSG.

The λ_{max} value is an important validating parameter in AHP, it is used as a benchmarking index to evaluate the validity of input in the model by calculating the consistency ratio (CR) (Saaty 1990). The CR value is calculated using the three following steps:

1) Calculate the eigenvector and λ_{max} for each matrix.
2) Calculate the consistency index (CI) for each matrix using the formula:

   $CI = \frac{(\lambda \max - n)}{(n-1)}$
3) Compute the consistency ratio (CR) using the formula:

   $CR = \frac{CI}{RI}$

   where RI is the random index obtained from a fixed set of values as shown in Table 3.3.

The value of the random consistency index (RI) for matrices of order 1 to 10 is obtained from a large number of simulation runs and varies depending upon the order of matrix, using a sample size of 500 (Saaty 1994).

Table 3.3 Average random index (RI) based on matrix size.

Size of matrix (n)	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Random index (RI)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source: Saaty (1994)

In general, the acceptable CR value range is no more than 10% (or 0.10) for all matrix sizes. If the CR value is equal to, or less than 0.1, it implies the model has achieved a good level of consistency in the comparative judgements (Saaty 1990). If the CR value is larger than 0.1, it suggests that inconsistency has occurred and thus, the input of the evaluation matrix should be reviewed. In such case, there are two possible courses of action to follow: the analysts can remove any matrix with CR value less than 0.10 to eliminate the inconsistency like in Lee & Hwang (2010), or the analysts can repeat the process until the consistency is obtained like in Opasanon & Lertsanti (2013). In the second case, the analysts will review the relative pairwise comparison input with the respondents, investigate which answers are causing the inconsistency and request the respondents to review and adjust their answers accordingly (Cox, Alwang, and Johnson 2000). The consistency property is crucial to ensure the decision-maker reliability of the model in determining the priorities of criteria and alternatives (Atthirawong and MacCarthy 2002).

AHP's strengths

Saaty (2001) observed ten characteristics when applying AHP as a decision-making tool, they are: 1) unity, 2) complexity, 3) interdependence, 4) hierarchy structure, 5) measurements, 6) consistency, 7) synthesis, 8) trade-off, 9) judgement and consensus and 10) process repetition. In AHP application, the first step must be to analyze and systemize any *complexity* problems (sometimes with multiple procedures) into clear-cut *hierarchy structure,* with a stated goal to achieve, the criteria and sub-criteria, and the alternatives. Once the hierarchy has been structured, criteria at each level are processed through pairwise comparison to produce the priorities among them; thus, AHP offers the *synthesis* of priorities. The pairwise comparisons are given in terms of how much criteria X is more important than criteria Y, either for quantitative criteria or qualitative criteria. By performing the pairwise comparison, AHP allows user to assess the relative weight of multiple criteria in an intuitive manner, through a *repeated process.* After the pairwise comparison is completed, a set of comparison matrices of all criteria are constructed to convert individual comparative (pairwise) judgements into ratio scale measurements (the preferences are quantified by using a nine-point scale – See Section 3 for further explanation of the AHP procedure); hence, eliminating different *measurements* in different units and ensuring *unity* in comparison (Atthirawong and MacCarthy 2002). AHP is indisputably efficient because the pairwise comparison allows *trade-offs* between the tangible and intangible factors and eliminates the *interdependencies* between the criteria (Kasirian and Yusuff 2013). When all matrices are developed and all pairwise comparison are obtained, AHP requires the procedure of calculating the *consistency* ratio to make sure all the pairwise comparison are consistent (for example: if X is more important than Y, Y is more important than Z, then X is more important than Z and it cannot be the other way round). The AHP requires the consistency ratio not to exceed a certain threshold to guarantee a good level of consistency in the comparative judgements. An acceptable consistency ratio is indispensable for any AHP models, as the consistent property ensures reliability in determining the priorities of a set of criteria for decision makers (Atthirawong and MacCarthy 2002). Finally, as the AHP approach is a subjective methodology (Cheng and Li, 2001), information and the priority weights of criteria obtained from different decision makers (using direct questioning or a questionnaire method), can achieve the *consensus* and align *judgement* of different stakeholders in the problem.

Not only AHP can capture tangible and intangible attributes but it also can quantify the intangible in a decision making process (Aras, Erdoğmuş, and Koç 2004; Atthirawong and MacCarthy 2002; Lee and Hwang 2010). AHP is a superior method for MCDM problems with various strengths according to Soma (2003), as AHP is an empowering tool – it creates a platform for stakeholders to express their views and evaluations without the prolonged discussion among them. AHP is also a focusing tool as it assists in organizing and structuring complex realities and incorporates all attributes and alternatives for a solution (Soma 2003). AHP can also reduce conflicts and smooth the decision making process to agree on an optimal solution (Soma 2003).

AHP's setbacks

On the other hand, AHP does have its own weaknesses, namely its subjectivity (Cheng and Li 2001) and the inability to consider constraints that exist in the decision environment (Badri 1999). AHP might be an empowering tool but only if the researchers perform a correct delivery of the content; otherwise, the model is expected to suffer from biased views, misinterpretation and misleading responses from the questions (Soma 2003). Under properly model constructing, AHP might also present a fragmented reality, oversimplified nature of the problems (Soma 2003). Moreover, AHP is incapable of considering the possible interdependencies among criteria, sub-criteria on each level (since the pairwise comparison is considering each criteria independently) (Kasirian and Yusuff 2013). In other words, AHP is only accurate when the relationship of criteria, sub-criteria is hierarchical in the decision levels (Kasirian and Yusuff 2013). The limitations which are significantly relevant to this research's model will be discussed exclusively in Section 5.1.

The solution to most of these issues can be solved if the modelist understands and commits to ensure the four key assumptions in his AHP model: 1) The need to search for alternatives is justified; 2) Decision makers must have strong insights; 3) Decision makers must understand the operation and 4) Decision makers will provide managerial judgements and specialized knowledge (Saaty 1985).

Showcase with a simple model using BPMSG

Regarding the tool to support the calculation in the model, the thesis will use the open-source AHP program online called AHP Online System (or AHP-OS) at Business Performance Management Singapore (website at https://bpmsg.com/ahp/index.php). AHP-OS was developed and is currently maintained by Dr. Klaus D. Goepel and it will be used to calculate eigenvalues and eigenvectors (Goepel 2018). The advantages of the AH-OS lie in the open-access nature of the tool, the ability to divide different calculation steps or combine as one project for each AHP model, and the user-friendly interface. AHP-OS's weaknesses are the non-integration with different input such as Excel like the XLSTAT add-in tool, and it does not have automation calculation or advanced functions to conduct what-if or sensitivity analyses like Expert Choice.

To better understand how the method works and how to utilize the open-source tool AHP-OS, we can review a sample decision problem extracted from Saaty (1990). The goal is to buy the best house as in hierarchy structure represented in Figure 3.3. There are eight criteria to be coded as a number from one to eight (for shortening purpose), including Size of house (1), Location to bus line (2), Neighborhood (3), Age of house (4), Yard space (5), Modern facilities (6), General condition (7), and Financing available (8). For the candidates, there are three alternatives, which are identified as House A, House B and House C.

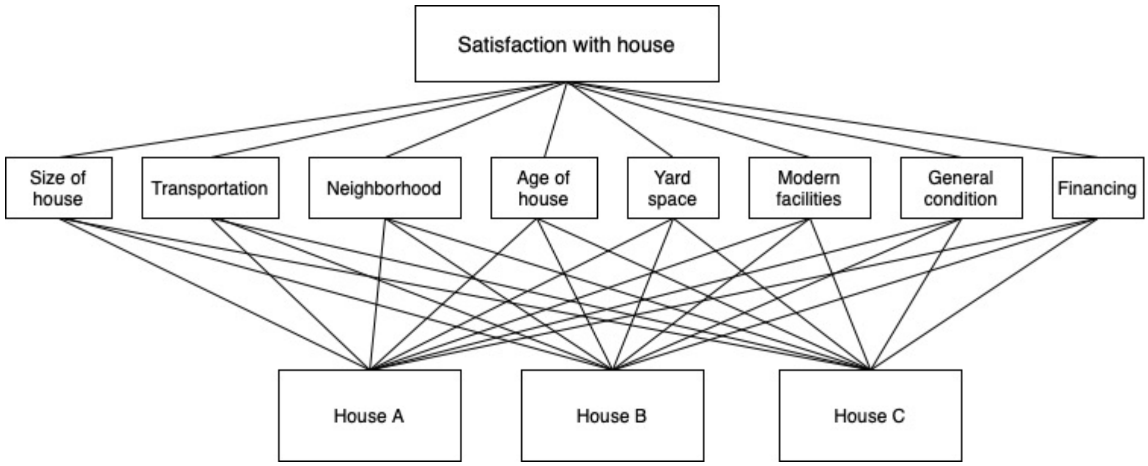


Figure 3.3: Decomposition of the problem into a hierarchy
Source: Saaty (1990)

Next step, the author collects the pairwise comparison judgments from the respondents. One important procedure is the determination of the sample size for the survey's input to ascertain the reliability of the AHP problem. According to Saaty & Özdemir (2014), there are no fixed rules for the required sample size for AHP surveys. In fact, a large sample size may lead to unreliability in the results in the presence of high degree of inconsistency (Cheng and Li 2002; Thanki, Govindan, and Thakkar 2016; Wong and Li 2008). For example, in this house problem, one input (the owner of the future house) is sufficient to produce reliable results (Saaty and Özdemir 2014). Therefore, only one comparison matrix is generated for analysis.

On the second level concerning the criteria, questionnaires are sent out in forms of questions: *"Which criteria between **Size of house** and **Transportation** is more important and by what degree?"*. The responses will be in numerical form, for example, value five (5) under row (1) and column (2) whose interpretation is that **Size of house** has a *strong importance* compared to **Transportation** (See Table 3.4)

Table 3.4: Pairwise comparison matrix for level 1

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Priority vectors
(1)	**1**	**5**	**3**	**7**	**6**	**6**	$\frac{1}{3}$	$\frac{1}{4}$	0.173
(2)	$\frac{1}{5}$	**1**	$\frac{1}{3}$	**5**	**3**	**3**	$\frac{1}{5}$	$\frac{1}{7}$	0.054
(3)	$\frac{1}{3}$	**3**	**1**	**6**	**3**	**4**	**6**	$\frac{1}{5}$	0.188
(4)	$\frac{1}{7}$	$\frac{1}{5}$	$\frac{1}{6}$	**1**	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{7}$	$\frac{1}{8}$	0.018
(5)	$\frac{1}{6}$	$\frac{1}{3}$	$\frac{1}{3}$	**3**	**1**	$\frac{1}{2}$	$\frac{1}{5}$	$\frac{1}{6}$	0.031
(6)	$\frac{1}{6}$	$\frac{1}{3}$	$\frac{1}{4}$	**4**	**2**	**1**	$\frac{1}{5}$	$\frac{1}{6}$	0.036
(7)	**3**	**5**	$\frac{1}{6}$	**7**	**5**	**5**	**1**	$\frac{1}{2}$	0.167
(8)	**4**	**7**	**5**	**8**	**6**	**6**	**2**	**1**	0.333
									λ_{MAX} = 9.669, CI = 0.238, CR = 0.169

Legend: Bold values are respondents' input; the remaining values are reciprocals.
Source: Saaty (1990)

Figure 3.4 illustrated the input interface on AHP-OS, for the foremost pairwise comparison between first criteria Size of house (1) and Transportation (2) with a value importance of five (5).

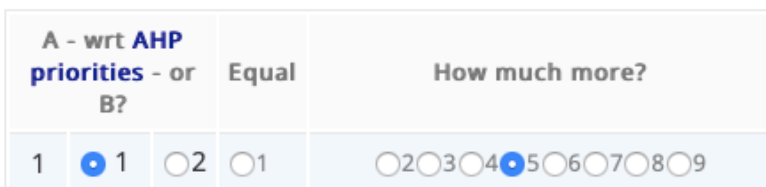


Figure 3.4: AHP-OS interface to calculate the priority of attributes
Source: By author (extracted from screenshot on AHP Priority Calculator at https://bpmsg.com/ahp/ahp-calc.php)

The result returned a total sum of 28 comparisons and the principal eigenvalue is 9.669 as in Table 3.4a; the priorities of all attributes and the consistency ratio (CR) is 17.0% as in Table 3.4b. The priority vector of each attribute (or in other literature, known as criteria weight) is referred to as "priority", the λ_{max} is referred to as "principal eigenvalue" on AHP-OS interface.

Table 3.4a: Decision matrix result (left)

	1	2	3	4	5	6	7	8
1	1	5.00	3.00	7.00	6.00	6.00	0.33	0.25
2	0.20	1	0.33	5.00	3.00	3.00	0.20	0.14
3	0.33	3.00	1	6.00	3.00	4.00	6.00	0.20
4	0.14	0.20	0.17	1	0.33	0.25	0.14	0.12
5	0.17	0.33	0.33	3.00	1	0.50	0.20	0.17
6	0.17	0.33	0.25	4.00	2.00	1	0.20	0.17
7	3.00	5.00	0.17	7.00	5.00	5.00	1	0.50
8	4.00	7.00	5.00	8.00	6.00	6.00	2.00	1

Table 3.4b: Priorities result (right)

Cat		Priority	Rank	(+)	(-)
1	1	17.3%	3	13.2%	13.2%
2	2	5.4%	5	2.3%	2.3%
3	3	18.8%	2	26.1%	26.1%
4	4	1.8%	8	1.0%	1.0%
5	5	3.1%	7	1.4%	1.4%
6	6	3.6%	6	1.5%	1.5%
7	7	16.7%	4	11.9%	11.9%
8	8	33.3%	1	22.8%	22.8%

Principal eigen value = 9.669
Eigenvector solution: 8 iterations, delta = 1.0E-8
Number of comparisons = 28
Consistency Ratio CR = 17.0%

Source: By author (extracted from from screenshot on AHP Priority Calculator)

The Consistency Ratio discussion

One remarkable concern from the problem is that the CR is higher than the 0.10 threshold (17%). The AHP-OS has a useful feature that it indicates by highlighting potential pairwise comparison to the users to review the input from these values, in order to improve overall consistency. Regarding this problem, the system suggests three pairwise comparisons: between (1) and (3), (1) and (7), (3) and (7). An example of the indicator interface can be seen in Figure 3.5

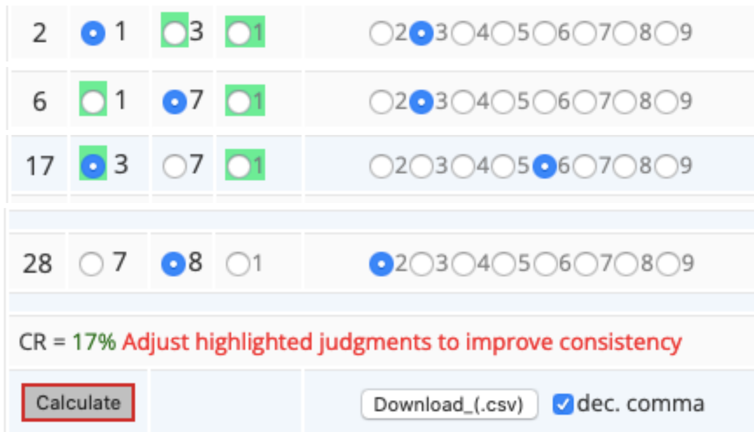


Figure 3.5: AHP-OS suggests which pairwise comparison to review to improve CR.

To continue with level 3 of the hierarchy, we have the result in Table 3.5.

Table 3.5: Comparison matrices at alternative level (level 3) and their local priorities

(1) ***Size of house***

	A	B	C	Priority
A	1	6	8	75.40%
B	1/6	1	4	18.10%
C	1/8	1/4	1	6.50%
				λmax = 3.135, CR = 14.1%

(2) ***Location to bus line***

	A	B	C	Priority
A	1	7	1/5	23.30%
B	1/7	1	1/8	5.40%
C	5	8	1	71.30%
				λmax = 3.247, CR = 25.8%

(3) ***Neighborhood***

	A	B	C	Priority
A	1	8	6	75.40%
B	1/8	1	1/4	6.50%
C	1/6	4	1	18.10%
				λmax = 3.135, CR = 14.1%

(4) ***Age of house***

	A	B	C	Priority
A	1	1	1	33.30%
B	1	1	1	33.30%
C	1	1	1	33.30%
				λmax = 3.000, CR = 0%

(5) ***Yard space***

	A	B	C	Priority
A	1	5	4	67.40%
B	1/5	1	1/3	10.10%
C	1/4	3	1	22.60%
				λmax = 3.086, CR = 9.0%

(6) ***Modern facilities***

	A	B	C	Priority
A	1	8	6	74.70%
B	1/8	1	1/5	6.00%
C	1/6	5	1	19.30%
				λmax = 3.197, CR = 20.6%

(7) ***General condition***

	A	B	C	Priority
A	1	1/2	1/2	20.00%
B	2	1	1	40.00%
C	2	1	1	40.00%
				λmax = 3.000, CR = 0%

(8) ***Financing available***

	A	B	C	Priority
A	1	1/7	1/5	7.20%
B	7	1	3	64.90%
C	5	1/3	1	27.90%
				λmax = 3.065, CR = 6.8%

Source: Saaty (1990)

In the final step, we combine local and global priorities to identify the candidates' ultimate ranking (See Table 3.6). To discover the final priorities of each candidate, we take the sum of all the products between each local priorities with the global priorities. Take House A as an example, the final priority of House A concerning all eight criteria is equal to:

$$House\ A = 0.74 \times 0.17 + 0.67 \times 0.07 + 0.74 \times 0.17 + 0.33 \times 0.02 + 0.67 \times 0.04 + 0.73 \times 0.04 + 0.20 \times 0.18 + 0.07 \times 0.31 = 0.4193$$

Table 3.6: Local and global priorities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	0.17	**0.07**	**0.17**	**0.02**	**0.04**	**0.04**	**0.18**	**0.31**
A	0.74	0.67	0.74	0.33	0.67	0.73	0.20	0.07
B	0.19	0.10	0.07	0.33	0.10	0.07	0.40	0.64
C	0.07	0.23	0.19	0.33	0.23	0.21	0.40	0.28

Source: Saaty (1990)

Similarly, we can compute House B and House C's final priorities to be 0.3372 and 0.2433 respectively. For the conclusion of this problem, House A is ranked as first choice (with highest final priority 0.4193), House B is ranked as second-best choice (0.3372) and House C is ranked as third choice 0.2433.

Back to the problem of this study, the research question is similar to a location problem using AHP model; therefore, the process will follow the generic solution process, proposed by Yang & Lee, (1997) as in Figure 3.6.

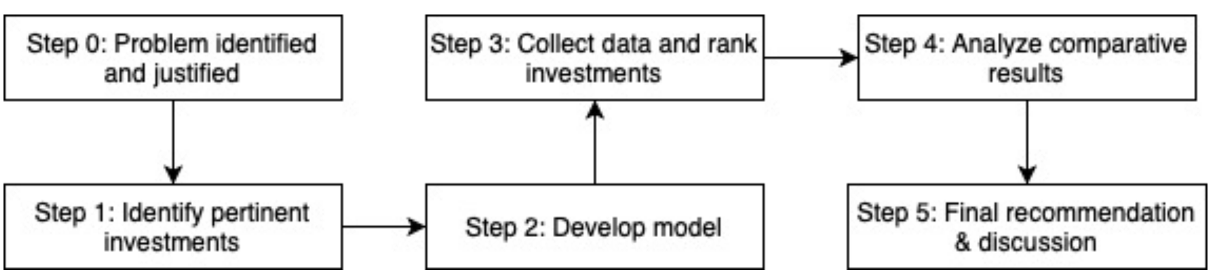


Figure 3.6: Solution process for the research's AHP model

3.1 Determination of investment criteria

Before proposing numerous potential investment criteria (Table 2.14a-f) as candidates for the model, the investment criteria list was filtered and reduced to a short list of potential investment to send to three professors and one expert for their review (one professor specialized in transportation and logistics, one professor in geography and maritime transportation, one professor in maritime and intermodal transportation and one expert in polar research with 46 years in Arctic expedition and 15 years in academic research). Finally, the author reached consensus to propose a total of seven investment criteria in the AHP model, which are: Ice-class fleet, SAR capability, Refuge port, Climatic forecast, Crew capability, Communication infrastructure and Legal stand.

Even though Arctic shipping and especially the status-quo of the NWP is well-known to the respondents, the author still provided detailed information on the investments alternatives to make sure the comprehension of respondents is aligned with the author's original intention about the investment criteria. The list of criteria with a brief explanation about the reason they are being chosen for the model is provided in Appendix 1. The complete handout for respondents in the questionnaire can be found in Appendix 2.

3.2 Questionnaire and AHP matrices

Once all investment alternatives have been identified, a questionnaire was developed and distributed to the respondents who accepted the invitation. The questionnaire consisted of 21 questions, asking participants to rank pairwise investment criteria, using the same nine-point rating scale as in Table 3.2 (See complete questionnaire in Appendix 3). The following is an sample question taken from Appendix 3.

Question: Which strategic investment criteria between Ice-class fleet and Crew competency is more important and by what degree?

Answer:

More important criteria: ☐Ice-class fleet – ☐Crew competency

Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9. Other:

Sample response for Question 1:

More important criteria: ☒Ice-class fleet – ☐Crew competency

Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☒9. Other:

Interpretation:

If the respondent chose Ice-class fleet and file a score of 9, it means that Ice-class fleet in his opinion is extremely more important compared to Crew competency.

The goal is to establish the ranking of all seven criteria and their priority weights compared against each other. The result will provide the ranking and the weights of each investment criteria. Each investment is compared against each other to develop the matrix that generates the priority weights (priority vectors). For illustrative purposes, the author performed a complete questionnaire of pairwise comparisons, the matrix results are shown on the left of Table 3.8 and the resulting weights for the criteria on the righthand side of Table 3.8. The higher the rank, the more important the role the criteria will play. It means that top-ranked criteria are highly regarded compared to the low-ranked ones.

Table 3.8a: Sample result of matrix (left) (right)

	1	2	3	4	5	6	7
1	1	0.14	0.20	2.00	1.00	0.25	6.00
2	7.00	1	1.00	7.00	3.00	6.00	7.00
3	5.00	1.00	1	3.00	4.00	1.00	9.00
4	0.50	0.14	0.33	1	0.50	0.25	0.50
5	1.00	0.33	0.25	2.00	1	1.00	1.00
6	4.00	0.17	1.00	4.00	1.00	1	2.00
7	0.50	0.14	0.11	2.00	1.00	1.00	1

Principal eigen value = 7.547

Consistency Ratio CR = 6.8%

Table 3.8b: Priorities of investment criteria

Category		Priority	Rank
1	Ice-class fleet A	6.2%	5
2	Search and rescue B	35.5%	1
3	Refuge port C	26.5%	2
4	Climatic forecast D	4.2%	7
5	Crew capability E	8.0%	4
6	Communication F	14.3%	3
7	Legal stand G	5.3%	6

Source: By author (using BPMSG AHP-OS online tool here)

The overall goal of the thesis is to determine the top strategic investments and the rankings among seven investment perspectives to support the traffic development of the NWP. Therefore, it is placed at the top of the hierarchy. The seven criteria proposed are placed on the second level. In this problem, the criteria are also the candidates, they will be evaluated through pairwise comparison against each other, to identify their score in terms of the final goal. The problem is illustrated as a hierarchy using AHP method as shown below (See Figure 3.7).

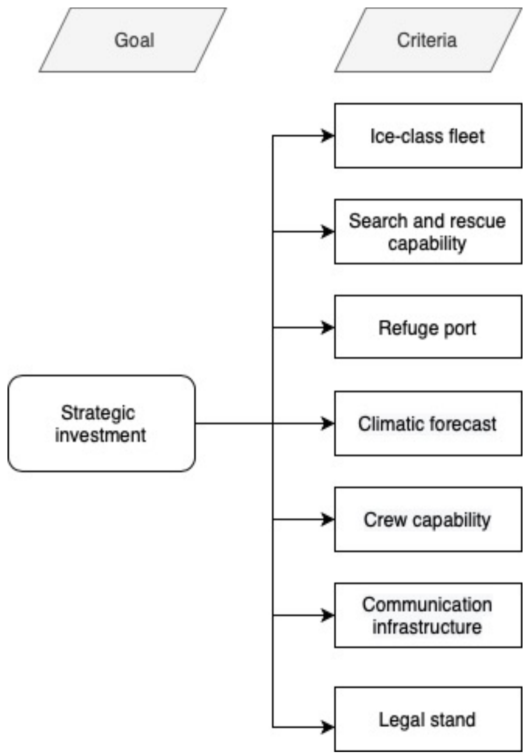


Figure 3.7: Final AHP hierarchy of the research question.
Source: By author.

3.3 Data collection

As mentioned as one of the four key assumptions for an effective AHP model, the decision makers play a crucial role in the success of the model. Therefore, the data collection is a decisive process in this thesis.

As mentioned previously in Chapter 3, there is no minimum requirements on the sample size for AHP surveys; as long as the participants' input fits the following prerequisites to be considered trustworthy: the consistency of their judgements and their validity in the subject (Saaty and Özdemir 2014). In other words, quality of the data comes before quantity of the data. However, there exists a cap of seven (or eight) respondents in AHP survey input to ensure the requirements of consistency (Saaty and Özdemir 2014).

During April to November 2022, the author brainstormed the potential list of respondents for their input for the AHP, grouping them into three major backgrounds with a planned sample size of eight respondents as follow:

1) Professor in Arctic shipping field (approximately 2-3 participants)
2) Managers from shipping companies (approximately 2-3 participants)
3) Government authorities in Arctic port projects (approximately 1-2 participants).

The evaluation process was conducted with inclusion criteria for these three groups with several requirements to ensure their input for the model are relevant, insightful, and bring the discovery effect for the research question. For the first group, the research intends to invite leading professors in Arctic shipping field (this group will be named in short as Academia group). These professors have academic interests and are well-known, having break-through publications in Arctic and Canadian Arctic field, including but not limited to shipping and maritime transportation, supply chain management, law, geography and history, environment, climate change, strategic infrastructure development, public policy and geopolitics topics. The second group, the key representatives from shipping companies (this group will be named in short as Corporate), are managers from Arctic shipping companies, with current or former intention to operate Arctic waters in the near future. They are expected to have at least more than five years in maritime shipping (this group did not include the expert invited for the preliminary list), currently working or having previous employment experiences in Arctic shipping works and projects, possessing either operational or commercial experiences of Arctic shipping operations. The last group is the government authorities in Arctic development projects, named as Government. These official representatives are expected to be directly involved in Arctic development projects, based on the description of their positions, expected to have at least five years of related experiences in Canadian Arctic involvement.

Data processing

As stated in the ethical declaration, to achieve the maximum confidentiality (impossible to identify a participant's name), the input from respondents were encrypted and stored in password-protected devices. Each respondent's input was codified into a combination of alphabetical and numerical characters to preserve their identity and the input confidentiality. The decryption key was only available to the researcher (the author of this thesis), and the results will be disseminated as aggregate data, making it impossible to trace back the respondents' identities.

Recruitment process

The initial population size was around 20 people with different forecasted acceptance ratio associated to each group. For Academia, the population size was five professors from Québec region and Canadian universities, with an expected success ratio of 50%. For Corporate, the population size was ten people from 4 – 5 maritime shipping companies with operation in the Canadian Arctic region, the expected success was rated at 30%. For Government, the population size was expected to be five people from Canada's governmental organizations and authorities, with an expected success ratio of 20%. The respondent's identification process was different for each group, for example for the Corporate group, the author narrowed down the Arctic shipping companies and then identified the participants based on public domain searching engines including company's public organization charts or personal professional profile (e.g., LinkedIn, personal website). For Academia, the author used search result on academic literature and contacted the authors accordingly. For Government, the author used public report on Canadian Arctic topics and contacted the report's authors. By October 2022, this initial planning procedure was complete, and the author initiated the approaching stage by the beginning of November 2022. The author prepared a list of all the potential respondents with their name, title, group, contact information (e.g., email, website) with their positions, organizations and area of interests. The major solicitation method was through email contact, based on the respondents list whereas the author sent out invitation emails, introducing the thesis and inviting them to participate in the research by answering a structured questionnaire.

However, after two months of recruitment (November and December 2022), the success ratio had been low. Therefore, the author had to expand the population size to ensure the desired quantities of input, seven respondents, for the model was achieved. From November 2022 to March 2023, a total of 45 persons were contacted for the questionnaire, 35 people were contacted using email and 10 people were approached using LinkedIn first for work email. By March 07, 2023, the data collection process was complete, and the goal to collect seven input was achieved. Twelve respondents accepted to participate in the research (success ratio of 27%) and seven of them (consisting of three respondents from Academia, three from Corporate and one from Government) sent back to the author their filled questionnaire (turnaround ratio of 16%).

Dealing with high consistency ratio

Out of the seven inputs, two of them had consistency ratio (CR) larger than the threshold 10% (0.10), one input had CR of 18.7% and the other input had CR of 14.5%. In the literature, there are two possible solutions when CR is over 0.10. The first solution is to exclude the input from the sample, like how Lee & Hwang (2010) did with their data set – the authors removed 148 out of 264 respondents whose CR exceeded the value of 0.10. This solution is convenient to deploy; however, this approach is only suitable if the sample is large enough. The second approach, similar to Cox et al. (2000) and Opasanon & Lertsanti (2013), is to re-approach the respondents to have them review their responses and adjust accordingly until CR threshold is achieved. Before approaching the respondents again, the model analyst should review the judgement matrix, then explain the criteria to respondents if needed and ask them to re-evaluate their response. This process is to be repeated until an appropriate CR is obtained. The second approach saves the effort spent on recruiting new respondents, but there are risks that current respondents may not agree to alter their initial response. In such a rejection scenario, the model analysts must either restart the process with new respondents or analyze the results with great caution. In Soma (2003) study on how to involve stakeholders in fisheries management in Trinidad and Tobago, they proceeded with a group of sample with CR larger than 0.10 (the fisherman's responses have CR over 0.20 compared with fisheries manager's responses with CR under 0.10). The authors respected the high consistency ratio in their final analysis and suggested that the questionnaires be tested comprehensively, and a smaller group of focused interviewees be carefully selected in future studies.

As proven in Saaty (1990, 2013), it is crucial to respect the consistency ratio (CR) threshold of less than 0.10 in order for the result to be consistent with the data. Therefore, in this research, the author chose to proceed with the second solution. The two input questionnaires were sent back to the respective interviewees with suggestions on which pairwise comparison(s) to be changed (based on the AHP-OS suggestion) and by how much. The suggestion(s) were respectfully communicated to the interviewees, to ask them whether they would accept to alter their initial evaluation, alongside with a brief explanation and suggestions from the AHP-OS interface. Fortunately, the two respondents agreed to adjust their initial answer. There were three pairwise comparisons changed in the input with CR of 18.7% and two pairwise comparisons changed in the other input with CR 14.5%. After the revision, the CR were improved and matched the threshold requirements, being at 8.7% and 5.8% respectively.

4. Analysis and findings

This chapter will perform the Step 4: Analyze comparative results as shown in Figure 3.6 by illustrating the calculation developed for the result and analyze the parameters to determine if the models are processed correctly.

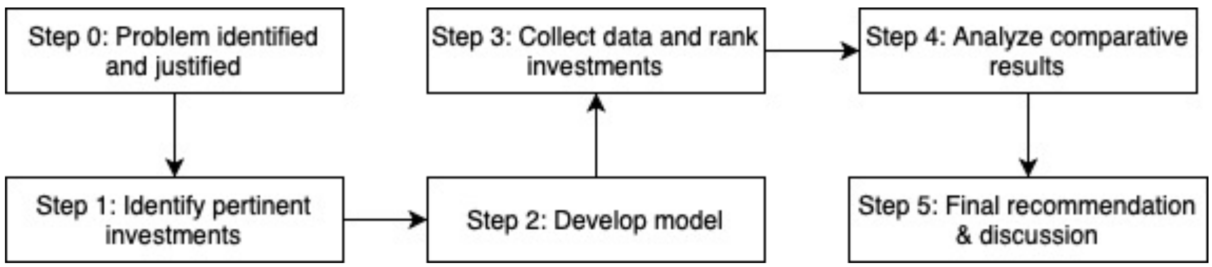


Figure 3.6: Solution process for the research's AHP model

4.1 Calculation of the AHP matrix

This section will demonstrate step-by-step calculation of what AHP-OS performs to produce the result of CR and the priorities. We will take the 7x7 matrix derived from Respondent 1's input (coded as C02) as the example for the calculation.

Based on the respondent's questionnaire, we arrive with this comparison matrix (Code C02) as in Figure 4.1.

	A	B	C	D	E	F	G
A	1	3	5	7	3	1	7
B	1/3	1	2	3	1/3	1	9
C	1/5	1/2	1	3	1/5	1/3	5
D	1/7	1/3	1/3	1	1/7	1/3	7
E	1/3	3	5	7	1	1	7
F	1	1	3	3	1	1	7
G	1/7	1/9	1/5	1/7	1/7	1/7	1

Figure 4.1: Comparison matrix of Respondent 1 (Code C02)

Note: A, B, C, D, E, F, G are short abbreviations for seven investment criteria in the following order: (A) Ice-class fleet, (B) SAR capability, (C) Refuge port, (D) Climatic forecast, (E) Crew capability, (F) Communication infrastructure and (G) Legal stand.

The calculation from the software developed by Klaus D. Goepel at Business Performance Management Singapore uses the power method for approximating eigenvalues and eigenvectors (Goepel 2018). The calculation starts with the first step of non-zero approximation of (1,1,1,1,1,1,1) and using 7 iterations (Goepel 2018). The calculation is given below:

Iterations **Approximations**

$$x_1 \begin{bmatrix} 1 & 3 & 5 & 7 & 3 & 1 & 7 \\ 0.3333 & 1 & 2 & 3 & 0.3333 & 1 & 9 \\ 0.2 & 0.5 & 1 & 3 & 0.2 & 0.3333 & 5 \\ 0.1428 & 0.3333 & 0.3333 & 1 & 0.1428 & 0.3333 & 7 \\ 0.3333 & 3 & 5 & 7 & 1 & 1 & 7 \\ 1 & 1 & 3 & 3 & 1 & 1 & 7 \\ 0.1428 & 0.1111 & 0.2 & 0.1428 & 0.1428 & 0.1428 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 27 \\ 16.6667 \\ 10.2333 \\ 9.2857 \\ 24.3333 \\ 17 \\ 1.8825 \end{bmatrix} \rightarrow 1.8825 \begin{bmatrix} 14.3423 \\ 8.8532 \\ 5.4359 \\ 4.9325 \\ 12.9258 \\ 9.0303 \\ 1 \end{bmatrix}$$

$$x_2 \begin{bmatrix} 1 & 3 & 5 & 7 & 3 & 1 & 7 \\ 0.3333 & 1 & 2 & 3 & 0.3333 & 1 & 9 \\ 0.2 & 0.5 & 1 & 3 & 0.2 & 0.3333 & 5 \\ 0.1428 & 0.3333 & 0.3333 & 1 & 0.1428 & 0.3333 & 7 \\ 0.3333 & 3 & 5 & 7 & 1 & 1 & 7 \\ 1 & 1 & 3 & 3 & 1 & 1 & 7 \\ 0.1428 & 0.1111 & 0.2 & 0.1428 & 0.1428 & 0.1428 & 1 \end{bmatrix} \begin{bmatrix} 27 \\ 16.6667 \\ 10.2333 \\ 9.2857 \\ 24.3333 \\ 17 \\ 1.8825 \end{bmatrix} = \begin{bmatrix} 296.3444 \\ 116.0444 \\ 71.7698 \\ 44.4301 \\ 229.6778 \\ 156.7349 \\ 16.8694 \end{bmatrix} \rightarrow 16.8694 \begin{bmatrix} 17.5669 \\ 6.8789 \\ 4.2544 \\ 2.6337 \\ 13.615 \\ 9.291 \\ 1 \end{bmatrix}$$

$$x_3 \begin{bmatrix} 1 & 3 & 5 & 7 & 3 & 1 & 7 \\ 0.3333 & 1 & 2 & 3 & 0.3333 & 1 & 9 \\ 0.2 & 0.5 & 1 & 3 & 0.2 & 0.3333 & 5 \\ 0.1428 & 0.3333 & 0.3333 & 1 & 0.1428 & 0.3333 & 7 \\ 0.3333 & 3 & 5 & 7 & 1 & 1 & 7 \\ 1 & 1 & 3 & 3 & 1 & 1 & 7 \\ 0.1428 & 0.1111 & 0.2 & 0.1428 & 0.1428 & 0.1428 & 1 \end{bmatrix} \begin{bmatrix} 296.3444 \\ 116.0444 \\ 71.7698 \\ 44.4301 \\ 229.6778 \\ 156.7349 \\ 16.8694 \end{bmatrix} = \begin{bmatrix} 2278.1928 \\ 876.7757 \\ 504.8794 \\ 352.5124 \\ 1621.2743 \\ 1265.488 \\ 148.0012 \end{bmatrix} \rightarrow 148.0012 \begin{bmatrix} 15.3931 \\ 5.9231 \\ 3.4113 \\ 2.3818 \\ 10.9544 \\ 8.5505 \\ 1 \end{bmatrix}$$

$$x_4 \begin{bmatrix} 1 & 3 & 5 & 7 & 3 & 1 & 7 \\ 0.3333 & 1 & 2 & 3 & 0.3333 & 1 & 9 \\ 0.2 & 0.5 & 1 & 3 & 0.2 & 0.3333 & 5 \\ 0.1428 & 0.3333 & 0.3333 & 1 & 0.1428 & 0.3333 & 7 \\ 0.3333 & 3 & 5 & 7 & 1 & 1 & 7 \\ 1 & 1 & 3 & 3 & 1 & 1 & 7 \\ 0.1428 & 0.1111 & 0.2 & 0.1428 & 0.1428 & 0.1428 & 1 \end{bmatrix} \begin{bmatrix} 2278.1928 \\ 876.7757 \\ 504.8794 \\ 352.5124 \\ 1621.2743 \\ 1265.488 \\ 148.0012 \end{bmatrix} = \begin{bmatrix} 17065.8229 \\ 6841.3928 \\ 3942.5331 \\ 2827.9685 \\ 12304.4792 \\ 9649.9146 \\ 1134.6062 \end{bmatrix} \rightarrow 1134.606 \begin{bmatrix} 15.0412 \\ 6.0297 \\ 3.4748 \\ 2.4925 \\ 10.8447 \\ 8.5051 \\ 1 \end{bmatrix}$$

$$x_5 \begin{bmatrix} 1 & 3 & 5 & 7 & 3 & 1 & 7 \\ 0.3333 & 1 & 2 & 3 & 0.3333 & 1 & 9 \\ 0.2 & 0.5 & 1 & 3 & 0.2 & 0.3333 & 5 \\ 0.1428 & 0.3333 & 0.3333 & 1 & 0.1428 & 0.3333 & 7 \\ 0.3333 & 3 & 5 & 7 & 1 & 1 & 7 \\ 1 & 1 & 3 & 3 & 1 & 1 & 7 \\ 0.1428 & 0.1111 & 0.2 & 0.1428 & 0.1428 & 0.1428 & 1 \end{bmatrix} \begin{bmatrix} 17065.8229 \\ 6841.3928 \\ 3942.5331 \\ 2827.9685 \\ 12304.4792 \\ 9649.9146 \\ 1134.6062 \end{bmatrix} = \begin{bmatrix} 131604.042 \\ 52861.8359 \\ 30610.8646 \\ 21777.2497 \\ 95617.8686 \\ 74115.3581 \\ 8661.5797 \end{bmatrix} \rightarrow 8661.5 \begin{bmatrix} 15.194 \\ 6.103 \\ 3.534 \\ 2.5142 \\ 11.0393 \\ 8.5568 \\ 1 \end{bmatrix}$$

$$x_6 \begin{bmatrix} 1 & 3 & 5 & 7 & 3 & 1 & 7 \\ 0.3333 & 1 & 2 & 3 & 0.3333 & 1 & 9 \\ 0.2 & 0.5 & 1 & 3 & 0.2 & 0.3333 & 5 \\ 0.1428 & 0.3333 & 0.3333 & 1 & 0.1428 & 0.3333 & 7 \\ 0.3333 & 3 & 5 & 7 & 1 & 1 & 7 \\ 1 & 1 & 3 & 3 & 1 & 1 & 7 \\ 0.1428 & 0.1111 & 0.2 & 0.1428 & 0.1428 & 0.1428 & 1 \end{bmatrix} \begin{bmatrix} 131604.042 \\ 52861.8359 \\ 30610.8646 \\ 21777.2497 \\ 95617.8686 \\ 74115.3581 \\ 8661.5797 \end{bmatrix} = \begin{bmatrix} 1017284.64 \\ 407225.526 \\ 235830.931 \\ 167397.932 \\ 738312.877 \\ 571994.506 \\ 66816.506 \end{bmatrix} \rightarrow 66816.5 \begin{bmatrix} 15.2251 \\ 6.0946 \\ 3.5295 \\ 2.5053 \\ 11.0498 \\ 8.5607 \\ 1 \end{bmatrix}$$

$$x_7 \begin{bmatrix} 1 & 3 & 5 & 7 & 3 & 1 & 7 \\ 0.3333 & 1 & 2 & 3 & 0.3333 & 1 & 9 \\ 0.2 & 0.5 & 1 & 3 & 0.2 & 0.3333 & 5 \\ 0.1428 & 0.3333 & 0.3333 & 1 & 0.1428 & 0.3333 & 7 \\ 0.3333 & 3 & 5 & 7 & 1 & 1 & 7 \\ 1 & 1 & 3 & 3 & 1 & 1 & 7 \\ 0.1428 & 0.1111 & 0.2 & 0.1428 & 0.1428 & 0.1428 & 1 \end{bmatrix} \begin{bmatrix} 1017284.64 \\ 407225.526 \\ 235830.931 \\ 167397.932 \\ 738312.877 \\ 571994.506 \\ 66816.506 \end{bmatrix} = \begin{bmatrix} 7844550.08 \\ 3139623.41 \\ 1817504.36 \\ 1290930.1 \\ 5689734.56 \\ 4412219.68 \\ 515657.102 \end{bmatrix} \rightarrow 515657.1 \begin{bmatrix} 15.2127 \\ 6.0886 \\ 3.5246 \\ 2.5035 \\ 11.034 \\ 8.5564 \\ 1 \end{bmatrix}$$

After iterating 7 times using the power method, X = (15.21272576, 6.088587548, 3.524637496, 2.503466145, 11.03394976, 8.556499397, 1) is the eigenvector of the Matrix 1. Then we use the Rayleigh quotient to compute an approximation of the dominant eigenvalue of (A) by first computing the product of A_x:

$$A_x \begin{bmatrix} 1 & 3 & 5 & 7 & 3 & 1 & 7 \\ 0.3333 & 1 & 2 & 3 & 0.3333 & 1 & 9 \\ 0.2 & 0.5 & 1 & 3 & 0.2 & 0.3333 & 5 \\ 0.1428 & 0.3333 & 0.3333 & 1 & 0.1428 & 0.3333 & 7 \\ 0.3333 & 3 & 5 & 7 & 1 & 1 & 7 \\ 1 & 1 & 3 & 3 & 1 & 1 & 7 \\ 0.1428 & 0.1111 & 0.2 & 0.1428 & 0.1428 & 0.1428 & 1 \end{bmatrix} \begin{bmatrix} 15.2127 \\ 6.0886 \\ 3.5246 \\ 2.5035 \\ 11.034 \\ 8.5564 \\ 1 \end{bmatrix} = \begin{bmatrix} 117.2843 \\ 46.9537 \\ 27.1808 \\ 19.3096 \\ 85.0745 \\ 65.976 \\ 7.7109 \end{bmatrix}$$

Based on the product, we have:

$A_x \times x \times x \times x \times x \times x \times x = (15.2127258 \times 117.284288) + (6.08858755 \times 46.9536521) + (3.5246375 \times 27.1808312) + \ldots + (1 \times 7.71095727) = 3725.182277$

And:

$x \times x \times x \times x \times x \times x \times x = (15.2127258 \times 15.2127258) + (6.08858755 \times 6.08858755) + (3.5246375 \times 3.5246375) + \cdots + (1 \times 1) = 483.1500649$

The λ value can be computed by:

$\lambda = (A_x \times x \times x \times x \times x \times x \times x)/(x \times x \times x \times x \times x \times x \times x) = 3725.182277 / 483.1500649 = 7.710197198$

Following the previous procedure in Figure 3.2 (Chapter 3 Methodology), we then perform consistency check by computing the Consistency Index (CI) and Consistency Ratio (R). Given that n = 7 (seven criteria) and Random Index (RI) = 1.32 (obtained from the RI's index table – Table 3.3), we have:

n = 7

$CI = \frac{(\lambda\max - n)}{(n-1)} = 0.1183662$

RI = 1.32

$CR = \frac{CI}{RI} = 0.089671363$

Once we have obtained the eigenvalue of 7.710197198, we can find the eigenvectors.

$$\begin{bmatrix} 1 & 3 & 5 & 7 & 3 & 1 & 7 \\ 0.3333 & 1 & 2 & 3 & 0.3333 & 1 & 9 \\ 0.2 & 0.5 & 1 & 3 & 0.2 & 0.3333 & 5 \\ 0.1428 & 0.3333 & 0.3333 & 1 & 0.1428 & 0.3333 & 7 \\ 0.3333 & 3 & 5 & 7 & 1 & 1 & 7 \\ 1 & 1 & 3 & 3 & 1 & 1 & 7 \\ 0.1428 & 0.1111 & 0.2 & 0.1428 & 0.1428 & 0.1428 & 1 \end{bmatrix} \begin{bmatrix} A \\ B \\ C \\ D \\ E \\ F \\ G \end{bmatrix} = 7.710197198 \begin{bmatrix} A \\ B \\ C \\ D \\ E \\ F \\ G \end{bmatrix}$$

Based on the coefficients of the variables and the equivalent sum matrix, we have the following equations:

$$\begin{cases} A + 3B + 5C + 7D + 3E + 1F + 7G = 7.710197198A \\ 1/3A + B + 2C + 3D + 1/3E + F + 9G = 7.710197198B \\ 1/5A + 1/2B + C + 3D + 1/5E + 1/3F + 5G = 7.710197198C \\ 1/7A + 1/3B + 1/3C + D + 1/7E + 1/3F + 7G = 7.710197198D \\ 1/3A + 3B + 5C + 7D + E + F + 7G = 7.710197198E \\ A + B + 3C + 3D + E + F + 7G = 7.710197198F \\ 1/7A + 1/9B + 1/5C + 1/7D + 1/7E + 1/7F + G = 7.710197198G \\ A + B + C + D + E + F + G = 1 \end{cases}$$

Solving the equation, we have the eigenvectors, or the priorities of criteria based on Respondent's 1 comparison matrix.

A = 0.319; B = 0.127; C = 0.072; D = 0.05; E= 0.233; F = 0.177; G = 0.021

After checking all seven respondents' input, there are two inputs that had a consistency ratio larger than 10%. As proven in Saaty (1990, 2013), it is crucial to respect the consistency ratio (CR) threshold of less than 0.10 in order for the result to be consistent with the data. As proposed in Section 3.3, there are two possible solutions for this, either excluding the result or reviewing the responses. In this research, the author chose to proceed with the second solution. The two input questionnaires were sent back to the respective interviewees with suggestions on which pairwise comparison(s) to be changed (based on the AHP-OS suggestion) and by how much. The suggestion(s) were respectfully communicated to the interviewees, to ask them whether they would accept to alter their initial evaluation, alongside with a brief explanation and suggestions from the AHP-OS interface. Fortunately, the two respondents agreed to adjust their initial answer. There were three pairwise comparisons changed in the input with CR of 18.7% and two pairwise comparisons changed in the other input with CR 14.5%. After the revision, the CR were improved and matched the threshold requirements, being at 8.7% and 5.8% respectively.

Once we have performed all components of the respondent's input matrix to verify if the CR is within acceptable threshold, we continue to consolidate individual inputs into a group preference matrix by using geometric mean to compute the consolidated matrix.

The elements of the consolidated decision matrix (all participants) are calculated as (weighted) geometric mean of all individual participants. The geometric mean method is calculated with the following equation.

Geometric mean $b_{ij} = (a_{1ij} \times a_{2ij} \times \ldots \times \ a_{kij})^{\frac{1}{k}}$

whereas *i, j* are the row and column of each respective criteria, and *k* is the number of participants.

To compute b_{AB} (where A is the first criteria Ice-class fleet and B is the second criteria SAR capability), we fill in the corresponding components into the equation.

$$b_{AB} = (a_{1AB} \times a_{2AB} \times \ldots \times \ a_{7AB})^{\frac{1}{7}}$$

Therefore, we can obtain this value to be:

$$b_{AB} = (3 \times \tfrac{1}{9} \times \ 3 \ \times \ 8 \ \times \ \tfrac{1}{2} \ \times 7 \ \times \ 1)^{\frac{1}{7}} \ = 1\tfrac{3}{5}$$

Next, we repeat the calculation for the rest of the matrix and the consolidated group's response matrix can be obtained as shown in Figure 4.2:

	A	B	C	D	E	F	G
A	1	1 3/5	1 5/6	1 3/4	3/5	1 2/7	4 2/5
B	5/8	1	1 5/7	1 1/5	5/8	1 1/2	5
C	5/9	4/7	1	1	3/8	2/3	4.6
D	4/7	5/6	1	1	1/2	1	4 1/4
E	1 2/3	1 4/7	2 2/3	2	1	3	4 3/5
F	7/9	2/3	1 5/9	1	1/3	1	3 5/8
G	2/9	1/5	2/9	1/4	2/9	2/7	1

Figure 4.2: Consolidated matrix of all respondents

Once we have the consolidated matrix, we proceed with the same procedure to obtain the eigenvalue and eigenvector for the individual respondents.

Through this calculation, the parameters obtained are as below:

Eigenvalue (λ) = 7.135

n = 7

CI = (7.135 – 7) / 6 = 0.0225

CR = CI / Random Index (RI of 7 = 1.32) or 0.0225 / 1.32 = 0.017 or 1.7%

Since the CR is less than 10%, the result is accepted, and we can come up with the global priorities of the seven criteria based on the consolidated matrix of all respondents as shown in Table 4.1

Table 4.1: Global priorities of seven investment criteria

Ranking	Code	Criteria	Weights
2	A	Ice-class fleet	18.60%
3	B	SAR capability	15.90%
6	C	Refuge port	10.80%
4	D	Climatic forecast	12.30%
1	E	Crew capability	26.50%
5	F	Communication infrastructure	12.30%
7	G	Legal stand	3.50%

4.2 Interpretation and discussion of ranking results

4.2.1 The priorities

In this section, the local priority of individual input is analyzed to see if the priorities of the criteria reflect the same ranking order as the consolidated ranking. Table 4.2a specifies the local priorities of all seven individual input for all seven investment criteria and Table 4.2b, based on these local priorities, translates those findings into the local ranking for each respondent.

Table 4.2a: Local priorities of seven investment criteria from seven respondents' inputs

Code	Criteria	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Respondent 5	Respondent 6	Respondent 7
		C02	C35	C21	C01	C05	C18	C16
A	Ice-class fleet	31.90%	4.90%	33.30%	14.60%	4.70%	24.00%	18.90%
B	SAR capability	12.70%	32.60%	19.20%	3.30%	20.60%	4.20%	24.40%
C	Refuge port	7.20%	9.70%	14.80%	16.70%	3.40%	6.10%	10.60%
D	Climatic forecast	5.10%	7.00%	5.20%	21.70%	40.40%	15.70%	4.50%
E	Crew capability	23.30%	19.20%	21.00%	32.70%	24.80%	23.70%	11.40%
F	Communication infrastructure	17.70%	24.80%	4.40%	8.90%	4.10%	24.40%	5.40%
G	Legal stand	2.10%	1.80%	2.20%	2.10%	2.00%	2.00%	24.90%

Crew capability stands in the top four highest-ranked investment criteria in all of seven respondent's input. Respondent 4 (Code C01) ranked it as the most important investment at 32.7%; Respondent 1 (Code C02), Respondent 3 (C21) and Respondent 5 (Code C05) classified it as the second most important; and Respondent 2 (Code C35) and Respondent 6 (C18) graded it as third. Only Respondent 7 (Code C16) listed Crew capability in fourth place at 11.4%. For the second most-important investment criteria in global priorities – Ice-class fleet, two respondents (Respondent 1 and Respondent 3) judged it as the most important criteria at 31.9% and 33.3% respectively, while Respondent 6 and Respondent 7 filed it as second and third most-important. Two respondents (Respondents 4 and 5) rated it in fourth position and only Respondent 2 deemed it in sixth place. Comparing with Crew capability with a standard deviation (SD) of 6.42%, the Ice-class fleet has a higher SD at 11.68% among seven respondents, ranging from 4.7% to 33.3%. The third most-important criteria – SAR capability, has an even more diverse ranking among the respondents: Respondent 2 ranked it as the most-important investment criteria, Respondent 7 graded it as the second most-important and Respondent 4 categorized it as number four. Two respondents (Respondent 3 and Respondent 5) listed it in third place while two other respondents (Respondent 4 and Respondent 6) ordered it in sixth place. Among the seven investment criteria, there is a consensus among six respondents that Legal stand is the least important investment criteria, except for one respondent (Respondent 7), who regarded it as the most important criteria.

Table 4.2b: Local ranking of seven investment criteria from seven respondents' inputs

Code	Criteria	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Respondent 5	Respondent 6	Respondent 7
		C02	**C35**	**C21**	**C01**	**C05**	**C18**	**C16**
A	Ice-class fleet	1	6	1	4	4	2	3
B	SAR capability	4	1	3	6	3	6	2
C	Refuge port	5	4	4	3	6	5	5
D	Climatic forecast	6	5	5	2	1	4	7
E	Crew capability	2	3	2	1	2	3	4
F	Communication infrastructure	3	2	6	5	5	1	6
G	Legal stand	7	7	7	7	7	7	1

There is no complete resemblance in the local ranking among the inputs of the seven respondents; however, there exists a high degree of similarity between some profiles. Based on Table 4.2b, Respondent 4 and Respondent 5 shared the most resemblance between their responses where they assessed Crew capability and Climatic forecast as the first and second most important criteria. They also ranked three criteria – Ice-class fleet, Communication infrastructure and Legal stand similarly at fourth, fifth and seventh place. Not having many similarities compared to Respondent 4 and Respondent 5 are the two pairs: Respondent 1 – Respondent 3 and Respondent 2 – Respondent 6. For Respondent 1 and Respondent 3, they regarded Ice-class fleet and Crew capability as first and second place. For Respondent 2 and Respondent 6, they ranked Crew capability as third place and Legal stand as the least important criteria. Among the seven respondent's input, Respondent 7 is the only one who considered Legal stand as the most important criteria.

Criteria-wise, Legal stand is the criteria with the most consensus among the respondents, with six out of seven responses agreeing it to be in the last place in the ranking chart. Crew capability and Refuge port both received three votes each to be on the second place and the fifth place.

4.2.2 Recommendations to Government

In the scope of this thesis, the author will offer recommendations which comprehensively take into account various aspects, including the rankings derived from the AHP model, an examination of their implementation feasibility according to varying levels of complexity, and their alignment with short-term or long-term objectives.

From the literature, Dawson et al. (2017) have produced a noteworthy report commissioned by Transport Canada, wherein they employed a Delphi interview approach involving 30 highly knowledgeable experts. With the original ranking order from the thesis's result, the summary of their recommendations is listed below:

Table 4.3a: Recommendations from the literature for all seven investment criteria

No	Investment opportunities	Recommendation in Dawson et al. (2017)
1	Crew capability	Systematic training for crew members, relevant safety knowledge based on mechanics of the vessels, physiological and psychological support and guidance
2	Ice-class fleet	Vessel complements and upgrade, fleet expansion for Coast Guard's current fleet
3	SAR capability	Comprehensive action plans, preventive protocols for commercial ship operators in disastrous events.
4	Climatic forecast	Improvements in data quality for marine weather forecasts, real-time seasonal ice forecasting, and efficient transmission between broadcasting points and vessels
5	Communication infrastructure	Improvement on charting, ice and weather data interpretation, enhanced sharing of real-time, standardized meteorological and oceanic data among partners and relevant stakeholders
6	Refuge port	Investment in at least one deep-water port, a system of shallow water ports, docking and other basic port infrastructure
7	Legal stand	improving the availability of information and limiting traffic impact on cultural and ecologically sensitive areas

Source: Dawson et al. (2017)

Another aspect related to our recommendations is taking into consideration the level of difficulty of their implementation. Irrespective of the investment criteria, endeavors related to implementation entail multiple elements, including financial funding, technological advancements, the perplexity of bureaucratic procedures, and the availability of talents, among others. In the scope of this thesis, the author attempts to propose an approach to conceptualize the order of priority for investment criteria, based on personal reference, considering three factors only (financial, technology and bureaucracy), as an illustrative example for evaluating the difficulty associated with these investments. For each of these three dimensions, the author tries to assess the level of difficulty using a five-point scale, with the highest level of complexity as level five, based on the author's own judgment. Ideally, future research can perform this assessment though expert's interview as input, but due to the time constraint of this thesis's progress, the author would only demonstrate this approach using only his own evaluation. Therefore, the author comes up with the following ranking based on the levels of difficulty inherent in the implementation of these investments.

Table 4.3b: Ranking investment criteria by the level of difficulty for their implementation (5 = most difficult, 1 = least difficult)

No	Investment opportunities	Financial	Technology	Bureaucratic	Overall difficulty
1	Refuge port	4	2	4	10
2	SAR capability	3	3	3	9
3	Legal stand	2	1	5	8
4	Ice-class fleet	3	3	1	7
5	Climatic forecast	1	3	2	6
6	Communication infrastructure	2	1	2	5
7	Crew capability	1	1	1	3

The final aspect to consider in order to establish the investment priority is the combination of each investment's viability, its potential impact within both short-term and long-term horizons, and the fit between the investment and the federal government's strategic vision.

Given the inherent dynamic nature in regulatory frameworks, it is imperative that the established priorities remain adaptive to these ongoing, ever-changing alterations. The approach is anticipated to serve as a valuable point of reference for policymakers, aiding them in the strategic allocation of resources and efforts that align with both short-term and long-term objectives. Therefore, the author has put forth an integrative approach to comprehend the prioritization of investments, taking into consideration their feasibility and future outlook, as detailed below:

Table 4.3c: Ranking investment by short-term or long-term goal and outlook

No	Investment opportunities	Recommendation
1	Crew capability	Short-term feasibility with both short and long-term impact
2	Climatic forecast	Short-term feasibility with both short and long-term impact
3	Communication infrastructure	Long-term feasibility with both short and long-term impact
4	Ice-class fleet	Long-term feasibility with long-term impact
5	SAR capability	Long-term feasibility with long-term impact
6	Refuge port	Long-term feasibility with long-term impact
7	Legal stand	Long-term feasibility with long-term impact

Overall, there is no single correct order of priority for investment ranking considering all different aspects, rather, there will be more than one prioritization for the different investments, depending on different aspects considered. Table 4.4 gives the order of priority for the seven investment criteria side by side based on the three aspects considered above.

Table 4.4: Ranking investment by different aspects

Aspects of rating recommendation (based on)	**Ranking of investment opportunities (highest ranked to lowest ranked criteria based on AHP analysis)**	**Short or long-term goal (degree of feasibility to conduct investment versus outlook of impact)**	**Level of difficulty for implementation (easiest to hardest to implement)**
1	Crew capability	Crew capability	Crew capability
2	Ice-class fleet	Climatic forecast	Communication infrastructure
3	SAR capability	Communication infrastructure	Climatic forecast
4	Climatic forecast	Ice-class fleet	Ice-class fleet
5	Communication infrastructure	SAR capability	Legal stand
6	Refuge port	Refuge port	SAR capability
7	Legal stand	Legal stand	Refuge port

For Crew capability investment criteria, it is a broadly supported fact that crews with higher levels of training and experience contribute more actively to safety adherence and make considerable contribution to reduced consequences in case of distress. However, it is crucial to shed light on additional aspects; namely, the physiological and psychological challenges faced by crew members that are seldom addressed (Yahan and Minglu, 2021). Prolonged voyage time in the vicinity of icebergs might increase the risk of navigation fatigue for the captain who must remain in command all the time and exhaustion for crew members who must deal with constantly changing steering demands (Yahan and Minglu, 2021). Therefore, in addition to systematic training for crew members, future investments should include relevant safety knowledge based on mechanics of the vessels and offer psychological support and guidance as well.

Furthermore, government could support in various ways in this investment criteria. For instance, Transport Canada has the potential to engage in collaborative initiatives with the IMO, to develop and provide free training programs for SAR personnel or offer subsidized training opportunities to crew members employed by commercial shipping lines. Government agencies can consider the establishment and dissemination of historical data of ice conditions and maritime traffic in Arctic regions to foster increased engagement in research concerning Canadian Arctic shipping, thereby promoting knowledge in the field.

The Ice-class fleet investment should be dedicated to support Coast Guard's current fleet through fleet expansion (additional number of vessels) and vessel complement (additional staffs). Theses upgrades will enable Canadian Coast Guards to extend its services across a larger geographical area and for longer operating seasons. Furthermore, the installation of new technologies on CCG vessels would facilitate comprehensive charting of traversing area.

According to Guy & Lasserre (2016), only a limited number of carriers maintain specialized fleets designated for Arctic operations, primarily due to the perception of these fleets as costly investments and an economic challenge. The decision to acquire ice-class vessels is an entirely integral component of the fiscal planning undertaken by Arctic shipping companies themselves. In light of this, from the governmental standpoint, federal maritime association, e.g Transport Canada, might consider the formulation and allocation of financial support programs. These programs could take the form of subsidies or financial assistance packages specifically aimed at Canadian-based transportation companies engaged in providing sealift services to Northern communities, namely two officially designated maritime transport companies: Nunavut Eastern Arctic Shipping – NEAS Inc and Nunavut Sealink and Supply – NSSI Inc., and other companies whose Arctic operations are actively promoted including Nunavut Tunngavik Incorporated, Fednav Limited, Desgagnés Transarctik, Marine Transportation Services (MTS – formerly the Northern Transportation Company Limited (NCTL)). Such initiatives can empower the development of ice-class fleets capable of meeting the stringent requirements associated with navigating the NWP and the Canadian Arctic. Consequently, these fleets can extend their operational schedules beyond the conventional summer shipping season, thereby enhancing the provision of essential supplies to Northern communities.

Concerning SAR capabilities, proper training should be provided to decision-makers along the Northern Marine Transportation Corridors (NMTC) in preparation for disaster events. Additionally, commercial ship operators should develop preventive protocols to coordinate transportation of SAR response equipment in the event of an incident (Dawson, Copland, et al., 2017).

The SAR responsibility lies fairly within the purview of the federal government. Therefore, unlike Ice-class fleet criteria, the Canadian government will have greater autonomy in controlling financial and managerial aspects of SAR operations, offering them a higher degree of influence over this investment domain. For instance, the government can consider granting the CGC more fundings to grow their fleet and better equipment, train crews and expand their operational activities. Furthermore, the enhancement of SAR capabilities can be achieved through increasing the accessibility of training opportunities. Another relevant proposal is that CGC can consider recruiting more Indigenous members into the current SAR crews, thus harnessing their local expertise and knowledge of the intricacies of the northern terrain and climatic conditions. Notably, this investment opportunity exhibits a mutually reinforcing, interlinked relationship with other investment criteria, including Legal stands, Refuge port and Communication infrastructure. SAR capabilities are significantly bolstered when the Legal stand investment are successfully implemented making vessel registry mandatory to the NMTC, eventually enabling enhanced monitoring and support of Arctic shipping activities and distress effort. On the other hand, the successful implementation or improvement of Refuge port facilities, Climatic forecasting capabilities, and Communication infrastructure can, reciprocally, contribute to the enhancement of SAR capabilities.

For Climatic forecast, there should be more focused improvements in data quality for marine weather forecasts, real-time seasonal ice forecasting, and efficient transmission between broadcasting points and vessels (Dawson, Copland, et al., 2017). Similar to SAR capabilities, the responsibility of the government in terms of Climatic forecast is to make the data updated and available. The investment cannot simply be limited to feeding more data but also on how to improve data quality and real-time update, and the transmission between broadcasting points and end-users (vessels, stations and so on). This investment is also enhanced when Communication infrastructure is improved.

In terms of Communication infrastructure, Dawson et al. (2017) called for improvement on charting, ice and weather data interpretation for better communication to end-users. Furthermore, Dawson et al. (2017) encouraged sharing of real-time, standardized meteorological and oceanic data among partners and relevant stakeholders. Improvements in Communication infrastructure may aim at fortifying signal strength, bolstering stability, and enhancing resilience. Potential strategies may include the installation of satellite telecommunications systems, the construction of additional broadcasting stations, and investments in the broader telecommunications infrastructure, such as bringing better broadband infrastructure to Northern communities, include both fiber-optic cables and LEO (Low Earth Orbit) satellites to help alleviate traffic and bandwidth limitations (NTI, 2020).

Regarding Refuge port, Dawson et al. (2017) proposed investment in at least one deep-water port, a system of shallow water ports, docking and other basic port infrastructure to facilitate marine access in Canadian North (Dawson, Copland, et al., 2017).

Refuge port can be considered one of the most appealing investments, since it can bring immediate, apparent change to the shipping landscape in Canadian Arctic. When this thesis idea was first developed in 2021, there was no operational deep-water port in the Canadian Arctic waters, the most well developed was the deep-water port project plan in Iqaluit that is supposed to operate in summer 2023. Eventually, in July 2023, the Government of Nunuvat announced the official opening of Iqaluit Deep Sea Port. It cost \$84.9 million, of which the federal contribution represents 75 per cent and the Government of Nunavut provided the remaining \$21.2 million. The project entailed the construction of a deep-sea port with the capacity to accommodate cargo shipments, facilitate fuel storage, and provide docking facilities for Canadian Coast Guard vessels. As introduced in the press release for the opening of the Iqaluit port, the facilities "feature a dredged fixed dock mooring space, cargo laydown area, barge ramp, and a fuel manifold. Additional improvements were made to small craft marine facilities by providing an additional breakwater, floating dock infrastructure, and all tide boat launching facilities." (Department of Economic Development and Transportation, 2023, p.2)

Finally, for Legal stand, Dawson et al. (2017) emphasized the mandatory traversal reports for all commercial vessels and non-local pleasure craft through the Canadian Coast Guard's NORDREG vessel registry system, aiming to monitor vessel traffic (Dawson, Copland, et al., 2017). As mentioned in Section 2.4.4, Article 234 in UNCLOS and the UNDRIP – Polar Code's mobilities commitments might hold the key to provide guidelines to address complex, evolving marine issues. In straight-forward terms, Canada could adopt a more aggressive approach in advocating for the comprehensive understanding and rigorous enforcement of Article 234 (in the UNCLOS). Furthermore, Canada could consider the formal incorporation, with legal provisions and associated ramifications, of integrating UNDRIP and the Polar Code's commitment into its legal framework.

5. Conclusion

Global warming has led to a decline in Arctic sea ice, which has created the potential for increased access to energy and mineral resources and the opening of new shipping routes through the Arctic. As a result, the increased shipping activity in the Arctic is a well-documented trend supported by various indicators throughout the literature. Within the scope of this thesis, the investigation of this trend has been conducted through the examination of three key indicators: the number of trips counted, the number of unique ships counted, and the volume of ballast water as a byproduct discharge of shipping activities. The combination of these three indicators confirms a rising trend in Arctic shipping activities.

The thesis also examined a multitude of literature works on shipping history of the NWP, spanning over a century (1906 – 2022). The findings demonstrated an upward trajectory across three key dimensions within the NWP: temporal trends in shipping activities, the dominance of Canada-registered vessels utilized for domestic transit, and the prevalence of international flag-bearing ships for international transit.

The navigation on the NWP poses considerably greater challenges compared to the NSR; therefore, the transit records through quantity (trip counts and ship types) and quality (transit volume) analysis conclude that the NWP exhibits a lesser degree of traffic in comparison to the NSR. The literature review endorsed that the NSR is more viable than the NWP in the short term, owing to three main attributes: the stability and predictability of sea-ice dynamics on the NSR, the availability of port infrastructure and maritime services and the existence of comprehensive insurance policies specifically tailored to NSR voyages. The NWP, in contrast, confronts numerous systemic challenges for traffic development, including the constantly changing nature of sea ice on the NWP, the complex geographic nature of the Canadian Arctic Archipelago, with the severely insufficient port and maritime infrastructure. However, the prospect for significant enhancements remains promising, through various federal and local policies to facilitate and drive additional traffic on the NWP in the long run.

The literature review and analysis on the commercial viability of the NWP conducted in this thesis yielded a diverse array of conclusions, comprising both positive and negative results, on the subject whether it is beneficial for shipping firms to use the NWP compared with traditional maritime routes. Consequently, the thesis extrapolates three key observations from the comprehensive analysis of the literature review: 1) While the NWP proves to be a profitable option for summer transit, its feasibility for year-round transit remains arguable; 2) The NWP exhibits a high degree of replaceability with the Suez Canal route for Asia – Europe transit; 3) In contrast to traditional beliefs, the Panama Canal route remains the preferred option for transit from Asia to the East Coast of North America, surpassing the utilization of the NWP.

An additional noteworthy finding derived from this thesis is that there was a significant negative correlation between sea-ice concentration and shipping activity in the Canadian Arctic (Pizzolato et al. 2014, 2016). Contrary to prevailing thinking that the continuous reduction of sea ice would serve as the primary momentum for enhancing accessibility to Arctic maritime shipping activities, the thesis endorses the literature stand that sea ice retreat merely acts as an enabler for the expansion of shipping activity in Canadian Arctic. Multiple scholarly works corroborate the fact that external factors including economic activities, solid regulatory framework, shipping lines' interest and infrastructure developments wield greater influence over shipping activity than the sea ice trend. Therefore, this thesis endeavors to highlight the existing gap in the literature with respect to which strategic investments are required to be made and how they should be prioritized, by the Canadian government, to facilitate navigation in the NWP and support maritime traffic development in the Canadian Arctic.

The AHP, as the methodology chosen for the studies, facilitates the establishment of a prioritized sequence for criteria, thereby enabling the formulation of recommendations to policymakers based on the criticality and urgency of each criterion's significance. AHP allows for the modulation of the problem, thereby enabling the consolidation of qualitative data through a concise methodology. Moreover, it offers an impartial evaluation platform through the utilization of pairwise comparisons and scoring techniques. AHP represents a sophisticated analytical approach that may pose challenges for individuals unfamiliar with its intricacies. The successful implementation of this methodology necessitates an exploration of relevant literature to comprehend its operational requirements. The methodology requires the participation of a dedicated pool of knowledgeable individuals possessing a strong background in the subject and familiar with the process itself. Furthermore, the model analyst must devise an extensive questionnaire following a format with a substantial number of pairwise comparisons. This approach, however, can result in certain respondents exhibiting inconsistencies in their responses. Consequently, this would require the analyst to make adjustments when the inconsistency ratio exceeds 10% (this matter will be further discussed in the Limitation section). This raises concerns regarding the trade-off between upholding the integrity of the questions and meeting the technical requirements of the AHP model.

This study represents a pioneering effort in utilizing the AHP to provide ranking for different strategic investment criteria in the Canadian Arctic. The findings derived from the AHP analysis indicate that Crew capability holds the highest priority, as reflected by its superior weight. Subsequently, the Ice-class fleet occupies the second position, while SAR capability is ranked third. Both Climatic forecast and Communication infrastructure share equal weights and are placed fourth and fifth, respectively. Lastly, Legal stand is positioned at the lowest rank.

5.1 Limitations

This thesis is not without limitations, which are important to acknowledge and consider during the interpretation of the findings. The author observed three limitations regarding the methodology and two limitations regarding the execution of the thesis.

The first limitation lies in the design stage of the model. The structure of the problem once analysed and constructed cannot be modified afterwards, potentially limiting the flexibility of the AHP methodology in certain scenarios. The selection and establishment of the criteria for analysis were solely determined by the author and must be set up prior to approaching the respondents. While the author sought the evaluation of the set of investment criteria from three professors and one expert (See Section 3.1), it remains unclear whether the respondents concurred with these criteria, unless explicitly stated. The existence of unexpressed disagreements may have potentially contributed to the notable rate of non-response observed during the data collection phase.

Secondly, it was decided to restrict the number of candidates to a maximum of eight respondents (Saaty and Özdemir, 2014). The existing literature acknowledges that there are no fixed rules governing the necessary sample size for studies employing the AHP model, as a large sample size can potentially introduce higher inconsistency (Cheng and Li 2002; Thanki et al. 2016; Wong and Li 2008). Nevertheless, it is worth noting that numerous papers utilizing the AHP model have used relatively large sample sizes, as demonstrated by studies involving 264 participants (Lee and Hwang, 2010), 70 professionals in Song and Yeo (2004) and 26 experts in Tseng & Yip (2021). These numbers represented the initial sample size, excluding unqualified or non-response inputs.

Furthermore, the implementation of the AHP model itself presents challenges. The means of delivery, the use of long questionnaires to administer the AHP could introduce variability in the responses (Soma, 2003). The number of pairwise comparisons in the questionnaires can also be extensive and time-consuming for both the respondents and the model analyst. The number of pairwise comparisons is contingent upon the levels within the AHP model, as well as the number of criteria, sub-criteria, and candidates. Fortunately, the questionnaire design necessitated only 21 pairwise comparisons, corresponding to 21 questions. Based on our estimation, respondents were expected to spend a maximum of 20 minutes completing the questionnaire. However, it is important to note that in future research, if the model analyst decides to incorporate additional sub-levels and candidates into the model, the number of pairwise comparisons will substantially increase. Consequently, respondents who lack familiarity with the AHP methodology may encounter greater difficulties in providing consistent inputs for the questionnaire.

Lastly, an inherent limitation in the AHP methodology is the issue of consistency in respondents' input. To address this, respondents are advised to adjust their responses in case of inconsistency. However, ensuring complete consistency across all respondents may be challenging and may introduce some level of subjectivity or inconsistency in the final results. The author's inclination would be to maintain the original responses rather than requesting the respondents to alter their answers to match the consistency ratio.

On the other hand, there are two limitations that are distinctive about this thesis, namely the lack of the Inuit representation in the respondents and the lack of consideration of difficulties and external impact in conducting these investment criteria. Despite diligent efforts to establish connections and engage with Inuit representatives during the data collection process, the government group involved in the study still ended up lacking representation from the Inuit community. The absence of Inuit voice could hinder the validity of the study's findings, as the perspectives and insights of this crucial stakeholder group may not have been fully incorporated.

Secondly, the investment analysis conducted in the study may not have adequately accounted for feasibility and the practical difficulties associated with executing the proposed investment strategies. While the investment criteria and recommendations may seem promising on paper, real-world implementation could encounter various challenges. Factors such as resource constraints, logistical complexities, regulatory hurdles, and technological limitations might affect the feasibility of executing the proposed investment plans. Additionally, external factors beyond the scope of the study, such as economic fluctuations, market conditions, or geopolitical dynamics, could significantly impact the success and outcomes of the investment initiatives.

5.2 Future research

Future research could focus on addressing several issues based on the results of this thesis. Future studies can consider integrating the AHP with the Delphi method, especially during the stage of criteria identification like in Lirn et al. (2004); Rosa Pires Da Cruz et al. (2013); Teng et al. (2020); Tseng & Yip (2021); thereby, combining the strengths of both approaches. This combination would enable the inclusion of expert opinions and facilitate consensus-building among participants and the model analyst; thus, leading to a more harmonious process and reliable results.

The result from this study holds the potential to serve as weighted criteria for future decision-making models concerning Canadian Arctic shipping. These models can address various potential research questions covering various aspects such as infrastructure development, sovereignty, economic contribution, environmental and cultural impacts, and other related areas of research.

Furthermore, it would be interesting to repeat the models to examine the stability and consistency of the obtained results over an extended period of time. By reiterating the analysis at different time periods, researchers can evaluate whether the respondents consider the relative importance of the criteria to change or remain the same.

The findings of this study have significant managerial implications for policy makers. By considering the ranking of investment criteria generated through this research, policy makers can identify both short-term and long-term areas of focus. Lower-ranking investments should not be interpreted as a call for inaction and higher-ranking favors immediate intervention. Instead, lower-ranking criteria suggest a relatively lower priority compared to higher-ranking investments. Understanding the prioritization of investment criteria allows policy makers to allocate resources and efforts strategically. This prioritization helps in resource allocation, decision-making, and the development of action plans that align with the identified short-term and long-term goals. The ranking of investment criteria from this study hopefully will provide valuable reference for policy makers in allocating resources and formulating action plans that align with the identified short-term and long-term priorities, facilitating a holistic and effective approach to investment decision-making.

Bibliography

Afenyo, Mawuli, Yufeng Lin, Adolf K. Y. Ng, and Changming Jiang. 2020. "The Opportunities and Challenges of Developing the Arctic Area and Shipping in Canada." Pp. 216–26 in *Arctic Shipping: Climate Change, Commercial Traffic And Port Development*, *Routledge studies in transport analysis*, edited by F. Lasserre and O. Faury. Lodi ; New York: Routledge, Taylor & Francis Group.

Aporta, Claudio. 2009. "The Trail as Home: Inuit and Their Pan-Arctic Network of Routes." *Human Ecology* 37(2):131–46. doi: 10.1007/s10745-009-9213-x.

Aporta, Claudio, Stephanie C. Kane, and Aldo Chircop. 2018. "Shipping Corridors through the Inuit Homeland." *Limm Issue #10*.

Aras, Haydar, Şenol Erdoğmuş, and Eylem Koç. 2004. "Multi-Criteria Selection for a Wind Observation Station Location Using Analytic Hierarchy Process." *Renewable Energy* 29(8):1383–92. doi: 10.1016/j.renene.2003.12.020.

Arctic Council. 2009. *Arctic Marine Shipping Assessment 2009 Report*. Arctic Council.

Arzel, Olivier, Thierry Fichefet, and Hugues Goosse. 2006. "Sea Ice Evolution over the 20th and 21st Centuries as Simulated by Current AOGCMs." *Ocean Modelling* 12(3–4):401–15. doi: 10.1016/j.ocemod.2005.08.002.

Atthirawong, Walailak, and Bart MacCarthy. 2002. "An Application of the Analytical Hierarchy Process to International Location Decision-Making." *The 7th Annual Cambridge International Manufacturing Symposium: Restructuring Global Manufacturing* 1–18.

Badri, Masood A. 1999. "Combining the Analytic Hierarchy Process and Goal Programming for Global Facility Location-Allocation Problem." *International Journal of Production Economics* 62(3):237–48. doi: 10.1016/S0925-5273(98)00249-7.

Bartenstein, Kristin. 2011. "The 'Arctic Exception' in the Law of the Sea Convention: A Contribution to Safer Navigation in the Northwest Passage?" *Ocean Development & International Law* 42(1–2):22–52. doi: 10.1080/00908320.2011.542104.

Bell, Jim. 2017. "Bye, Bye BIPR: Nunavut Port-Road Scheme Still Frozen." *Nunatsiaq News*, January 9.

Benz, Lukas, Christopher Münch, and Evi Hartmann. 2021. "Development of a Search and Rescue Framework for Maritime Freight Shipping in the Arctic." *Transportation Research Part A: Policy and Practice* 152:54–69. doi: 10.1016/j.tra.2021.07.006.

Bobylev, Leonid P., K. I͡A Kondrat′ev, and Ola M. Johannessen, eds. 2003. *Arctic Environment Variability in the Context of Global Change*. Berlin ; New York : Chichester, UK: Springer ; Praxis Pub.

Borgerson, Scott G. 2008. "Arctic Meltdown - The Economic and Security Implications of Global Warming." *Foreign Affairs* 87(2):63–77.

Boult, David A. 2004. *Hunger in the Arctic: Food (In)Security in Inuit Communities - A Discussion Paper*. Ajunnginiq Centre - National Aboriginal Health Organization (NAHO).

Bourbonnais, Pascale, and Frederic Lasserre. 2015. "Winter Shipping in the Canadian Arctic: Toward Year-Round Traffic?" *Polar Geography* 38(1):70–88. doi: 10.1080/1088937X.2015.1006298.

Boylan, Brandon M. 2021. "Increased Maritime Traffic in the Arctic: Implications for Governance of Arctic Sea Routes." *Marine Policy* 131:104566. doi: 10.1016/j.marpol.2021.104566.

Buixadé Farré, Albert, Scott R. Stephenson, Linling Chen, Michael Czub, Ying Dai, Denis Demchev, Yaroslav Efimov, Piotr Graczyk, Henrik Grythe, Kathrin Keil, Niku Kivekäs, Naresh Kumar, Nengye Liu, Igor Matelenok, Mari Myksvoll, Derek O'Leary, Julia Olsen, Sachin Pavithran.A.P., Edward Petersen, Andreas Raspotnik, Ivan Ryzhov, Jan Solski, Lingling Suo, Caroline Troein, Vilena Valeeva, Jaap van Rijckevorsel, and Jonathan Wighting. 2014. "Commercial Arctic Shipping through the Northeast Passage: Routes, Resources, Governance, Technology, and Infrastructure." *Polar Geography* 37(4):298–324. doi: 10.1080/1088937X.2014.965769.

Byers, Michael, and Nicole Covey. 2019. "Arctic SAR and the 'Security Dilemma.'" *International Journal: Canada's Journal of Global Policy Analysis* 74(4):499–517. doi: 10.1177/0020702019890339.

CASA. 2007. *Canadian Arctic Shipping Assessment, Main Report*. *Prepared for Transport Canada*. The Mariport Group Ltd.

Chan, Farrah T., Sarah A. Bailey, Chris J. Wiley, and Hugh J. MacIsaac. 2013. "Relative Risk Assessment for Ballast-Mediated Invasions at Canadian Arctic Ports." *Biological Invasions* 15(2):295–308. doi: 10.1007/s10530-012-0284-z.

Cheng, Eddie W. L., and Heng Li. 2001. "Information Priority-setting for Better Resource Allocation Using Analytic Hierarchy Process (AHP)." *Information Management & Computer Security* 9(2):61–70. doi: 10.1108/09685220110388827.

Cheng, Eddie W. L., and Heng Li. 2002. "Construction Partnering Process and Associated Critical Success Factors: Quantitative Investigation." *Journal of Management in Engineering* 18(4):194–202. doi: 10.1061/(ASCE)0742-597X(2002)18:4(194).

CNW. 2017. "OmniTRAX Announces Indefinite Closure of the Hudson Bay Railway from Amery to Churchill." June 9.

Coates, Ken, and Greg Poelzer. 2010. *On the Front Lines of Canada's Northern Strategy*. Saskatoon, Saskatchewan: Federation of Canadian Municipalities.

Comiso, Josefino C. 2002. "A Rapidly Declining Perennial Sea Ice Cover in the Arctic: A RAPIDLY DECLINING PERENNIAL ICE." *Geophysical Research Letters* 29(20):17-1-17–4. doi: 10.1029/2002GL015650.

Cox, Anna M., Jeffrey Alwang, and Thomas G. Johnson. 2000. "Local Preferences for Economic Development Outcomes: Analytical Hierarchy Procedure." *Growth and Change* 31(3):341–66. doi: 10.1111/0017-4815.00132.

Crocker, Greg, Katherine Wilson, and Steve McCourt. 2002. *Analysis of the Canadian Ice Service Digital Charts Database for Ice Climate Trends in Canadian Waters*. *Contract report for Canadian Ice Service, Environment Canada*. Number 01-04. Ballicater Consulting Ltd.

Dalaklis, Dimitrios, Megan L. Drewniak, and Jens-Uwe Schröder-Hinrichs. 2018. "Shipping Operations Support in the 'High North': Examining Availability of Icebreakers along the Northern Sea Route." *WMU Journal of Maritime Affairs* 17(2):129–47. doi: 10.1007/s13437-018-0142-7.

Dawson, J., M. E. Johnston, and E. J. Stewart. 2014. "Governance of Arctic Expedition Cruise Ships in a Time of Rapid Environmental and Economic Change." *Ocean & Coastal Management* 89:88–99. doi: 10.1016/j.ocecoaman.2013.12.005.

Dawson, Jackie, Luke Copland, Magaret Johnston, Larissa Pizzolato, Steve Howell, Ron Pelot, Laurent Etienne, Lindsay Matthews, and Jim Parsons. 2017. *Climate Change Adaptation Strategies and Policy Options for Arctic Shipping. A report prepared for Transport Canada.* Ottawa, Canada: Transport Canada.

Derksen, C., S. L. Smith, M. Sharp, L. Brown, S. Howell, L. Copland, D. R. Mueller, Y. Gauthier, C. G. Fletcher, A. Tivy, M. Bernier, J. Bourgeois, R. Brown, C. R. Burn, C. Duguay, P. Kushner, A. Langlois, A. G. Lewkowicz, A. Royer, and A. Walker. 2012. "Variability and Change in the Canadian Cryosphere." *Climatic Change* 115(1):59–88. doi: 10.1007/s10584-012-0470-0.

Dvorak, Robert Ernest. 2009. "Engineering and Economic Implications of Ice-Classed Containerships." Graduate Theses, Massachusetts Institute of Technology, United States.

Eger, K. M. 2010. "Canadian Ports on the Northwest Passage." *CHNL*. Retrieved from (http://www.arctis-search.com/Canadian+Ports+on+the+Northwest+Passage).

Eguíluz, Victor M., Juan Fernández-Gracia, Xabier Irigoien, and Carlos M. Duarte. 2016. "A Quantitative Assessment of Arctic Shipping in 2010–2014." *Scientific Reports* 6(1):30682. doi: 10.1038/srep30682.

Endresen, Øyvind, Hanna Lee Behrens, Sigrid Brynestad, Aage Bjørn Andersen, and Rolf Skjong. 2004. "Challenges in Global Ballast Water Management." *Marine Pollution Bulletin* 48(7–8):615–23. doi: 10.1016/j.marpolbul.2004.01.016.

Engler, Cecilia, and Ronald Pelot. 2013. *Analysis of Marine Traffic Along Canada's Coasts: Factors Influencing Arctic Traffic. Contractor Report*. DRDC CORA CR 2013-065. Ottawa: Defence R&D Canada Centre for Operational Research & Analysis.

Falkingham, John C., Richard Chagnon, and Steve McCourt. 2001. *Sea Ice in the Canadian Arctic in the 21st Century*. Ottawa , Canada: Port and Ocean Engineering under Arctic Conditions (POAC).

Fan, Lei, William W. Wilson, and Bruce Dahl. 2012. "Impacts of New Routes and Ports on Spatial Competition for Containerized Imports into the United States." *Maritime Policy & Management* 39(5):479–501. doi: 10.1080/03088839.2012.705027.

Fan, Lei, William W. Wilson, and Bruce Dahl. 2015. "Risk Analysis in Port Competition for Containerized Imports." *European Journal of Operational Research* 245(3):743–53. doi: 10.1016/j.ejor.2015.03.051.

Farahani, Reza Zanjirani, Maryam SteadieSeifi, and Nasrin Asgari. 2010. "Multiple Criteria Facility Location Problems: A Survey." *Applied Mathematical Modelling* 34(7):1689–1709. doi: 10.1016/j.apm.2009.10.005.

Flato, G. M., and G. J. Boer. 2001. "Warming Asymmetry in Climate Change Simulations." *Geophysical Research Letters* 28(1):195–98. doi: 10.1029/2000GL012121.

Ford, J., and D. Clark. 2019. "Preparing for the Impacts of Climate Change along Canada's Arctic Coast: The Importance of Search and Rescue." *Marine Policy* 108:103662. doi: 10.1016/j.marpol.2019.103662.

Giguère, Marie-Andrée, Claude Comtois, and Brian Slack. 2017. "Constraints on Canadian Arctic Maritime Connections." *Case Studies on Transport Policy* 5(2):355–66. doi: 10.1016/j.cstp.2017.03.004.

Goepel, Klaus D. 2018. "Implementation of an Online Software Tool for the Analytic Hierarchy Process (AHP-OS)." *International Journal of the Analytic Hierarchy Process* 10(3). doi: 10.13033/ijahp.v10i3.590.

Government of Canada. 2019. *Canada's Arctic and Northern Policy Framework*. Ottawa: Government of Canada.

Government of Canada. 2022a. "Ballast Water Management of Ships: International Convention."

Government of Canada. 2022b. "Investments Supporting the Arctic and Northern Policy Framework."

Government of Canada. n.d. "Canadian Geographical Names Database."

Government of the Northwest Territories. 2011. *On Track - Status, Challenges, and Current Initiatives of the Department of Transportation*. Northwest Territories - Department of Transportation.

Greco, Salvatore, Matthias Ehrgott, and José Rui Figueira, eds. 2016. "Ten Years of Success of Multiple Criteria Decision Analysis and Reasons for This New Edition." Pp. xix–xx in *Multiple Criteria Decision Analysis: State of the Art Surveys*. Vol. 233, *International Series in Operations Research & Management Science*. New York, NY: Springer New York.

Griffiths, Franklyn. 2005. "New Illusions of a Northwest Passage." Pp. 303–19 in *International Energy Policy, the Arctic and the Law of the Sea*. Brill | Nijhoff.

Gunnarsson, Bjørn. 2016. "Future Development of the Northern Sea Route." February 18, 2016.

Gunnarsson, Björn. 2021. "Recent Ship Traffic and Developing Shipping Trends on the Northern Sea Route—Policy Implications for Future Arctic Shipping." *Marine Policy* 124:104369. doi: 10.1016/j.marpol.2020.104369.

Guy, Emmanuel. 2006. "Evaluating the Viability of Commercial Shipping in the Northwest Passage." *Journal of Ocean Technology* 1(1):9–18.

Guy, Emmanuel, and Frédéric Lasserre. 2016. "Commercial Shipping in the Arctic: New Perspectives, Challenges and Regulations." *Polar Record* 52(3):294–304. doi: 10.1017/S0032247415001011.

Guy, Emmanuel, and Bruno Urli. 2006. "Port Selection and Multicriteria Analysis: An Application to the Montreal-New York Alternative." *Maritime Economics & Logistics* 8(2):169–86. doi: 10.1057/palgrave.mel.9100152.

Hansen, Carsten Ørts, Peter Grønsedt, Christian Lindstrøm Graversen, Christian Hendricksen, and D. C.). Arctic Institute (Washington. 2016. *Arctic Shipping: Commercial Opportunities and Challenges*.

Hassol, Susan Joy. 2004. *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*. Cambridge, U.K. ; New York, N.Y: Cambridge University Press.

Headland, R. K. 2010. "Ten Decades of Transits of the Northwest Passage." *Polar Geography* 33(1–2):1–13. doi: 10.1080/1088937X.2010.492105.

Headland, R. K. 2022. "Transits Of The Northwest Passage To End Of The 2022 Navigation Season." *Polar Information Sheets*. Retrieved November 29, 2022 (https://www.spri.cam.ac.uk/resources/infosheets/).

Heleniak, Timothy. 2021. "The Future of the Arctic Populations." *Polar Geography* 44(2):136–52. doi: 10.1080/1088937X.2019.1707316.

Hoegh-Guldberg, Ove, and John F. Bruno. 2010. "The Impact of Climate Change on the World's Marine Ecosystems." *Science* 328(5985):1523–28. doi: 10.1126/science.1189930.

Holbech, Henrik, and Knud Ladegaard Pedersen. 2018. "Ballast Water and Invasive Species in the Arctic." Pp. 115–37 in *Arctic Marine Resource Governance and Development*, *Springer Polar Sciences*, edited by N. Vestergaard, B. A. Kaiser, L. Fernandez, and J. Nymand Larsen. Cham: Springer International Publishing.

Honderich, John. 1987. *Arctic Imperative: Is Canada Losing the North?* Toronto ; Buffalo: University of Toronto Press.

Howell, S. E. L., and J. J. Yackel. 2004. "A Vessel Transit Assessment of Sea Ice Variability in the Western Arctic, 1969–2002: Implications for Ship Navigation." *Canadian Journal of Remote Sensing* 30(2):205–15. doi: 10.5589/m03-062.

Hreinsson, Hjalti. 2020. *The Increase In Arctic Shipping 2013-2019 - Arctic Shipping Status Report (ASSR) #1*. Arctic Council.

Hreinsson, Hjalti. 2021. *Shipping In The Northwest Passage: Comparing 2013 With 2019 - Arctic Shipping Status Report (ASSR) #3*. Arctic Council.

Huebert, Rob. 2011. "Climate Change and Canadian Sovereignty in the Northwest Passage." *Canadian Arctic Sovereignty and Security: Historical Perspectives* (No. 4 (2011): Canadian Arctic Sovereignty and Security: Historical Perspectives):383–99.

IMO. 2016. "Ballast Water Management."

IMO. 2017. "Milestone for Polar Protection as Comprehensive New Ship Regulations Come into Force."

IMO. 2019. "Implementing the Ballast Water Management Convention - IMO Frequently Asked Questions." Retrieved (https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/FAQ%20-%20Implementing%20the%20Ballast%20Water%20Management%20Convention.pdf).

IPCC. 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.

Department of Economic Development and Transportation. 2023. *Iqaluit Deep Sea Port Officially Opens*. Iqaluit, Nunavut.

Ircha, Michael C., and John Higginbotham. 2016. "Canada's Arctic Shipping Challenge: Towards a Twenty- First Century Northwest Passage." Pp. 232–45 in *Climate Change and Adaptation Planning for Ports*, *Routledge studies in Transport Analysis*. New York: Routledge.

Jensen, Øystein. 2007. *The IMO Guidelines for Ships Operating in Arctic Ice-Covered Waters: From Voluntary to Mandatory Tool for Navigation Safety and Environmental Protection?* FNI-rapport 2/2007. The Fridtjof Nansen Institute.

Jing, Liang, Bing Chen, Baiyu Zhang, and Hongxuan Peng. 2012. "A Review of Ballast Water Management Practices and Challenges in Harsh and Arctic Environments." *Environmental Reviews* 20(2):83–108. doi: 10.1139/a2012-002.

Kasirian, M. N., and R. M. Yusuff. 2013. "An Integration of a Hybrid Modified TOPSIS with a PGP Model for the Supplier Selection with Interdependent Criteria." *International Journal of Production Research* 51(4):1037–54. doi: 10.1080/00207543.2012.663107.

Kenney, Gerard. 2013. "Henry Larsen and the St. Roch." *The Canadien Encyclopedia*.

Khon, V. Ch., and I. I. Mokhov. 2010. "Arctic Climate Changes and Possible Conditions of Arctic Navigation in the 21st Century." *Izvestiya, Atmospheric and Oceanic Physics* 46(1):14–20. doi: 10.1134/S0001433810010032.

Lajeunesse, Adam. 2012. “A New Mediterranean? Arctic Shipping Prospects for the 21st Century.” *Journal of Maritime Law & Commerce* 43(4):521–37.
Lalonde, Suzanne, and Frédéric Lasserre. 2013. “The Position of the United States on the Northwest Passage: Is the Fear of Creating a Precedent Warranted?” *Ocean Development & International Law* 44(1):28–72. doi: 10.1080/00908320.2012.726832.
Lasserre, Frédéric. 2014. “Case Studies of Shipping along Arctic Routes. Analysis and Profitability Perspectives for the Container Sector.” *Transportation Research Part A: Policy and Practice* 66:144–61. doi: 10.1016/j.tra.2014.05.005.
Lasserre, Frédéric. 2015. “Simulations of Shipping along Arctic Routes: Comparison, Analysis and Economic Perspectives.” *Polar Record* 51(3):239–59. doi: 10.1017/S0032247413000958.
Lasserre, Frédéric. 2022. “Canadian Arctic Marine Transportation Issues, Opportunities and Challenges.” *The School of Public Policy Publications* 15(6). doi: http://dx.doi.org/10.11575/sppp.v15i1.72626.
Lasserre, Frédéric, Leah Beveridge, Mélanie Fournier, Pierre-Louis Têtu, and Linyan Huang. 2016. “Polar Seaways? Maritime Transport in the Arctic: An Analysis of Shipowners’ Intentions II.” *Journal of Transport Geography* 57:105–14. doi: 10.1016/j.jtrangeo.2016.10.004.
Lasserre, Frédéric, and Olivier Faury, eds. 2021. *Arctic Shipping: Climate Change, Commercial Traffic and Port Development*. First issued in paperback. London New York: Routledge.
Lasserre, Frédéric, Qiang Meng, Chuanbei Zhou, Pierre-Louis Têtu, and Olga Alexeeva. 2019. “Compared Transit Traffic Analysis along the NSR and the NWP.” in *Arctic Shipping: Climate Change, Commercial Traffic and Port Development*, *Routledge studies in transport analysis*. Routledge.
Lasserre, Frédéric, and Sébastien Pelletier. 2011. “Polar Super Seaways? Maritime Transport in the Arctic: An Analysis of Shipowners’ Intentions.” *Journal of Transport Geography* 19(6):1465–73. doi: 10.1016/j.jtrangeo.2011.08.006.
Lavissière, Alexandre, Romain Sohier, and Mary C. Lavissière. 2020. “Transportation Systems in the Arctic: A Systematic Literature Review Using Textometry.” *Transportation Research Part A: Policy and Practice* 141:130–46. doi: 10.1016/j.tra.2020.09.003.
Lee, Deok Joo, and Jooho Hwang. 2010. “Decision Support for Selecting Exportable Nuclear Technology Using the Analytic Hierarchy Process: A Korean Case.” *Energy Policy* 38(1):161–67. doi: 10.1016/j.enpol.2009.08.069.
Lirn, T. C., H. A. Thanopoulou, M. J. Beynon, and A. K. C. Beresford. 2004. “An Application of AHP on Transhipment Port Selection: A Global Perspective.” *Maritime Economics & Logistics* 6(1):70–91. doi: 10.1057/palgrave.mel.9100093.
Liu, Miaojia, and Jacob Kronbak. 2010. “The Potential Economic Viability of Using the Northern Sea Route (NSR) as an Alternative Route between Asia and Europe.” *Journal of Transport Geography* 18(3):434–44. doi: 10.1016/j.jtrangeo.2009.08.004.
Lu, Dongqin, Gyei-Kark Park, Kyounghoon Choi, and Sangjin Oh. 2014. “An Economic Analysis of Container Shipping Through Canadian Northwest Passage.” *International Journal of E-Navigation and Maritime Economy* 1:60–72. doi: 10.1016/j.enavi.2014.12.001.

Marsh, James H. 2013. "Roald Amundsen Crosses the Northwest Passage." *The Canadien Encyclopedia*.
Marsh, William M., and Martin M. Kaufman. 2013. *Physical Geography: Great Systems and Global Environments*. Cambridge ; New York: Cambridge University Press.
Maurette, Fred. 2010. *Rate, Impact and Scope of Climate Change in the Canadian Arctic. Synthesis Report*. DRDC CORA CR 2010–190.
Meng, Qiang, Yiru Zhang, and Min Xu. 2017. "Viability of Transarctic Shipping Routes: A Literature Review from the Navigational and Commercial Perspectives." *Maritime Policy & Management* 44(1):16–41. doi: 10.1080/03088839.2016.1231428.
Mikkola, Harri, and Juha Käpylä. 2013. "Arctic Economic Potential: The Need for a Comprehensive and Risk-Aware Understanding of Arctic Dynamics." (Finnish Institute of International Affairs (FIIA) briefing paper).
Moe, Arild. 2014. "The Northern Sea Route: Smooth Sailing Ahead?" *Strategic Analysis* 38(6):784–802. doi: 10.1080/09700161.2014.952940.
Mussells, Olivia, Jackie Dawson, and Stephen Howell. 2017. "Navigating Pressured Ice: Risks and Hazards for Winter Resource-Based Shipping in the Canadian Arctic." *Ocean & Coastal Management* 137:57–67. doi: 10.1016/j.ocecoaman.2016.12.010.
Nabulsi, Mira. 2022. "A TikToker Reveals How Expensive Groceries Are In Nunavut & It Puts Toronto's Prices To Shame." December 9.
National Round Table on the Environment and the Economy (Canada), ed. 2009. *True North: Adapting Infrastructure to Climate Change in Canada's North*. Ottawa: National Round Table on the Environment and the Economy.
Nir, An-Shuen, Kuang Lin, and Gin-Shuh Liang. 2003. "Port Choice Behaviour--from the Perspective of the Shipper." *Maritime Policy & Management* 30(2):165–73. doi: 10.1080/0308883032000069262.
NSIDC. 2022. *Monthly Archives: October 2022*. National Snow & Ice Data Center.
Ocean Conservancy. 2017. *Navigating the North: An Assessment of the Environmental Risks of Arctic Vessel Traffic*. Anchorage, AK.
Opasanon, Sathaporn, and Pattarakamol Lertsanti. 2013. "Impact Analysis of Logistics Facility Relocation Using the Analytic Hierarchy Process (AHP)." *International Transactions in Operational Research* 20(3):325–39. doi: 10.1111/itor.12002.
Østreng, Willy, Karl Magnus Eger, Brit Fløistad, Arnfinn Jørgensen-Dahl, Lars Lothe, Morten Mejlænder-Larsen, and Tor Wergeland. 2013a. "Shipping and Arctic Infrastructure." Pp. 177–239 in *Shipping in Arctic Waters*. Berlin, Heidelberg: Springer Berlin Heidelberg.
Østreng, Willy, Karl Magnus Eger, Brit Fløistad, Arnfinn Jørgensen-Dahl, Lars Lothe, Morten Mejlænder-Larsen, and Tor Wergeland. 2013b. "The Northeast, Northwest and Transpolar Passages in Comparison." Pp. 299–353 in *Shipping in Arctic Waters*. Berlin, Heidelberg: Springer Berlin Heidelberg.
Pahl, Julia, and Brooks A. Kaiser. 2018. "Arctic Port Development." Pp. 139–84 in *Arctic Marine Resource Governance and Development*, *Springer Polar Sciences*, edited by N. Vestergaard, B. A. Kaiser, L. Fernandez, and J. Nymand Larsen. Cham: Springer International Publishing.
Parkinson, Claire L., Donald J. Cavalieri, Per Gloersen, H. Jay Zwally, and Josefino C. Comiso. 1999. "Arctic Sea Ice Extents, Areas, and Trends, 1978-1996." *Journal of Geophysical Research: Oceans* 104(C9):20837–56. doi: 10.1029/1999JC900082.

Paterson, Thomas. 2011.“Cost Comparison of Shipping in the Arctic.” Presented at the Arctic Shipping North America 2011, October, St. John’s.

Pelletier, Jeff. 2023. “Iqaluit’s New Deepsea Port Set to Finally Open.” *Nunatsiaq News*, July 24.

Pic, Pauline, Julie Babin, Frédéric Lasserre, Linyan Huang, and Kristin Bartenstein. 2021. “The Polar Code and Canada’s Regulations on Arctic Navigation: Shipping Companies’ Perceptions of the New Legal Environment.” *The Polar Journal* 11(1):95–117. doi: 10.1080/2154896X.2021.1889838.

Pizzolato, Larissa, Stephen E. L. Howell, Jackie Dawson, Frédéric Laliberté, and Luke Copland. 2016. “The Influence of Declining Sea Ice on Shipping Activity in the Canadian Arctic: SEA ICE AND SHIPPING, CANADIAN ARCTIC.” *Geophysical Research Letters* 43(23):12,146-12,154. doi: 10.1002/2016GL071489.

Pizzolato, Larissa, Stephen E. L. Howell, Chris Derksen, Jackie Dawson, and Luke Copland. 2014. “Changing Sea Ice Conditions and Marine Transportation Activity in Canadian Arctic Waters between 1990 and 2012.” *Climatic Change* 123(2):161–73. doi: 10.1007/s10584-013-1038-3.

Prowse, Terry D., Chris Furgal, Barrie R. Bonsal, and Thomas W. D. Edwards. 2009. “Climatic Conditions in Northern Canada: Past and Future.” *Springer* 38(No. 5):257-265 (9 pages).

Pullen, Thomas C., and Charles Swithinbank. 1991. “Transits of the Northwest Passage, 1906–90.” *Polar Record* 27(163):365–67. doi: 10.1017/S0032247400013164.

Rosa Pires Da Cruz, Maria, João J. Ferreira, and Susana Garrido Azevedo. 2013. “Key Factors of Seaport Competitiveness Based on the Stakeholder Perspective: An Analytic Hierarchy Process (AHP) Model.” *Maritime Economics & Logistics* 15(4):416–43. doi: 10.1057/mel.2013.14.

Rothwell, Donald R. 2012. “International Straits and Trans-Arctic Navigation.” *Ocean Development & International Law* 43(3):267–82. doi: 10.1080/00908320.2012.698924.

Saaty, Thomas L. 1985. “Decision Making for Leaders.” *IEEE Transactions on Systems, Man, and Cybernetics* SMC-15(3):450–52. doi: 10.1109/TSMC.1985.6313384.

Saaty, Thomas L. 1989. “Group Decision Making and the AHP.” Pp. 59–67 in *The Analytic Hierarchy Process*, edited by B. L. Golden, E. A. Wasil, and P. T. Harker. Berlin, Heidelberg: Springer Berlin Heidelberg.

Saaty, Thomas L. 1990. “How to Make a Decision: The Analytic Hierarchy Process.” *European Journal of Operational Research* 48(1):9–26. doi: 10.1016/0377-2217(90)90057-I.

Saaty, Thomas L. 1994. “How to Make a Decision: The Analytic Hierarchy Process.” *Interfaces* 24(6):19–43. doi: 10.1287/inte.24.6.19.

Saaty, Thomas L. 2008. “Decision Making with the Analytic Hierarchy Process.” *International Journal of Services Sciences* 1(1):83–98.

Saaty, Thomas L. 2013. “The Modern Science of Multicriteria Decision Making and Its Practical Applications: The AHP/ANP Approach.” *Operations Research* 61(5):1101–18. doi: 10.1287/opre.2013.1197.

Saaty, Thomas L., and Mujgan Sağır Özdemir. 2014. “How Many Judges Should There Be in a Group ?” *Annals of Data Science* 1(3–4):359–68. doi: 10.1007/s40745-014-0026-4.

Sarrabezoles, Aurélie, Frédéric Lasserre, and Zebret Hagouagn'rin. 2016. "Arctic Shipping Insurance: Towards a Harmonisation of Practices and Costs?" *Polar Record* 52(4):393–98. doi: 10.1017/S0032247414000552.

Scriven, Danielle R., Claudio DiBacco, Andrea Locke, and Thomas W. Therriault. 2015. "Ballast Water Management in Canada: A Historical Perspective and Implications for the Future." *Marine Policy* 59:121–33. doi: 10.1016/j.marpol.2015.05.014.

Serreze, Mark C., and Jennifer A. Francis. 2006. "The Arctic Amplification Debate." *Climatic Change* 76(3–4):241–64. doi: 10.1007/s10584-005-9017-y.

Serreze, Mark C., Marika M. Holland, and Julienne Stroeve. 2007. "Perspectives on the Arctic's Shrinking Sea-Ice Cover." *Science* 315(5818):1533–36. doi: 10.1126/science.1139426.

Snook, Jamie, Ashlee Cunsolo, and Robyn Morris. 2018. "A Half Century in the Making: Governing Commercial Fisheries Through Indigenous Marine Co-Management and the Torngat Joint Fisheries Board." Pp. 53–73 in *Arctic Marine Resource Governance and Development*, *Springer Polar Sciences*, edited by N. Vestergaard, B. A. Kaiser, L. Fernandez, and J. Nymand Larsen. Cham: Springer International Publishing.

Soma, Katrine. 2003. "How to Involve Stakeholders in Fisheries Management—a Country Case Study in Trinidad and Tobago." *Marine Policy* 27(1):47–58. doi: 10.1016/S0308-597X(02)00050-7.

Somanathan, Saran, Peter C. Flynn, and Jozef K. Szymanski. 2007. "Feasibility of a Sea Route through the Canadian Arctic." *Maritime Economics & Logistics* 9(4):324–34. doi: 10.1057/palgrave.mel.9100185.

Somanathan, Saran, Peter Flynn, and Jozef Szymanski. 2009. "The Northwest Passage: A Simulation." *Transportation Research Part A: Policy and Practice* 43(2):127–35. doi: 10.1016/j.tra.2008.08.001.

Song, Dong-Wook, and Ki-Tae Yeo. 2004. "A Competitive Analysis of Chinese Container Ports Using the Analytic Hierarchy Process." *Maritime Economics & Logistics* 6(1):34–52. doi: 10.1057/palgrave.mel.9100096.

Srinath, Badari Narayana. 2010. "Arctic Shipping: Commercial Viability of the Arctic Sea Routes." Master thesis, City University London - School of Engineering and Mathematical Science, London.

Statistics Canada. 2011. *Sea Ice Trends in Canada*.

Stephenson, Scott R., Laurence C. Smith, and John A. Agnew. 2011. "Divergent Long-Term Trajectories of Human Access to the Arctic." *Nature Climate Change* 1(3):156–60. doi: 10.1038/nclimate1120.

Stephenson, Scott R., Laurence C. Smith, Lawson W. Brigham, and John A. Agnew. 2013. "Projected 21st-Century Changes to Arctic Marine Access." *Climatic Change* 118(3–4):885–99. doi: 10.1007/s10584-012-0685-0.

Stewart, Emma J., Stephen Howell, Dianne Draper, John Yackel, and Adrienne Tivy. 2010. "Cruise Tourism in Arctic Canada: Navigating a Warming Climate." in *Tourism and change in polar regions: climate, environments and experiences*, *Routledge studies in contemporary geographies of leisure, tourism and mobility*. Milton Park, Abingdon, Oxon [England] ; New York: Routledge.

Stroeve, Julienne, Marika M. Holland, Walt Meier, Ted Scambos, and Mark Serreze. 2007. "Arctic Sea Ice Decline: Faster than Forecast: ARCTIC ICE LOSS-FASTER THAN FORECAST." *Geophysical Research Letters* 34(9). doi: 10.1029/2007GL029703.

Tavasszy, Lóránt, Michiel Minderhoud, Jean-François Perrin, and Theo Notteboom. 2011. "A Strategic Network Choice Model for Global Container Flows: Specification, Estimation and Application." *Journal of Transport Geography* 19(6):1163–72. doi: 10.1016/j.jtrangeo.2011.05.005.

Thanki, Shashank, Kannan Govindan, and Jitesh Thakkar. 2016. "An Investigation on Lean-Green Implementation Practices in Indian SMEs Using Analytical Hierarchy Process (AHP) Approach." *Journal of Cleaner Production* 135:284–98. doi: 10.1016/j.jclepro.2016.06.105.

Theocharis, Dimitrios, Stephen Pettit, Vasco Sanchez Rodrigues, and Jane Haider. 2018. "Arctic Shipping: A Systematic Literature Review of Comparative Studies." *Journal of Transport Geography* 69:112–28. doi: 10.1016/j.jtrangeo.2018.04.010.

Tivy, Adrienne, Stephen E. L. Howell, Bea Alt, Steve McCourt, Richard Chagnon, Greg Crocker, Tom Carrieres, and John J. Yackel. 2011. "Correction to 'Trends and Variability in Summer Sea Ice Cover in the Canadian Arctic Based on the Canadian Ice Service Digital Archive, 1960–2008 and 1968–2008.'" *Journal of Geophysical Research* 116(C6):C06027. doi: 10.1029/2011JC007248.

Tiwari, Piyush, Hidekazu Itoh, and Masayuki Doi. 2003. "Shippers' Port and Carrier Selection Behaviour in China: A Discrete Choice Analysis." *Maritime Economics & Logistics* 5(1):23–39. doi: 10.1057/palgrave.mel.9100062.

Tseng, Po-Hsing, and Tsz Leung Yip. 2021. "An Evaluation Model of Cruise Ports Using Fuzzy Analytic Hierarchy Process." *Maritime Business Review* 6(1):22–48.

Ugboma, Chinonye, Ogochukwu Ugboma, and Innocent C. Ogwude. 2006. "An Analytic Hierarchy Process (AHP) Approach to Port Selection Decisions – Empirical Evidence from Nigerian Ports." *Maritime Economics & Logistics* 8(3):251–66. doi: 10.1057/palgrave.mel.9100160.

Verny, Jerome, and Christophe Grigentin. 2009. "Container Shipping on the Northern Sea Route." *International Journal of Production Economics* 122(1):107–17. doi: 10.1016/j.ijpe.2009.03.018.

Wang, Muyin, and James E. Overland. 2009. "A Sea Ice Free Summer Arctic within 30 Years?" *Geophysical Research Letters* 36(7):n/a-n/a. doi: 10.1029/2009GL037820.

Wang, Nuo, Bing Yan, Nuan Wu, and Wei-Jie Zhao. 2016. "Comments on '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]." *Transportation Research Part A: Policy and Practice* 94:699–702. doi: 10.1016/j.tra.2016.09.004.

Ware, Chris, Jørgen Berge, Jan H. Sundet, Jamie B. Kirkpatrick, Ashley D. M. Coutts, Anders Jelmert, Steffen M. Olsen, Oliver Floerl, Mary S. Wisz, and Inger G. Alsos. 2014. "Climate Change, Non-indigenous Species and Shipping: Assessing the Risk of Species Introduction to a High- A Rctic Archipelago" edited by H. MacIsaac. *Diversity and Distributions* 20(1):10–19. doi: 10.1111/ddi.12117.

Wassmann, Paul, Carlos M. Duarte, Susana Agustí, and Mikael K. Sejr. 2011. "Footprints of Climate Change in the Arctic Marine Ecosystem: FOOTPRINTS OF CLIMATE CHANGE." *Global Change Biology* 17(2):1235–49. doi: 10.1111/j.1365-2486.2010.02311.x.

Wong, Johnny K. W., and Heng Li. 2008. "Application of the Analytic Hierarchy Process (AHP) in Multi-Criteria Analysis of the Selection of Intelligent Building Systems." *Building and Environment* 43(1):108–25. doi: 10.1016/j.buildenv.2006.11.019.

Yahan, Hu, and Ma Minglu. 2021. “Research on Key Problems of Arctic Navigation Safety.” *Journal of Physics: Conference Series* 1827(1):012094. doi: 10.1088/1742-6596/1827/1/012094.
Yang, Jiaqin, and Huei Lee. 1997. “An AHP Decision Model for Facility Location Selection.” *Facilities* 15(9/10):241–54. doi: 10.1108/02632779710178785.

Appendix 1 Investment criteria description

Investment criteria description

A- <u>Ice-class fleet</u>: Minimum requirement of ice-strengthened Polar Class carrier fleets makes fleet investment expensive to operate in Arctic waters.

This classification system regulated by the International Association of Classification Societies (IACS) aims to categorize ships with special hull design that can resist collisions with and pressure from sea ice, permitting it to navigate into ice-infested waters (Engler and Pelot, 2013a). According to Guy & Lasserre (2016), few carriers have specialized fleet as they are considered expensive fleet investment and an economic challenge. The decision to procure the ice-class fleet falls under the Arctic shipping companies' budget, but from the government's perspective, to support this investment, the federal maritime association (e.g., Transport Canada) should design and allocate funding programs, in the form of subsidies, or financial aid package offered to these companies, to help them build the ice-class fleet that can withstand the requirements of traversing the NWP.

B- <u>Search and rescue (SAR) capability</u>: Navigational activities in the NWP lack the support of sufficient SAR and salvage point facilities.

The NWP has severely underdeveloped SAR infrastructure and capabilities, whereas the "nearest assets may easily be located more than a thousand kilometers away from potential emergencies" (Hansen et al., 2016, p.16). The Canadian Coast Guards, the SAR agencies in charge for Canadian Arctic waters, has limited icebreaker capacity, and vessels have relied on privately contracted icebreakers when deemed necessary (Ocean Conservancy, 2017). As the shipping season for the NWP is only open during summer (July – October), Canada takes a seasonal approach to executing their SAR mission, with eight icebreakers deployed in the Canadian Arctic for the 2020 season (Sheehan et al., 2021).

C- <u>Refuge port</u>: There is a severe lack of maritime infrastructure and refuge ports along the NWP.

The NWP resides within the Canadian Arctic Archipelago, one of the most complex archipelago structures on earth, stretching approximately 2,400 kilometers from east to west and covering an area roughly 2.1 million km^2 with more than 36,000 islands but sparsely populated, making it extremely difficult to access. There is no operational deep-water port in the Canadian Arctic waters, the most well developed is the deep-water port project plan in Iqaluit that is supposed to operate in summer 2023. For vessels navigating the NWP, the absence of port means no calls for refueling, emergency or changes of crew.

D- <u>Climatic forecast</u>: Due to constant uncertainties with respect to climate changes year after year, the lack of reliable climatic forecast is a major constraint for Canadian Arctic shipping activities.

Mikkola & Käpylä (2013) mentioned major challenges are climatic factors (low temperature, physical obstacles generated by ice) and geography and bathymetry factors (broad and shallow continental shelves as grave dangers to Arctic-travelling vessels). It is estimated that only 12% of Canada's Arctic waters have been charted to international standards (Giguère

et al., 2017). Drifting ice, extreme cold (that supports ice blockage) and interannual variability of ice extent despite the trend in melting (Lasserre and Pelletier, 2011) are the major climate causes for the uncertainty on the NWP route.
E- <u>Crew capability</u>: Extensive training and competence standards are mandatory requirements for safe NWP transits, and qualified crew numbers are always in shortage. Crew competencies are required to comply with the International Maritime Organization (IMO) Guidelines and the Canadian Arctic Shipping Pollution Prevention Regulations (ASPPR) to transit through Canadian Arctic waters and the NWP. The structure of ice navigation training that follows the requirements is usually composed of four main categories with high price tag: theoretical training, practical training, on-the-job experience and simulator training (Østreng et al., 2013a). In a recent survey, 99 completed questionnaires were provided by shipping companies with both active and inactive operations in the Arctic, the responses considered that Canadian regulations to operate in Canadian Arctic waters were stricter than global marine regulations to operate in Arctic waters, thus posted a fundamental challenge as these regulations limited the commercial attractiveness of the route (Pic et al., 2021).
F- <u>Communication infrastructure</u>: Digital Very High Frequency (VHF), mobile telecommunication systems and other types of wireless technology to support maritime applications are generally not available in polar waters. Communication infrastructure is one of four technological aspects (along with pilotage, hydrographic and meteorological) without sufficient developments to support navigation on the NWP (Giguère et al., 2017). Communication technologies are crucial to shipping activities in Arctic water as they assist vessels to safely avoid collisions, maintain safe distance from maritime hazards, locate ships in distress and assist in search and rescue efforts (Ocean Conservancy, 2017).
G- <u>Legal stand:</u> There is growing, significant need for a more harmonized legal/regulatory framework to facilitate traffic growth on the NWP while ensuring safety, security and environmental protection. The most well-known clause that raises debates and shapes response of Arctic states and concerning Arctic stakeholders is Article 234 in the UNCLOS, based on which Canada claimed their sovereignty over the NWP, thus denying the interpretation put forward by the United States (US) and the European Union (EU), that the NWP is an international strait open to international shipping (Bartenstein, 2011; Lalonde and Lasserre, 2013). Canada places an environmental protection orientation to its assertion of sovereignty in Arctic waters, with good intentions: the Arctic ecosystem is fragile and a major oil spill from a poorly-suited vessel to Arctic navigation would prove disastrous (Guy and Lasserre, 2016). The legal stand of Canada's sovereignty over the NWP is crucial in Canada's quest to enforce vessels' compliance with Canada's ASPPR and registration with NORDREG.

Appendix 2 Recruitment letter and manual for respondents

INSTRUCTIONS INCLUDED WITH QUESTIONNAIRE

Title: STRATEGIC INVESTMENTS FOR TRAFFIC DEVELOPMENT OF THE NORTHWEST PASSAGE OF CANADA.

The following pages contain an anonymous questionnaire, which I would like to invite you to complete. This questionnaire was developed as part of a master's thesis at HEC Montréal.

Since your first impressions best reflect your true opinions, I would ask that you please answer the questions included in this questionnaire without any hesitation. There is no time limit for completing the questionnaire, although we have estimated that it should take around 20 minutes.

The information collected will be anonymous and will remain strictly confidential. It will be used solely for the advancement of knowledge and the dissemination of the overall results in academic or professional contexts.

The data collector agrees to refrain from disclosing any personal information (or any other information concerning participants in this study) to any other users or to any third party, unless the respondent expressly agrees to such disclosure or unless such disclosure is required by law.

You are free to refuse to participate in this project and you may decide to stop answering the questions at any time. By completing this questionnaire, you will be considered as having given your consent to participate in our research project and to the potential use of data collected from this questionnaire in future research.

If you have any questions about this research, please contact the principal investigator, *Uyen-Phuong, Nguyen*, at the phone number or email address indicated below.

HEC Montréal's Research Ethics Board has determined that the data collection related to this study meets the ethics standards for research involving humans. If you have any questions related to ethics, please contact the REB secretariat at (514) 340-6051 or by email at cer@hec.ca.

Thank you for your valuable contribution!

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The objective of this study is to identify the potentiality, in terms of ranking, for the strategic investments required, from Canada's perspective, to support the development of the NWP's traffic. As a participant, you are kindly requested to rank the criteria pairwise, on a scale of 1 to 9. A score of 1 means both alternatives are equally important, and a score of 9 means that one of the two items is extremely more important than the other. The ranking of the score and their definition are presented in the description table below (See Table 1). A description of the criteria will be provided in Appendix 1, to further clarify what the investment criteria entail and to be used as a reference during the questionnaire.

There is a total of 21 questions in the survey, to identify which criteria, among a set of seven criteria, are more important than the others. In order to answer each question, please select which of the two compared items is more important in your opinion and specify the score for each comparison.

Table 1: Nine-point rating scale description

Intensity of important	***Definition***	***Explanation***
1	Equal importance	Two factors contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one over the other.
5	Strong importance	Experience and judgement strongly favor one over the other.
7	Very strong importance	Experience and judgement very strongly favor one over the other.
9	Extreme importance	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed.

Source: Saaty (1990, 2008)

The research question and the model overview

The overall goal of the thesis is to find out the top strategic investments and the rankings among seven investment perspectives to support the traffic development of the Northwest Passage (NWP). Therefore, it is placed at the top of the hierarchy. The seven criteria proposed, based on a literature review of several studies of facility planning and location factors selection – are placed on the second level. In this problem, the criteria are also the candidates, they will be evaluated through pairwise comparison against each other, to identify their score in terms of the final goal. The problem is illustrated as a hierarchy using AHP method as below (See Figure 1).

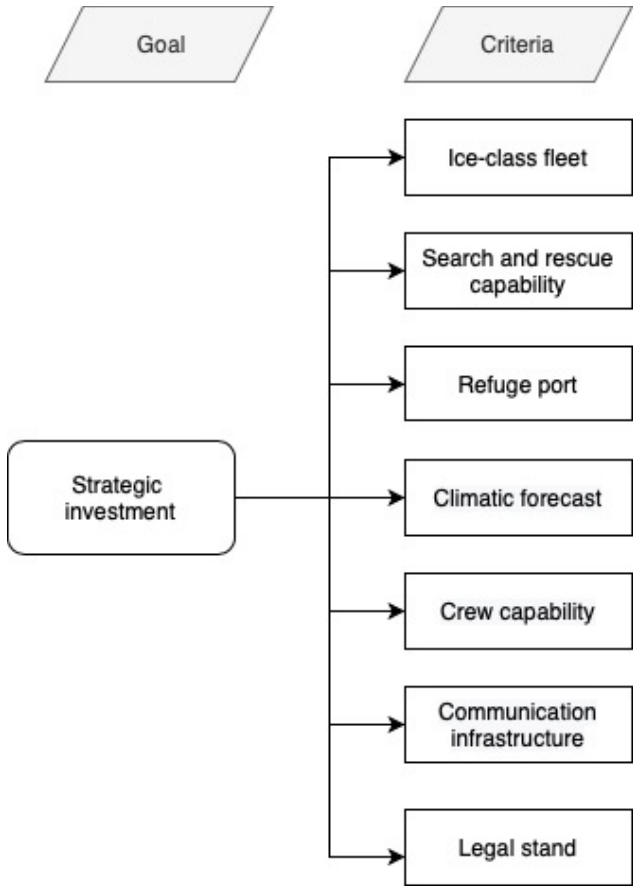

Figure 1: AHP hierarchy of the research question
Source: By the author.

Questionnaire: Ranking criteria (Total: 21 questions)

Purpose: The questionnaire will evaluate which criteria are more important than the others, among the set of seven criteria.

Expected result: Establish the ranking of all seven criteria, and how they compare against each other. The result will provide the ranking and the weights of each criteria. The higher the rank, the more important role the criteria play. It means that top-ranked criteria are highly regarded compared to the low-ranked ones. For example, here are the resulting weights for the criteria (See Table 2) based on a sample input of pairwise comparisons completed by the author for illustrative purposes only.

Table 2: Sample result of criteria ranking

Cat		Priority	Rank
1	Ice-class fleet A	8.6%	4
2	Search and rescue B	35.7%	1
3	Refuge port C	25.6%	2
4	Climatic forecast D	3.9%	7
5	Crew capability E	7.5%	5
6	Communication F	13.3%	3
7	Legal stand G	5.4%	6

Source: By author (using BPMSG AHP-OS online tool here)

Appendix 3 Questionnaire

Questionnaire

Q1- Which strategic investment factor between **Ice-class fleet (A)** and **Search and rescue capability (B)** is more important and by what degree?
Response:
More important criteria: ☐ Ice-class fleet (A) – ☐ Search and rescue capability (B)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q2- Which strategic investment factor between **Ice-class fleet (A)** and **Refuge port (C)** is more important and by what degree?
Response:
More important criteria: ☐ Ice-class fleet (A) – ☐ Refuge port (C)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q3- Which strategic investment factor between **Ice-class fleet (A)** and **Climatic forecast (D)** is more important and by what degree?
Response:
More important criteria: ☐ Ice-class fleet (A) – ☐ Climatic forecast (D)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q4- Which strategic investment factor between **Ice-class fleet (A)** and **Crew capability (E)** is more important and by what degree?
Response:
More important criteria: ☐ Ice-class fleet (A) – ☐ Crew capability (E)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q5- Which strategic investment factor between **Ice-class fleet (A)** and **Communication infrastructure (F)** is more important and by what degree?
Response:
More important criteria: ☐ Ice-class fleet (A) – ☐ Communication infrastructure (F)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q6- Which strategic investment factor between **Ice-class fleet (A)** and **Legal stand (G)** is more important and by what degree?
Response:
More important criteria: ☐ Ice-class fleet (A) – ☐ Legal stand (G)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q7- Which strategic investment factor between **Search and rescue capability (B)** and **Refuge port (C)** is more important and by what degree?
Response:
More important criteria: ☐ Search and rescue capability (B) – ☐ Refuge port (C)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q8- Which strategic investment factor between **Search and rescue capability (B)** and **Climatic forecast (D)** is more important and by what degree?
Response:

More important criteria: ☐ Search and rescue capability (B) – ☐ Climatic forecast (D)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q9- Which strategic investment factor between **Search and rescue capability (B)** and **Crew capability (E)** is more important and by what degree?
Response:
More important criteria: ☐ Search and rescue capability (B) – ☐ Crew capability (E)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q10- Which strategic investment factor between **Search and rescue capability (B)** and **Communication infrastructure (F)** is more important and by what degree?
Response:
More important criteria: ☐ Search and rescue capability (B) – ☐ Communication infrastructure (F)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q11- Which strategic investment factor between **Search and rescue capability (B)** and **Legal stand (G)** is more important and by what degree?
Response:
More important criteria: ☐ Search and rescue capability (B) – ☐ Legal stand (G)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q12- Which strategic investment factor between **Refuge port (C)** and **Climatic forecast (D)** is more important and by what degree?
Response:
More important criteria: ☐ Refuge port (C) – ☐ Climatic forecast (D)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q13- Which strategic investment factor between **Refuge port (C)** and **Crew capability (E)** is more important and by what degree?
Response:
More important criteria: ☐ Refuge port (C) – ☐ Crew capability (E)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q14- Which strategic investment factor between **Refuge port (C)** and **Communication infrastructure (F)** is more important and by what degree?
Response:
More important criteria: ☐ Refuge port (C) – ☐ Communication infrastructure (F)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q15- Which strategic investment factor between **Refuge port (C)** and **Legal stand (G)** is more important and by what degree?
Response:
More important criteria: ☐ Refuge port (C) – ☐ Legal stand (G)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q16- Which strategic investment factor between **Climatic forecast (D)** and **Crew capability (E)** is more important and by what degree?
Response:
More important criteria: ☐ Climatic forecast (D) – ☐ Crew capability (E)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q17- Which strategic investment factor between **Climatic forecast (D)** and **Communication infrastructure (F)** is more important and by what degree?
Response:
More important criteria: ☐ Climatic forecast (D) – ☐ Communication infrastructure (F)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q18- Which strategic investment factor between **Climatic forecast (D)** and **Legal stand (G)** is more important and by what degree?
Response:
More important criteria: ☐ Climatic forecast (D) – ☐ Legal stand (G)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q19- Which strategic investment factor between **Crew capability (E)** and **Communication infrastructure (F)** is more important and by what degree?
Response:
More important criteria: ☐ Crew capability (E) – ☐ Communication infrastructure (F)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q20- Which strategic investment factor between **Crew capability (E)** and **Legal stand (G)** is more important and by what degree?
Response:
More important criteria: ☐ Crew capability (E) – ☐ Legal stand (G)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Q21- Which strategic investment factor between **Communication infrastructure (F)** and **Legal stand (G)** is more important and by what degree?
Response:
More important criteria: ☐ Communication infrastructure (F) – ☐ Legal stand (G)
Evaluation: ☐1 – ☐2 – ☐3 – ☐4 – ☐5 – ☐6 – ☐7 – ☐8 – ☐9 – Other value:

Appendix 4 Ethics Approval Certificate

HEC MONTRĒAL

Comité d'éthique de la recherche

August 16, 2022

To the attention of:
Uyen Phuong Nguyen
HEC Montréal

Re: Ethics approval of your research project

Project No.: 2023-4933

Title of research project: A discussion of strategic planning of port infrastructure for the Northwest Passage of Canada

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Your research project has been evaluated in accordance with ethical conduct for research involving human subjects by the Research Ethics Board (REB) of HEC Montréal.

A Certificate of Ethics Approval attesting that your research complies with HEC Montréal's *Policy on Ethical Conduct for Research Involving Humans* has been issued, effective August 16, 2022. This certificate is **valid until August 01, 2023.**

In the current context of the COVID-19 pandemic, you must ensure that you comply with the directives issued by the Government of Quebec, the Government of Canada and those of HEC Montréal in effect during the state of health emergency.

Please note that you are nonetheless required to renew your ethics approval before your certificate expires using Form *F7 – Annual Renewal*. You will receive an automatic reminder by email a few weeks before your certificate expires.

When your project is completed, you must complete Form *F9 – Termination of Project*. (or *F9a – Termination of Student Project if certification is under the supervisor's name)*. **All students must complete an F9 form to obtain the "Attestation d'approbation complétée" that is required to submit their thesis/master's thesis/supervised project.**

If any major changes are made to your project before the certificate expires, you must complete Form *F8 – Project Modification*. .

Under the *Policy on Ethical Conduct for Research Involving Humans*, researchers are responsible for ensuring that their research projects maintain ethics approval for the entire duration of the research work, and for informing the REB of its completion. In addition, any significant changes to the project must be submitted to the REB for approval before they are implemented.

You may now begin the data collection for which you obtained this certificate.

We wish you every success in your research work.

REB of HEC Montréal

HEC MONTRĒAL

Comité d'éthique de la recherche

CERTIFICAT D'APPROBATION ÉTHIQUE

La présente atteste que le projet de recherche décrit ci-dessous a fait l'objet d'une évaluation en matière d'éthique de la recherche avec des êtres humains et qu'il satisfait aux exigences de notre politique en cette matière.

Projet # : 2023-4933

Titre du projet de recherche : A discussion of strategic planning of port infrastructure for the Northwest Passage of Canada

Chercheur principal :
Uyen Phuong Nguyen, HEC Montréal

Directeur/codirecteurs :
Jacques Roy
Professeur - HEC Montréal

Date d'approbation du projet : August 16, 2022

Date d'entrée en vigueur du certificat : August 16, 2022

Date d'échéance du certificat : August 01, 2023

Maurice Lemelin
Président
CER de HEC Montréal

Signé le 2022-08-17 à 15:25

HEC MONTRĒAL

Comité d'éthique de la recherche

December 02, 2022

To the attention of:
Uyen Phuong Nguyen

Project No.: 2023-4933

Project title:
Strategic investments for traffic development of the Northwest Passage of Canada

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Further to the evaluation of your Form F8 – Project Modification, the Research Ethics Board (REB) of HEC Montréal wishes to inform you of its decision:

The changes have been noted in the file. The current certificate will remain valid until the next renewal.

Thank you.

REB of HEC Montréal