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Assessment of the Northwest Passage as a new shipping route: Viability and added value

by

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Acknowledgements

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Abstract

Climate change can impact our lives in so many different ways, most of them unfortunately are negative. Increased temperatures are directly linked with ice melting in high latitude regions and the consequences can be devastating if it results in sea levels rising. One positive outcome resulting from the reduction in ice cap extension in the Arctic is the opening of water to shipping.

This study explores the possibility of commercially sailing Arctic routes, particularly the Northwest Passage connecting the Pacific and Arctic oceans through the Arctic Sea, as an alternative to traditional shipping lanes. Research in this field is not new but has been boosted recently because of new evidence confirming the retraction of sea-ice in the north. Perhaps because of this new-found interest in the topic, researchers have not been focused and the results have therefore been varied to the point where results do not bring value.

Therefore, the objective of this study is to investigate what trades and shipping sectors have the best opportunity to take advantage of the benefits of the Northwest Passage when compared to other shipping routes. We establish the duration the route is expected to be open via a review of sea-ice forecasting, its geographical advantages and the potential costs of sailing these waters. Trade patterns are analyzed to prioritize origin-destination trade partners and establish what are the parameters of the ships sailing between these. We then perform a multi-criteria analysis of the particularities that define the NWP combined with the characteristics of the trades that currently exist between countries that can realistically benefit from it. A Weighted Decision Matrix is used to score each alternative (trades) on the criteria (parameters of the NWP) identified as most impactful to the success of a voyage, resulting in a scoring system used to rank and compare each alternative.

The result is determining which type of trade has the best fit with the route and is thus better positioned to take advantage of this opportunity. We argue that this should be the focus of attention of future research on the profitability of shipping in the Arctic and of shipping companies that have been considering this possibility.

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Chapter 1 – Introduction

1.1 – Shipping Economics

For centuries, shipping has been a fundamental tool in trade and transportation that has enabled our society to grow and develop not only through business but also cultural exchanges. Nowadays, shipping represents more than 80% of global trade volume and its relevance will only increase as shipping is expected to continue growing (UNCTAD, 2017), barring major economic crisis.

For shipping companies, as is the case for any business, cost minimization is a top priority, especially so in an industry know for low margins and profitability (McKinsey&Company, 2016) (see Figure 15). Amongst many cost parameters that result from a complex operation such as international navigation, fuel costs are widely regarded as the single largest operational factor, ranging from 50-60% of direct costs (Lasserre, 2014) and it is a constant concern for ship managers.

A variety of factors directly affect a vessel's fuel consumption rate, like engine efficiency, fuel type and characteristics, speed, wind, sea conditions and many more. Fuel consumption has improved by an order of magnitude in just over one hundred years (Stopford, 2009) as Figure 1 illustrates. Fuel types and engines have also evolved from wind and sails, to coal powered steamships of the 19th century, to diesel engines that use a variety of oils purposefully developed for specific applications. There has been a recent trend of using liquefied natural gas (LNG) as fuel (UNCTAD, 2017), which might be a response to stricter environmental regulations that will be brought in force by the International Maritime Organization (IMO) by 2020.

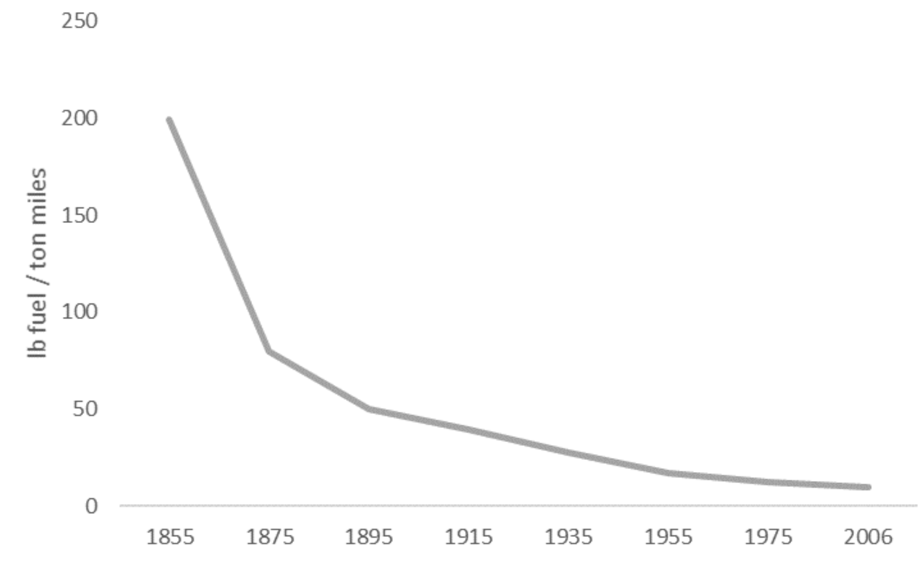

Figure 1 - Fuel consumption for a typical cargo ship – own work with data from Stopford (2009)

Speed has also seen fundamental changes. In the early 2000's the trend revolved around increased sailing speeds, especially for container liners. This culminated in the famous Maersk E-class which could reach a top speed of 25 knots. As bunker prices kept rising and global trade came to a halt in the aftermath of the 2008 mortgage crisis, pressure for more efficient vessel operation increased and one-way shipping companies quickly responded was by slow steaming, the practice of reducing a ship's sailing speed. In the liner business this has been associated with three major factors: oversupply of capacity, bunker prices and emission regulations (Jingbo Yin, et al., 2014) and has become a common practice. The result is reduced fuel consumption and costs as determined by the cubic relation between consumption and speed ($C = f(v^3)$).

These are just a few of the parameters that a ship operating crew needs to manage on daily basis to achieve cost efficient navigation. Fuel consumption is usually determined in weight of fuel consumed per mile sailed (see Figure 1), and consequently fuel costs are a function of the distance sailed. However, the distance sailed is rarely up for questioning as the shortest path will always be chosen if possible (not considering external factors such as toll routes or piracy concerns), and there is little debate as to what the shortest path from one port to another is.

1.2 – Developing New Routes

In recent years, however, new sailing routes have become a focus of research and new possibilities have emerged. Most prominently are the arctic routes, possible navigation lanes that have a potential to decrease sailing distances by as much as 40% for some trades (Schøyen & Bråthen, 2011). Although arctic navigation has existed for thousands of years, particularly by indigenous populations, it was not until the late 15^{th} century that Europeans considered these routes as alternatives to traditional trading lanes with India and Southeast Asia (Arctic Council, 2009). To this day, despite centuries of exploration, shipping in the arctic is still limited mostly to research, surveying and fishing (Eguílez, et al., 2016), with few cases of commercial operation.

What has brought the development of these routes back to the center of attention for many was not some innovation in shipping, new development in route planning or even trade. Arctic navigation is seen as a real possibility in the near future because of the increasing duration of ice-free summers that has opened these paths for ships where it was only a rare occasion in the past (Smith & Stephenson, 2013). This realization has sparked the interest not only of those who could directly benefit from it but also of researchers, and literature on the topic are plentiful nowadays (Benassi, et al., 2016).

Developing or changing a shipping network is also a crucial aspect in the success of a new route. Determining the best route is not as simple as balancing voyage costs and duration but involves many different cost parameters and intangible aspects that shipping lines often disregard, and that may be a crucial mistake. However, literature on the subject has been increasing in recent years, especially in the aftermath of the 08/09 world economic crisis that significantly reduced shipping margins and pushed companies to become creative (and strict) in cost evaluation.

1.3 – The Northwest Passage

The focus of this research is the Northwest Passage (NWP), a sailing route on the Arctic Sea crossing northern Canada and connecting the Pacific and the Atlantic oceans. Although within the NWP a few sailing alternatives exist, it is roughly described as starting in the Bering Strait between the Chukchi Peninsula (Russia) and Cape Prince of Wales (USA), through the Beaufort Sea, across a variety of straits depending on a specific route (M'Clure, Barrow and Prince of Wales Straits) and out through the Baffin Bay and Labrador Sea to the North Atlantic Ocean near southern Greenland.

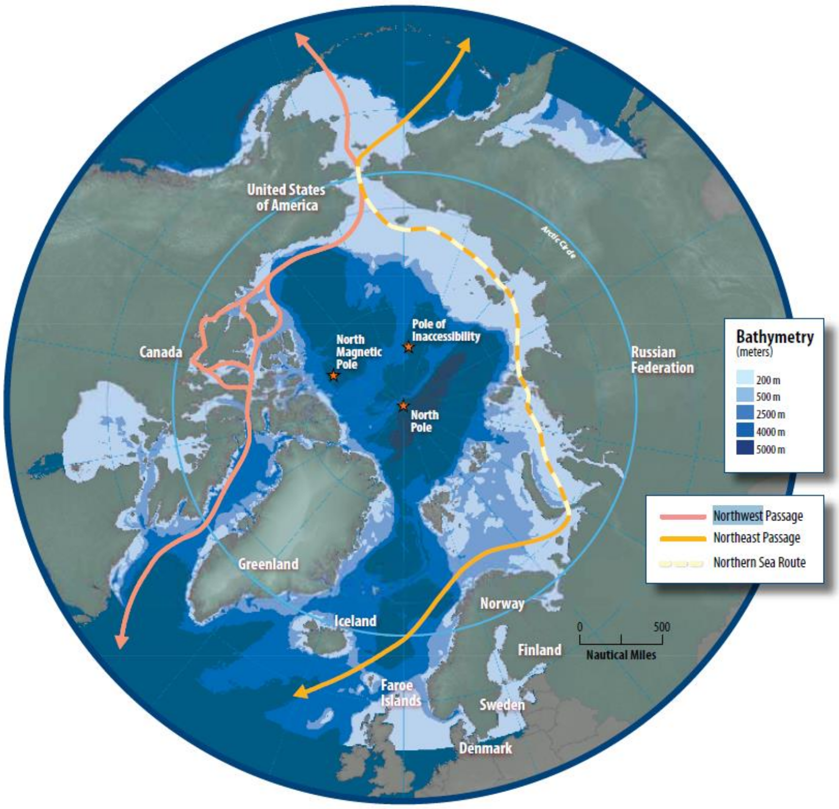

Figure 2 - Arctic Routes - Source: Arctic Council (2009)

The NWP, as opposed to its better known counterpart Northeast Passage (NEP) (sometimes referred to as Northern Sea Route although this is a common misconception since NSR refers to a specific set of routes in northern Russia that does not reach Europe), that also traverses the Arctic Ocean but throughout northern Russia via the Siberian and Barents Sea, is still on its infancy in terms of research, relevance and consideration for commercial use. The NSR has been more thoroughly investigated and discussed at this point in time (Guiguère, et al., 2017) for many reasons, such as the vast availability of natural resources and its development in northern Russia (particularly natural gas), the efforts from Russia to control and expand its borders in the region and the development, particularly in the Cold War years, of nuclear powered ice-breakers and commercial ports that allowed for greater exploration and provided infrastructure for navigation (Lasserre, 2014).

There is, nonetheless, great interest in studying and developing the NWP for future commercial use and there are several reasons for that. First, it represents a shorter route between northeast Asia and northern Europe when comparing with traditional shipping lanes like the Suez Canal route. Secondly, it poses fewer physical barriers to vessels due to lower draft and length constraints, especially compared to the NSR which presents depth restriction in several points (Arctic Council, 2009). Moreover, it is projected that the various trans-arctic routes may become interchangeable in the future and chosen according to current ice conditions, which strengths the need to research and develop the NWP (Melia, et al., 2016).

On the other hand, many challenges exist in considering the NWP for regular commercial use and the most obvious one is its availability regarding ice conditions. Although many studies point towards a larger open-water season for arctic shipping in the future, most still foresee a short window of time and work more in terms of *probability of navigating* in a specific period (usually between July – October) than actually forecasting the window itself. Nonetheless, regularly sailing through the Arctic Ocean will become a reality in upcoming decades (Smith & Stephenson, 2013) so researching the matter and establishing the basis on which this will happen is of great interest to every player in the shipping community and government and regulatory bodies.

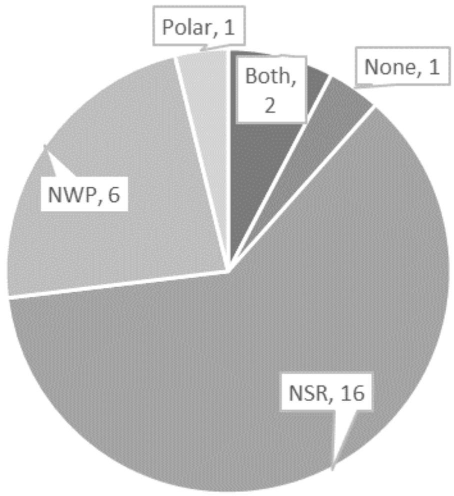

Figure 3 - Breakdown of arctic routes studies in academic research - own work with data from (Lasserre, 2014)

1.4 – Research Objective

If there is so much interest on the subject for all its potential, why hasn't it been effectively developed to the point of large-scale commercial operation? This research argues that the focus has been misguided and time has been wasted in studying the real possibilities of arctic navigation, particularly for the Northwest Passage. This is confirmed by Guiguère, et al. (2017) and has been pointed out by Lasserre (2015). In many cases containers were used as the subject of analysis, given the large scale of this industry and potential for substantial gains with the introduction of cost savings measures, however there are several factors inherent to this trade that make it a less than optimal candidate for arctic navigation.

1.4.1 – Research Question

The objective is to identify the specific trades that have the highest likelihood of being successful in shipping through the NWP with precise characteristics and parameters that make them more suitable for such endeavor. The challenge is to compare many different combinations of shipping possibilities, enough to have a good representation of trade that occurs between countries that have a reasonable motivation for considering the NWP an opportunity.

Therefore, the main Research Question for this study is:

"What are the trades that have the highest likelihood of benefiting from navigating The Northwest Passage as an alternative to traditional East-West navigation routes?"

To investigate this, we propose a set of sub-questions to answer that would indirectly satisfy the main question. These involve all aspects of what constitutes a good fit between route and trade characteristics and can be addressed individually. By answering these we believe it is possible to present a conclusion to the main research question.

The sub-questions are:

What parameters differentiate the NWP from traditional shipping lanes?

When, and to what extent, is the NWP navigable?

What are the origin-destination points that would benefit from the NWP in terms of distance reduction?

What trades exist between these points and what are their main characteristics?

The strategy to answer these questions will be discussed in further detail in Chapter 3 but consists of establishing the parameters identified above as key to the issue and determining which trades match and qualify as successful prospects. Initially, we will determine trades that, at first look, might benefit from this route. In this definition, different trades will be considered by cargo type and volume, origin/destination, type of vessel used and other factors.

Secondly, parameters that encompass the specificities of navigation through the NWP will be proposed and discussed. Thirdly we will focus on intangible variables, i.e. legal and/or regulatory issues, network development and the challenges of temporary routes, risk aversion and the effect of bunker prices.

A thorough analysis of existing literature will be presented in Chapter 2 which will allow us to determine all the key elements of the NWP. We will resort to public databases for information regarding information on trades active in the origin/destination pairs established and academic literature for technical characteristics.

1.5 – Motivation

The relevance for this research has been established and the interest in it will come from many areas. Shipping companies will investigate the results and consider whether or not they fit the profile of the optimal trade and develop (or not, which is just as good a conclusion) the possibility of sailing the Northwest Passage. Shipowners will see more value in the characteristics of vessels suited for this journey and can be a driving force in its development by increasing the available capacity of such transportation. Cargo owners will also benefit by quickly identifying potential in the route for their particular trade and start planning its use.

A whole separate set of players may find the research useful. Government authorities of the countries involved may focus their attention to the future development of the NWP and identify opportunities and risks. Moreover, they will be a deciding factor on the outcome given their influence in regulatory and legal framework and economic power to boost the industry. International shipping organizations and committees will captain the discussion in terms of standards and regulations and may use the findings to base and, more importantly, restrict the conversation to relevant topics.

Academic interest on the subject has been high, and hopefully this research will add value to what has been published so far. Future analysis on NWP may use the results presented here and focus their attention to the cases that have been established as most likely to succeed and delve more into specific trades. This will be the first paper proposing a more suitable research object for this field which we consider will guide more relevant conclusions with real world applications.

Chapter 2 – Background

Research on the matter can be roughly divided in two large categories: those related to ice conditions with a more scientific approach to the navigability of these waters (by means of sophisticated modelling and satellite imagery) and those that focus on the practical implications of the latter's conclusions (such as economic effects of introducing new routes and feasibility analysis for specific uses). A third set of articles will be presented as well discussing other subjects such as network development, legal aspects of navigating through the NWP and how regulations and policy might shape the future of the route.

The available literature will be reviewed and discussed in this Chapter and will be the foundation for the arguments and methodology used in this research. Moreover, it serves as the basic motivation and backbone of the research by showing that 1) there is a lack of focus on the existing literature that ultimately leads to low value conclusions and 2) it will also supply relevant parameters to the analysis.

2.1 The state of sea ice in the Arctic

2.1.1 Recent research parameters

It is a very acceptable fact that sea ice coverage in the Arctic has seen historically low figures recently and this is not only an academic realization but is also present in mainstream media. There is, however, considerable debate regarding the extent and rate of this decline and more importantly in forecasting this trend.

These mixed results stem from the basic premises adopted by each study and their methodology. First, there are several different simulation models being applied, and this is the main focus of the research conducted by Smith and Stephenson (2013) where they combine seven models to propose a balanced forecast. An interesting approach to determining the best models to be used for this purpose is carried by Khon et al. (2010) whereby the authors analyze how well each model reproduced historical observations. In doing so, they narrow down 9 models out of the initial 21 as the most suitable for simulating conditions in the NWP and observe that most models tend to "overestimate length of ice season and underestimate its decrease in recent decades" (Khon, et al., 2010, p. 761) which indicates this is a recent trend that has not yet been assimilated by climate models.

Most authors use global climate models (GCMs) for climate predictions, particularly from the World Climate Research Programme Coupled Model Intercomparison Project Phase 5 (CMIP5) which aims at coordinating modeling experiments, developing better predictability and understanding why models produce different results (WCRP, 2011). Although a great foundation for any climatic modeling research the GCMs from the CMIP5 are usually amended or personalized by each author for various reasons, such as adapting to the specific problem being addressed or to eliminate some bias in the data (Melia, et al., 2015). Knowledge of the variance and in forecasting models is of great importance and the concern of the study conducted by Guemas, et al. (2016) who establishes the source of the uncertainties arrive from the nature of the data collection and the complexity of the various systems acting simultaneously in weather forecasting. This study also compiles a thorough description of current forecast models and the limit to their predictability. Another methodology is to utilize satellite imagery to observe sea ice extent, concentration and age as verification of the results from simulations (Stroeve, et al., 2011).

A second important premise used in sea ice forecasting is deciding upon future scenarios for global temperatures to be used in the modeling. The most common and widely accepted proxy for such are the Representative Concentration Pathways (RCPs) established by the Intergovernmental Panel on Climate Change (IPCC), an international body of research for climate change set up by the United Nations (UN) in 1988.

These represent four potential trajectories of the concentration of greenhouse gases in earth's atmosphere for this century ranging from the most optimistic RCP 2.6 whereby the peak concentration will happen around 2030 and decline slightly to the pessimistic scenario RCP 8.5 where emissions and concentration will continue to grow into the end of the century (see Figure 4). A relevant remark is the RCP 2.6 scenario is the one closest to the Paris Agreement target for limiting the increase in global average temperature to 1.5° in comparison with preindustrial levels, since this projection is roughly equivalent to a mean global temperature increase of ~1.6 ± 0.4°C above these levels (Melia, et al., 2016).

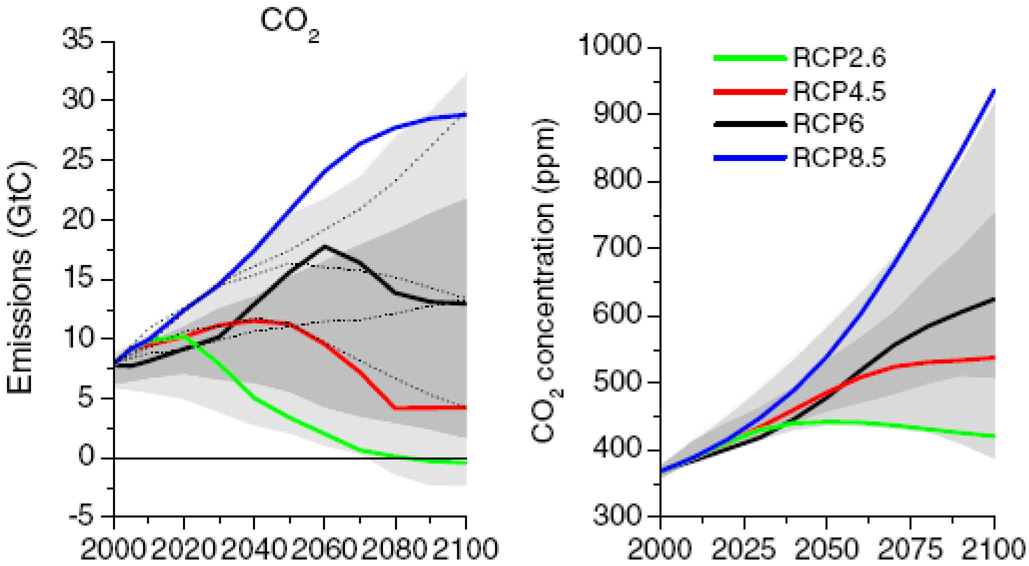

Figure 4 - RCP scenarios for emissions and CO2 concentration - Adapted from van Vuuren, et al. (2011)

RCPs are important for long and near-term climate modeling, potentially even extendable to projections up to the year 2300 with the use of Extended Concentration Pathways (ECPs) and can be used for mitigation and impact analysis as well (van Vuuren, et al., 2011). Most of the current literature on sea ice coverage uses these as proxies to climate scenarios in the future, however its use has been varied and that in and of itself is a source of variation in the results. Authors like Melia et al. (2016) consider three of the projections (RCPs 2.6, 4.5 and 8.5) in their studies, while Benassi et al. (2016) focused solely on RCPs 4.5 and 8.5, perhaps hinting at a sceptic view of the best-case scenario. Barnhart et al. (2015) produces maps of the open water seasons until the year 2100 with the use solely of RCP 8.5 and even states this is a conservative scenario given recent observations.

This shows that authors seem to have a pessimistic view on the future of GHG emissions and this has consequences on the results of their research. By utilizing the worst-case scenarios in their projections, they produce favorable conditions for navigation in the Arctic as higher concentration of CO_2 in the atmosphere leads to increased temperatures and reduced sea ice coverage.

Another source of variability in the literature stems from the targeted window being analyzed. As stated before, the focus of many studies is specific to the month of September, which is historically the one with lower extension of sea ice. This is the case for the research developed by Smith and Stephenson (2013) which maps the optimal routes solely during the month of September (which he calls “peak season”) in the Arctic.

Other authors focus on either determining a navigable window through the Northwest Passage (Liu, et al., 2017) or a projected number of months for which the NSR will be open (Benassi, et al., 2016). In their study titled “Melting ice, growing trade?” Benassi et al. (2016) develop an elaborate metric that considers three probability ranges that the NSR will present either less than 15% concentration of ice, less than 15cm thick ice or a combination of both factors. This realization is not easily assimilated by an academic, let alone an average reader, and does not contribute too much to the general state of this research field. (Pizzolato, et al., 2016) sets a shipping season of June-October, which is an improvement on the analysis in terms of how the results will be taken by the shipping community.

A great reference for the state of Arctic shipping in the future is the International Code for Ships Operating in Polar Waters (POLAR CODE), a regulatory framework developed by the IMO, based on previous instruments. The fundamental objective is to increase safety for ships and crew and prevent and/or mitigate potential environmental impacts caused by navigation in the Arctic (IMO, 2014). Adopted by the IMO in 2014, it went into effect in January 2017 and raises the bar in terms of restrictions and requirements when compared to MARPOL or SOLAS.

The POLAR CODE precisely determines a vessel’s structural strengthening category, as well as stability requirements, subdivisions, machinery, fire safety and lifesaving characteristics. It refers to the International Association of Classification Societies (IACS) standards for Polar Class as acceptable / equivalent categorization (see Table 1). These classifications are commonly used in current literature especially when comparing financial viability of arctic routes with the use of ice-strengthened vessels against regular ships (Lasserre, 2014). Since this is not, by any means, the only classification system in place, the question of equivalency arises when dealing with international certification, regulatory framework and even legal debate.

Table 2 is a proposition by Professor Claude Daley, of the Memorial University in St. John’s, Canada, for equivalency between several of these standards.

The Canadian Coast Guard establishes in its “Arctic Ice Regime Shipping System Standard”, through equivalency of standards, that the limiting ice thickness for and Open Water (OW) vessel is 0.15m while for PC6 vessels this threshold is 1.5m (Melia, et al., 2016). This is valuable information that should help any shipping company decide, given sea-ice projections, what type of strengthening their vessels must have to be authorized to operate in the Canadian Arctic and consequently have precise knowledge of the premium paid on such adventure. These are the two categories most commonly used by authors of economic feasibility studies.

Table 1 - Polar Class Descriptions. Source: (IACS, 2006)

Polar Class	Ice descriptions (based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multiyear ice inclusions.
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

As mentioned previously, the recent nature of sea ice research and its development means previously established models are sometimes not suitable for assertive forecasting. The conditions have been changing so dramatically and in such short notice that current data skews available parameters and we get either under or overestimations of future trends, none of which are of much value. Realizing this issue, the World Meteorological Organization (WMO) launched in 2011 the Polar Prediction Project (PPP) with the mission to *“promote cooperative international research enabling development of improved weather and environmental prediction services for the polar regions, on time scales from hours to seasonal.”* (PPP, 2018). One of the key initiatives is the Year of Polar Prediction (YOPP) that takes place from mid-2017 to mid-2019, a coordinated effort of intensive observation campaigns and model verification by a multidiscipline team of researchers from several universities and institutions.

The goal is to reduce uncertainty of the models, understanding of specific requirements in the region and improving prediction of weather conditions in polar regions (PPP, 2018). The project works towards developing weekly, monthly and seasonal forecasts, so application in shipping is suitable in the short-term when masters plan a voyage to long-term when companies consider the use of the arctic routes itself. Hopefully this will lead to, with the help of a narrow range of research subjects, more assertive studies about navigability conditions in the Arctic.

Table 2 - Ice-Class correspondence – Source: (Claude, 2014)

		RSS	IACS	
		Arc9 Arc8 Arc7 Arc6	PC1 PC2 PC3 PC4 PC5	Year-Round Navigation in Arctic Waters
Winter Navigation in Sub-Arctic Waters	1AS 1A	Arc5 Arc4	PC6 PC6	Summer Navigation in Arctic Waters
	1B 1C	Ice3 Ice2 Ice1		
	TRAFI	RSS		

In this section we have gone through the current state of sea ice research, its main parameters, limitations and how authors face the challenges of combining scope with objective. We have also discussed how there are several ways to assess the navigability of arctic routes and how the lack of clear research subject can lead to a very wide range of results that ultimately fall short of contributing to real world applications in terms of the commercial use of these routes.

2.1.2 What to expect

We have reviewed what the key parameters are in sea ice forecasting research and understand what researchers are focusing on in recent literature. We have also investigated some consequences to the shipping industry in terms of requirements to navigating water with ice, reflected in the development of the POLAR CODE. We will now focus on what these models have been forecasting for the Arctic and what conditions we may expect in the future of arctic shipping. This will be crucial to determine to what extent and for which duration shipping along the NWP will be viable and when. We will utilize this information and cross-reference it with trade analysis to locate most suitable candidates for this journey.

There is a high variability of conclusions from available literature on sea ice forecasting in the Canadian Arctic. This is in part by the very nature of climate forecasting being complex, but also from the varying methods used between authors, which is a common in academic research. However, there is a strong consensus on the fact that sea ice coverage in the arctic has been declining (see Figure 5)and will continue to do so in the foreseeable future under all existing climate scenarios (Stroeve, et al., 2011) (Smith & Stephenson, 2013) (Khon, et al., 2010) (Melia, et al., 2016) (Arctic Council, 2009) (Canadian Ice Service, 2016).

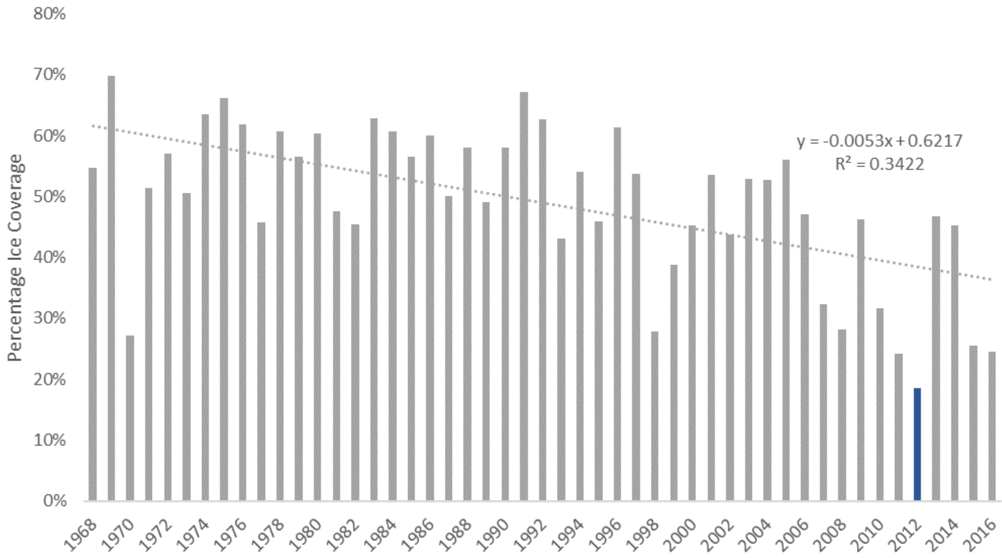

Figure 5 - Western Arctic minimum ice coverage graph, 1968 to 2016 (emphasis on lowest value and trendline added by author) – own work with data from Canadian Ice Service (2016)

The key issue is determining a reasonable window of navigation with a certain confidence interval. This does not need to be so precise, just enough to give a reasonable expectation of whether or not the next season will allow the use of the NWP and how many voyages will be possible. Such a prediction would be very useful for shipping companies and government institutions to prepare for the possibility of long-haul passages (Guemas, et al., 2016).

Smith and Stephenson (2013) analyzed not only the NWP and NSR, but also through the North Pole. They considered two types of vessels (common open-water and Polar Class 6) over seven different climate models and two climate change scenarios (RCP 4.5 and 8.5). This analysis shows that the NWP is the more advantageous route for voyages to/from eastern North America in every simulation when considering PC6 vessels and even for OW vessels by midcentury. It would not, however, be the best choice for voyages to/from the North Atlantic, in which case the NSR is the most favorable one. The positive news is that, by the years 2040-2059, the NWP will be navigable in September by regular OW vessels with a successful transit probability of 53% (for RCP 4.5) and 60% (for RCP 8.5). They conclude the analysis by stating: "Put simply, by midcentury, September sea ice conditions have changed sufficiently in the NWP such that trans-Arctic shipping to/from North America can commonly capitalize on the ~30% geographic distance savings that this route offers over the NSR." (Smith & Stephenson, 2013, p. 1192). It is important to point out that these results stem from a combined analysis of several models, where variations were observed between them. That is to say that some projections are more optimistic and others more pessimistic.

A different approach was used by Khon, et al. (2010), where the Coupled Model Intercomparison Project Phase 3 (CMIP3) simulations were compared to historical satellite imagery. According to the authors, the fit between observations and predictions was so good that it provided confidence to extrapolate the models to generate predictions for this century. These projections very between simulations, and the ones selected for analysis were those with the most realistic reproductions of historical conditions in the NWP. The conclusion is that, for the years between 2010-

2030 insignificant change is expected, however a significant increase will make the navigable window possibly as large as 4 months during the summer by 2080-2099 (see Figure 6).

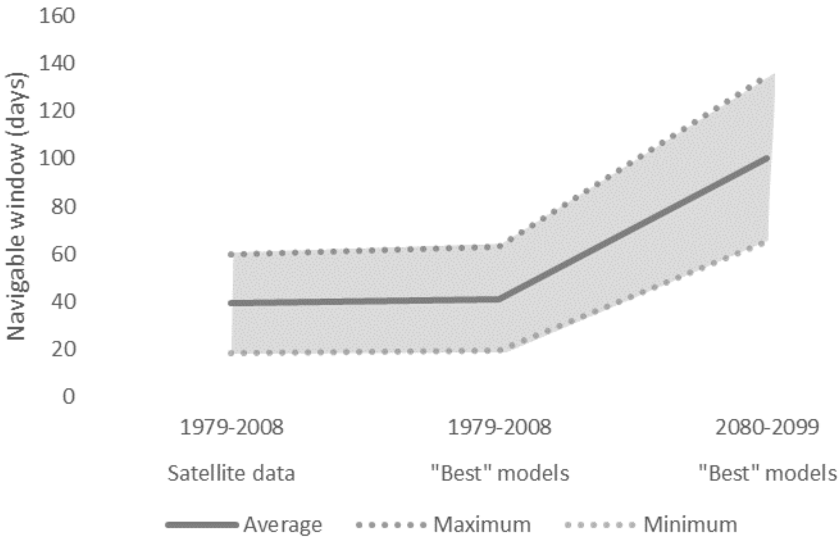

Figure 6 - Evolution of the NWP navigable window - own work with data from (Khon, et al., 2010)

These two studies are different, not only in their methodology, but most importantly in the way they asses navigability. While Smith and Stephenson (2013) compared routes by calculating the probability of a successful voyage, Khon, et al. (2010) simulates conditions to determine whether or not a route will be open. Most literature falls on one of these two concepts, either a probabilistic or deterministic result.

One of the studies that applies the former is the analysis on sea-ice decline and its implication on arctic shipping by Melia, et al. (2015). In their research, whose methodology has been discussed in 2.1.1, the authors conclude, on probabilistic terms, that in the early 21st century OW vessels will have a chance of 30% of finding favorable conditions, while PC6 vessels will see a very significant 90% chance and access to more routes due to their ice strengthening. For mid-century (2045-2059), OW vessels are expected to double their potential irrespective of the RCP scenario and PC6 vessels will be able to utilize even the northern NWP route (faster than the southern one) for “practically all Septembers”.

Most staggering are the results for late century (2075-2089), where Melia, et al. (2015) projects that OW transits in September will be guaranteed under RCP 8.5. The season (so not only the peak month of September, but a wider window of time where waters will be navigable) will likely range from 4 to 8 months under RCP 8.5 for open-water vessels. This has huge implications, making the NWP a likely route for an extended period every year. For PC6 vessels the season will be as long as June to February more than 80% of the years.

2.2 Assessing arctic shipping viability

In the previous section we reviewed literature focused on describing and forecasting sea-ice conditions in the Arctic. The purpose was to understand restrictions and constraints for vessels, and most importantly what we can expect in terms of navigability of the NWP, so that it can be applied in our analysis with a scientific base.

In this section we will investigate the economic and feasibility analysis being conducted, what parameters those studies see as crucial to the success of the NWP and especially what are the objects of these analysis. The here goal is to determine the key parameters that will be used to assess the candidate trades being analyzed.

2.2.1 Linking ice conditions to shipping

The first step is to establish that the indisputable phenomenon of reduction in sea-ice in the Arctic has direct impact on shipping potential in this region and what degree of impact may we expect. Again, several methodologies have been deployed to investigate this link, but the underlying results converge significantly to a positive connection to shipping activity, and potentially trade diversion, with the opening of the Northwest Passage. We will start by analyzing what the current situation of navigation the NWP is.

A quantitative analysis of shipping in the Arctic, from 2010 to 2014, is performed by Eguílez, et al. (2016) using AIS data. This studied classifies ships by different categories and concludes that Supply, Research and Survey vessels represented almost 60% of ships detected in the region (anywhere above the 66.4°N in latitude) in 2014, while cargo and tankers represent 17.1% and 4.7% respectively. These are low figures for commercial cargo-carrying use, especially when considered that most of these happened on the NSR, not on the NWP. Moreover, particularly for the NWP, the observations show a decrease in activity from 2011-2013 to 2014. This correlates with Figure 5, where we observe an increase in ice-coverage in 2013 and 2014 when compared with 2007-2012. The authors conclude that "… as of 2013, the Northwest Passage was not regularly used as a shipping route because the sea ice remains too thick for safe shipping" (Melia, et al., 2016).

To that point, Pizzolato, et al. (2014) performs a comprehensive correlation analysis between sea-ice data and observed vessels transits from 1990 and 2012 in the Northwest Passage. The source for the vessels observations is the Canadian Coast Guard and reports are within the Vessel Traffic Reporting Arctic Canada Traffic Zone (NORDREG). All vessels entering this region are mandated to inform daily positional data as well as when the enter/exit the NORDREG zone, which provides for a vast and fairly accurate representation of traffic in the NWP (authors estimate that 98% of vessels comply with the mandate). A total of 82,555 reports were considered in this analysis, after some quality control on the data, and this shows a major difference in the findings from Melia, et al. (2016), particularly in regards to the share of non-commercial use vessels observed (see Figure 7). Out of those, a combined 35.6% fit in cargo-carrying categories while 28% represent government and icebreaker vessels, a stark increase compared to the previous study. Categories do differ, which may affect the results, however the much larger dataset is probably the one responsible for the discrepancies.

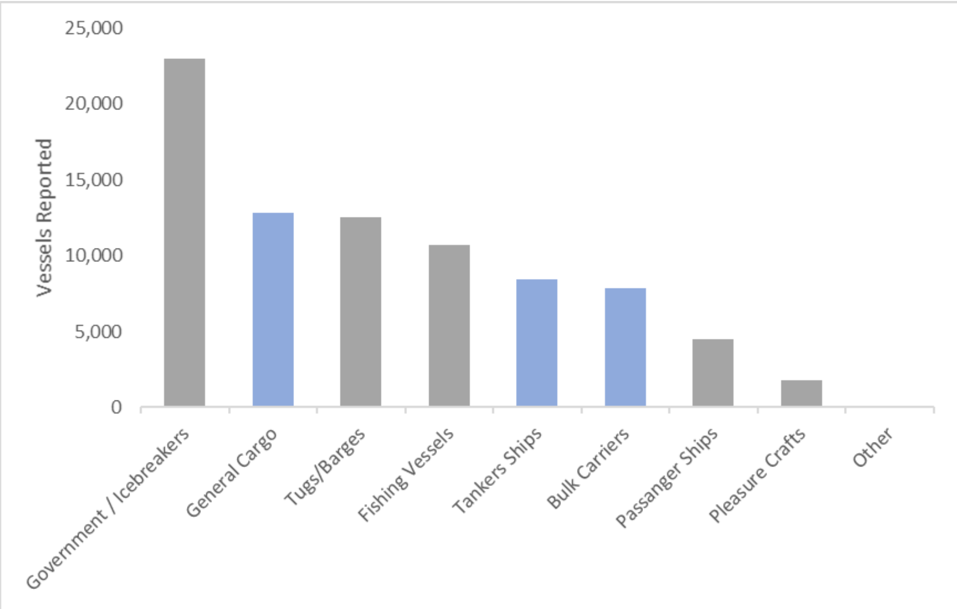

Figure 7 - Vessels reported in the NWP in the period 1990-2012 by category, with highlights to this research's interest – own work with data from Pizzolato, et al. (2014)

When crossing this information with sea-ice data from the Canadian Ice Service Digital Archive (CISDA, a mix of surface, aerial and satellite observations), the authors found "successively stronger negative correlations between total ice area and annual vessel counts" (Pizzolato, et al., 2014, p. 12152). In a follow-up research, the same authors performed a similar analysis (with slightly different methodology for determining shipping activity) with data up to 2015. In this study, they conclude that significant negative correlations exist between sea-ice concentration and shipping activity in the Canadian Arctic (Pizzolato, et al., 2016), however point out that multiyear ice seems to be what is still discouraging shipping companies from increasing their presence in the region.

Moreover, the authors point out that, despite there being a correlation between the two, sea-ice may not be the primary driver in shipping activity in the Arctic, but merely an enabler. This not only agrees with Eguílez, et al. (2016) and Benassi, et al. (2016), but also with Guiguère, et al. (2017) who sees the influence of a solid regulatory framework, fuel prices and local infrastructure developments as contributing more to shipping activity. It is important to point out, at this point, that all these authors mentioned that a significant share of shipping activity in the Canadian Arctic is still either destined or originated in Canada, therefore is most susceptible to the factor pointed out above. Full transits, those voyages that are originated and destined outside of the region, are still a rare occurrence.

An important event happened in the summer of 2013 when the Nordic Orion, a 75,000 dwt, ICE-1A[1] ice-strengthened bulker carrying coking coal, transited the NWP for its voyage from Vancouver, Canada, to Pori, Finland. Not only did it reportedly save $80,000 in fuel alone (REUTERS, 2013), it also carried 25% more cargo than it would be possible to if it had taken the Panama Canal, given draft restrictions of this crossing. More recently, A.P. Moeller-Maersk announced that it would sail its 3,600 TEU containership 'Venta Maersk' via the NSR in a voyage from Vladivostok to St.

[1] Equivalent to PC7, the lowest category in the POLAR CODE.

Petersburg, Russia, with the aid of an ice-breaker (Port Technology, 2018). The 'Venta Maersk' is one of 7 ice-class vessels ordered by Maersk in 2017. Another report is of the LNG tanker 'Christophe de Margerie' having journeyed from Norway to South Korea via the NSR unaided by any icebreakers in August 2017 (The New York Times, 2017), allegedly the first one to do so. This 299m and 80,200dwt double acting[2] vessel, a part of 15 similar ordered to the DSME, was built to Arc7[3] standards and is expected to sail year-round from the Yamal Region towards northern Europe, and towards Asia from July to December (Ship Technology, 2018).

Figure 8 - The Christophe de Margerie in icy waters – Copyright D. Lobusov – Source: (MarineTraffic.com, 2018)

The case of the Christophe de Margerie brings an extra flavor to the discussion given it is an LNG carrier. With increased navigation in the northern latitudes it is expected that fuel demand will also increase. Considering IMO 2020 regulations with regard to bunkering and fuel specification in certain areas of the world, LNG has gathered a lot of attention and many companies have delved in the LNG-fueled vessel business. This is very good news especially for the NSR where gas is the main driver of economic activity and it might make this route even more attractive as LNG extraction and storage booms in the region.

The NWP, however, does not benefit in the same way and barely any infrastructure exists for bunkering in northern Canada, although there are projects being developed in the field, such as the Makenzie Gas Project that would build a natural gas pipeline to northern Alberta (Prowse, et al., 2009). This paper studies the relationship between climatic change (with special interest in temperature increase and melting ice) and economic development in many sectors in Canada, not only maritime transportation. This is more evidence of the pushing force that this natural phenomenon has on the Arctic.

[2] Vessels that can operate backwards under heavy ice conditions.
[3] Equivalent to POLAR CODE PC3, so capable of year round navigation in second-year ice.

Shipping companies are willing to invest in ice-class vessels for their operations as has been made clear by these recent reports. With the window of navigation opening in the Arctic and the clear expectation that it will continue to do so, having vessels that can be self-sufficient in this journey not only guarantees this operation but does so while waving the assistance of costly ice-breakers. The link between sea-ice melting and shipping is apparent not only through the actions of these companies but has also been well documented by research literature and demonstrated in this section. Our attention thus turns to the consequences of the expected growth in Arctic navigation, to the analysis of whether or not it will prove to have the financial implications it promises and if so who has more to benefit from this new development.

2.2.2 Models

The most common methodology for assessing financial feasibility of a project is performing cash-flow analysis. Put simply, this technique measures the expected profitability of a project by applying several revenue and cost parameters to generate yearly cashflow statements of the project. It is, therefore, a simulation methodology that forecast future outcomes and allows one to evaluate whether these outcomes are worthwhile or not. Much like climatic forecasting (or any kind of parameter-based prediction) it relies heavily on the assumption it makes and the parameter it chooses to model the situation. We therefore expect a high variability in outcomes with even the slightest change in these initial parameters, especially when considering long-term analysis (20 to 30 years) and the effect that compound interest has on net present value, the most commonly regarded output of this methodology.

Another way of determining feasibility is by comparing alternatives based on isolated parameters and proportioning them in terms of a comparable unit (containers or metric tons of cargo carried, for example). When doing so, while keeping all other aspects constant, one can conclude that the change being considered (the different route and its implications, in our case) has positive or negative effects on that unit of measurement. A simple example would be to only compare distance sailed as a proxy to all cost elements of a voyage and conclude that the shortest route leads to cost savings and thus is economically viable (Benassi, et al., 2016). Of course, this would be an over simplification, but it illustrates the methodology.

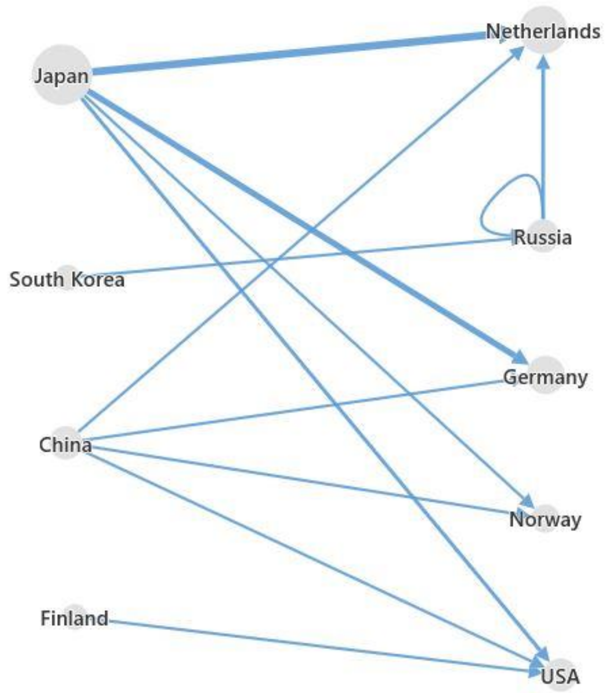

Figure 9 - Origin-Destination pairs in Arctic shipping literature – own work with data from Lasserre (2014)

The purpose of this section is to summarize the studies that use these methodologies with focus on arctic navigation, compare their conclusions and investigate whether it is worthwhile to pursue this endeavor. Additionally, this section will supply our study with parameters that will be very important in determining the trades that will benefit most from potential arctic shipping.

It is crucial to state that, to account for the restriction caused by sea-ice, nearly all studies use some form of projection for the conditions in the Arctic via historical data. This is necessary as the NWP, vis-à-vis other routes, is obviously hindered by this factor and it is the only reason why it is being just now considered as a viable option. This notion highlights the importance of the discussion in the previous section regarding sea-ice forecasting and aligns the methodology of the current research to the existing academic literature.

Many such analysis have been made with regards to arctic shipping, and so meta studies have also been published. One of these is performed by Frédéric Lasserre (2014) where he analyzes 26 different models, their assumptions, parameters and conclusions. This study gives an overview of academic literature on the topic but going deeper on the analysis is crucial to digging out the most valid parameters. Nonetheless, Lasserre's research is very useful and a great starting point to any analysis. Moreover, he uses these resources to propose a model of his own (which will be discussed in due time), and that further contributes to the research.

One of the very first studies to conduct such an analysis in the Northwest Passage was done by Somanathan, et al. (2007) in which the authors seek to determine, via a total cost calculation, if the NWP route would result in reduced costs when compared to the Panama Canal for a voyages between Yokohama (Japan) and St. John's

(Canada) or New York (USA). This study, as many others do, also considers two types of vessels – non-strengthened and ice-class CAC 3[4] – in its analysis to bring into consideration the higher costs of such ships. This implies not only in higher capital costs but consequently higher hull and machinery premiums and dry-docking expenses, which the authors claim have high correlation with each other. Other parameters that varied between the two routes were propulsion power (higher for arctic), bunker prices (which the authors considered different because they assumed bunkering would take place either in NY or St. John's, but had they assumed would take place in Yokohama no difference would exist) and other premiums (P&I, management fees, etc.). They conclude that the Yokohama – St. John's route is less costly via the NWP compared to the Panama Canal, but the contrary is found for Yokohama – New York, the reason being the additional length from St. John's to New York tipping the scale in favor of the Panama Canal.

Table 3 - Voyage time comparison Suez vs NSR vs NWP (days) – Source: (Wang, et al., 2016)

Transport time (days)	Suez	NSR		NWP	
		Transport Time	Saved Time	Transport Time	Saved Time
Rotterdam-Shanghai	32.6	22.6	10.0	24.4	8.2
Rotterdam-Yokohama	34.5	20.3	14.2	22.2	12.3

In a review of case studies, Schøyen and Bråthen (2011) focus on bulk shipping and the advantages of arctic routes (in this case, the NSR) versus the Suez Canal. Once again we observe the clear distinction of favorable geographic locations for shipments originating or destined to Asia through the arctic, making the case that only when the voyages involve northern China, Korea or Japan are they comparable to the traditional route (Buixadé Farré, et al., 2014) (see Table 3 and Figure 9). By comparing total cost per ton, the authors conclude that for a shipment of mineral fertilizers from Porsgrunn (southern Norway) and Shekou (southern China) the NSR was marginally cheaper at a 1.5% difference from the Suez route and adds this is hardly attractive especially when considering the intangible risks of an uncertain trip. For a shipment of iron ore between Narvik (northern Norway) and Qingdao (northern China) they observe a 5% reduction in total costs when considering the use of Panamax sized vessels. This choice was made due to restrictions in draught and ice-breaker beam dimensions and the authors suggest that if the use a Capesize was possible, economies of scale would play a role and additional cost reduction would be a result. On both cases the same methodology and key inputs were used in the comparisons (albeit with different values reflecting each scenario), and these are similar to the ones used by Somanathan, et al. (2007). Assumptions were made in terms of premiums required for design and construction of an ice-class vessel as well as OPEX for operating in the Arctic, resulting in an overall increase in 20% on the daily. Additional charges for Hull and Machinery (H&M) and Protection and Indemnity (P&I) premiums were estimated at $125.000.

One new parameter introduced in this study (and that few authors consider) is the type of freight contract involved in the shipment. This is important to examine for it might determine whether the shipping company can make the decision to take an

[4] Equivalent to POLAR CODE PC3

alternate route. A Contract of Affreightment involves a series of shipments at a fixed price per ton or other unit over a combined length of time. In such agreements the shipper can leave all the planning of the individual voyages to the shipowner, thus allowing the latter to use their resources in the most efficient way it can, which includes taking the route it sees fit, potentially making use of backhaul cargoes, switching the cargo between ships, etc. Stopford (2009) identifies this as common practice particularly for bulk shipments between Europe and the Far East, which makes this a very relevant freight market for the Northwest Passage as an alternative, opportunity-driven route. COAs have a cost structure similar to Voyage Charters, i.e. the shipowner baring all capital, operating and voyage costs.

In his review of the available models at the time, Lasserre (2014) summarizes the key parameters present in the studies and compares not only their values but also their justifications and/or original reasoning. For example, most researchers (roughly 70%) consider the use of some ice reinforcing in the vessels that will be sailing the arctic, however there is considerable variation of the strengthening itself even when comparing vessels sailing the same route, i.e. removing the difference in required standards that might arise from different regulations. This reflects immensely on the results of the economic analysis given higher levels of ice strengthening represents a higher capital premium on the vessels (see Figure 10).

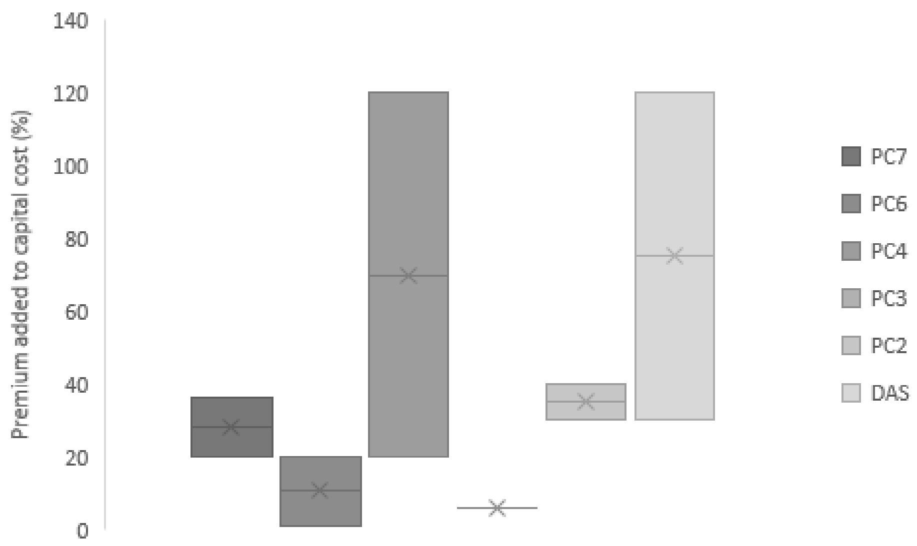

Figure 10 - Variations (min. and max. values) in premium applied to capital costs for each ice-strengthening standard present in Arctic shipping literature – own work with data from Lasserre (2014)

In terms of the object of research there is a definite majority (15 out of 26) of research on container shipping versus bulk or other categories. This is not surprising considering that containerized trade has shown the greatest increase in market share out of the major categories, already represents nearly 16% of seaborne trade in ton-miles and has more than tripled its TEU throughput in the last 20 years (UNCTAD, 2017). Researchers are therefore drawn to this phenomenon and tend to forget the more stable trades. Add to that the fact that the container market has been extremely active and dynamic in its structure with several mergers and alliances forming and shifting in past years which introduces greater interest in determining its profitability.

What might come as a surprise is the breakdown of results into the three main trades analyzed in these models, where we find containers demonstrated to be less likely to be profitable in alternative arctic routes than bulks or general cargo (see Figure 11). Upon further inspection of the results we realize that many of those who conclude on non-profitability had the assumption of limited shipments in the arctic routes, be it because of structural reasons (smaller vessels, physical restrictions, lower load factor) or intangible ones (high risks and low reliability). Nonetheless at least 4 of those 13 studies found some instances where these routes were favorable, albeit either by a small margin or on restricted routes.

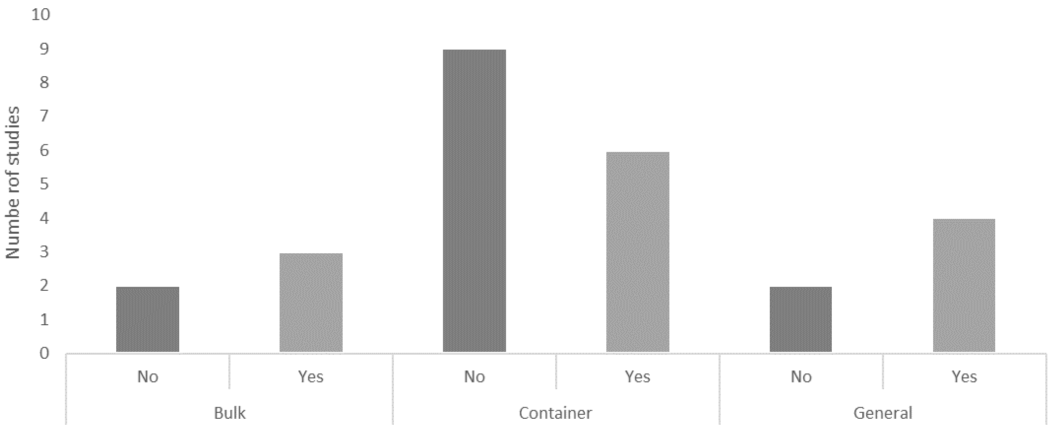

Figure 11 – Profitability conclusion by cargo – own work with data from Lasserre (2014)

Similar variations occur in as fuel costs, sailing speeds, insurance premiums and in many other parameters. This is normal in research and reflects the discrepancies in methodologies, data, biases, assumptions, etc. It is therefore expected that results would vary significantly as well, and they do. Not surprisingly then is the fact that there was an exact split (50%) between the 26 models compared in terms of their conclusions on whether arctic routes are economically feasible.

Lasserre's own model, developed with assumptions gathered from the literature reviewed, concludes the NWP would not be favorable for a route from Shanghai to Rotterdam given the reduced load factor. In fact, his sensitivity analysis shows this is the single most relevant cost parameter in comparing routes, contrary to most other authors who see bunker prices being the primary driver. This is so relevant to Lasserre that when considering a similar load factor on both east and westbound trips (at 60%), the NWP would be cheaper by almost 14% in this origin-destination pair. The break-even point would be at 52% load factor on the NWP. When considering Yokohama – Rotterdam, the Northwest Passage would be more attractive than the Suez route by 20% even with the different load factors (45% – 60% east and westbound respectively) and up to 27% at a 52% load factor, resulting is costs per TEU of $681.12 as opposed to $940.52 by sailing via the Suez (Lasserre, 2014).

The most interesting aspect of the study conducted by Schøyen and Bråthen (2011) is that they decided to compare the alternatives based on equal sailing times and consequently reduced sailing speeds, meaning that the only advantage of the arctic route would be to reduce fuel consumption the cost savings that derive from that. Every other aspect weights against the alternative in terms of added costs. This puts extreme significance on bunker prices as the determining factor in the utilization of arctic alternatives, however the authors see two other factors possibly playing a role.

One is the reduced emissions that result from taking shorter (and possibly sailing at slower speeds) routes may tip the scale in favor of arctic routes if emissions are either taxed or caps are put on shipping companies (forcefully or by their own internal policies).

Secondly, the potential for fuel savings may be waived in leu of reduced lead times which could significantly reduce total logistics costs for an industry. This is particularly interesting to companies that play the role of both the shipper and the shipowner, either by owning the cargo (Vale, for example) or being responsible for end-to-end logistics, as many container carriers have been involved with. When the company can manage the entire supply chain it can opt to minimize total cost by reducing its lead time and consequently pipeline and cycle inventory at the expense of higher transportation costs with shorter transportation time (Chopra & Meindl, 2016). This is exactly the case for the NWP at its current situation, whereby although many studies indicate the route is still not economically feasible in direct comparison to traditional routes it might be attractive to those that see the shipping leg of the supply chain as one more cost parameter in their overall logistics. This notion of two different ways of taking advantage of the shorter route will be further expanded in the discussions chapter.

Others also see this dilemma, such is the case of the Korean Maritime Institute (KMI) interviewed by Lee & Kim (2015), although in this case they have a bleaker view of the situation. It was their opinion that using arctic routes would not be beneficial to shipping companies as they would see lower profits by sailing a shorter route. No further explanation is giving towards this conclusion, but they emphasize that the ones who have more to benefit are cargo owners who have not been championing the use of alternative routes. This conflict is apparently solved by Wang, et al. (2016) in their paper commenting on the work of Frédéric Lasserre, whereby they introduce the notion of “cargo time value” to represent the value that shippers put on saved time brought by faster shipping, apparently neglegtec by Lasserre in his conclusions towards the feasibility of such routes. The authors believe that there is the possibility of charging premiums on freight rates when shorter shipping times are offered (see Figure 12). This is of course the case when shipping companies opt for taking advantage of the reduced distance by maitaining sailing speeds (when possible in these routes) and ultimately reducing the total voyage time, forfeiting the benefit of reduced sailing speeds and fuel costs. That is exactly why premiums are not only possible but justifiable, and the critic to Lasserre’s conclusion, as presented by Wang, et al. (2016), are grounded.

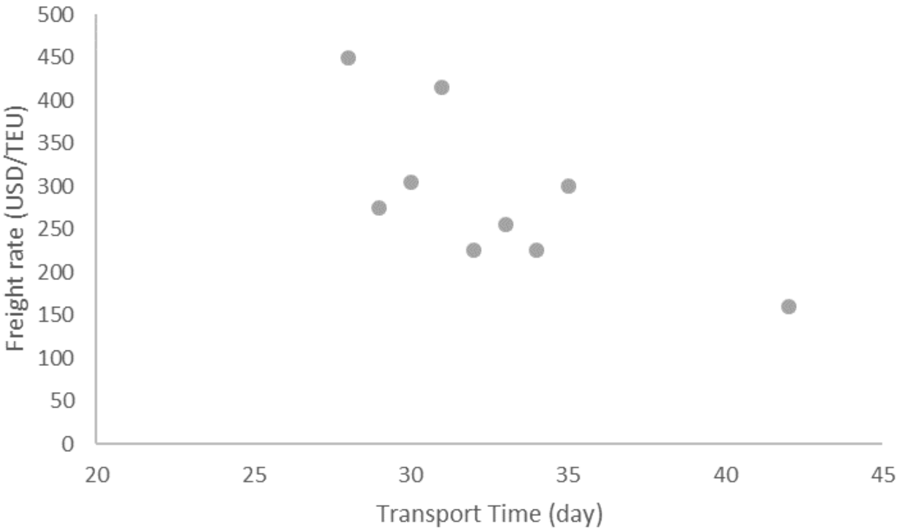

Figure 12 - Freight rates per transport time (Shanghai - Hamburg) - Source: Wang, et al. (2016)

2.3 Network Development

Utilizing a new route or changing a current one is not an easy task, nor does it come without cost. In container shipping, where adherence to schedule and predictability are key aspects, changing course, modifying port calls or adding and removing visits is very expensive and requires massive planning. Set up costs, paperwork, handling and port fees, bunkering schedule and costs are just some of the new parameters to be considered, and administrative costs for dealing with this information also adds up.

Lu et al. (2018) developed a model for an economic evaluation for changing between two transshipment stops in a container liner service though the optics of port competition and how ports can attract more traffic. Although this study incorporated several cost parameters into their model, it failed to consider indirect costs such as the ones mentioned above Notteboom and Vernimmen (2009) studied the effect of bunker prices on container shipping networks and determined it to have “a significant impact on the costs per TEU”, but highlights that liners have been slow to adapt to increasing bunker costs because, in part, of costs related to altering schedule and fleet management. This inertia effect (and costs associated with changes) is augmented by the increasingly complex alliance networks amongst liner companies whereby any change must be in agreement with every company involved.

Bulk shipping, on the other hand, does not seem to have the same issue. Some cases exist where cabotage service is used but these are very specific and usually set up with a specific purpose or project-related case, not resembling liner service such as with containers. Most bulk shipping consists of single port loading and few unloading per cargo, with a limited number of cargo-interested parties involved in the same shipment, most commonly only one in fact. This is not to say that multi-cargo shipments do not occur, they are quite common. Therefore, bulk schedules are usually modeled done as a shortest-route problem where cost factor are distance, port fees and daily costs (Cho & Perakis, 2001). In fact, by applying a model where iterations are crucial to finding the optimal solution, Korsvik, et al. (2010) intra-route changes are forced into the model periodically, showing not only they are not detrimental but are constantly being considered by planners, especially when deciding whether or not to accept spot cargoes in pursuit of higher revenues. Fagerholt and Ronen (2013) provides a comprehensive review of bulk shipping models where route optimization is the focus.

2.4 Other related topics

An important issue comes to surface when dealing with the Northwest Passage: who, if any, has control over these waters? At first glance answering Canada seems obvious, but it is not that straight forward. The United Nations Convention on the Law of the Sea (UNCLOS) dictate that for straits where international navigation takes place any ship shall have the right to innocent passage, which means although a nation still retains sovereignty over the waters of an international strait it may not suspend transit passage (United Nations, 1982).

This notion applies even in exclusive economic zones, which Canada claims is the case for all the NWP. It assumes its sovereignty in the area is a matter of physical control gained and maintained through force (Lajeunesse, 2008). However, this is a largely unpopulated area and the lack of presence and economic activity in the region may give rise to questions over Canadian sovereignty, which is part of the reason why the Canadian government has increased investments in the north. Authors Lackenbauer & Lajeunesse (2014) developed a policy paper where they advise authorities that the most effective way to confirm Canada's sovereignty would be to continue support of safe maritime traffic by assisting with communications, ice-breakers, patrolling, salvage vessels, amongst other practices. Moreover, they believe the expected increase in traffic in the region only reinforces "Canada's legal position by demonstrating an international acceptance of Canadian laws and regulations" (Lackenbauer & Lajeunesse, 2014). Additionally, Lajeunesse (2008) also claims establishing a port in the Arctic would be essential.

This does not mean Canada would not have an opportunity to regulate, to some extent, what goes on in these remote waters. Lajeunesse (2016) cites the inclusion of Article 234 in the UNCLOS as a great diplomatic achievement which guarantees the right to "adopt and enforce non-discriminatory laws and regulations" targeted towards control and prevention of pollution in ice-covered waters (United Nations, 1982). This opened the possibility of charging fees destined to these efforts, which further consolidates Canada's legal precedence of controlling the area, and Lajeunesse (2008) also advocates for this notion.

At this point in time Canada does not enforce fees over transit through the NWP, contrarily to what Russia has been doing. This has been stated as directly benefiting the case for economic feasibility of the NWP. However, it can also be seen as a missed opportunity of financing some much needed infrastructure projects in the region, which is the Russia's justification for charging such fees (Lasserre, 2014).

Another point where international relations come in play in the NWP is the current state of free trade agreements being negotiated (and questioned). With president Donald Trump threatening to renegotiate the terms of NAFTA and pushing for stricter bilateral deals with other trade partners there is a great deal of uncertainty for global trade. On the other hand, a free trade agreement between Canada and the EU (CETA) aims to eliminate virtually all tariffs, boosting and facilitating trade. This may have positives consequences for the NWP

2.5 Conclusion

In this Chapter we explored the available scientific literature on sea-ice forecasting, the implication to shipping and financial modelling of alternative routes. From the range in conclusions on the feasibility of Arctic navigation, brought upon mostly by the variability of initial parameters and assumptions, we confirmed the need for a greater focus on the research subject.

We've discussed critical parameters of the Northwest Passage and established the fundamental characteristics that directly impact shipping. Additionally, we determined what aspects are most impactful to the profitability of the route. These will be the basis of the analysis to be performed in the following chapters.

Chapter 3 – Methodology

Given the information and discussions gathered via the Literature Review presented in Chapter 2 we are now able to develop a strategy to address the research questions proposed in Chapter 1. The methodology is to first identify the prospect trades that will be analyzed in terms of its significance and characteristics and the specific parameters of the NWP that shape how sailing takes place through these waters. Finally, the two will be combined into a Weight Decision Matrix to determine which of the selected trades have the right match with the routes specificities in order to filter those with the highest likelihood of succeeding taking advantage of the route.

3.1 Trades

The NWP's main attractiveness is the fact that it can shorten the distance between loading and unloading ports, therefore it will only be utilized for trades that can reap this benefit. It has been established in the literature review there are limited countries in Asia that should be considered as potential candidates for using the NWP because of the possibility to capitalize on the shorter route. Similarly, on the other end, the only countries that will be considered as potentials are those located in to northern Europe or have direct maritime access to the North Sea region.

Three countries pose a dilemma in regard to whether or not considering them for this analysis because of their geographic location and size of their economy. First of these is Russia, which sprawls the entire Arctic region from east to west and has clear vested interest in shipping in the region, albeit much more focused on the Northern Sea Route given it runs through Russian waters. Russia is not only an economic superpower with its top-15 GPD world rank (UNSTATS, 2018) (see Figure 13) but it also has major political influence in the region. Although there is a chance that Russian trade with either Western Europe or Easter North America may utilize the NWP as a "switch transit route" as coined by Melia, et al. (2016) (when the different Arctic routes become interchangeable in their use according to sea-ice conditions at the time the voyage is being planned, which the authors believe will take place by mid-century), it is more likely that these will actually take place via the NSR. For this reason, we've decided not to consider russian trades in the analysis.

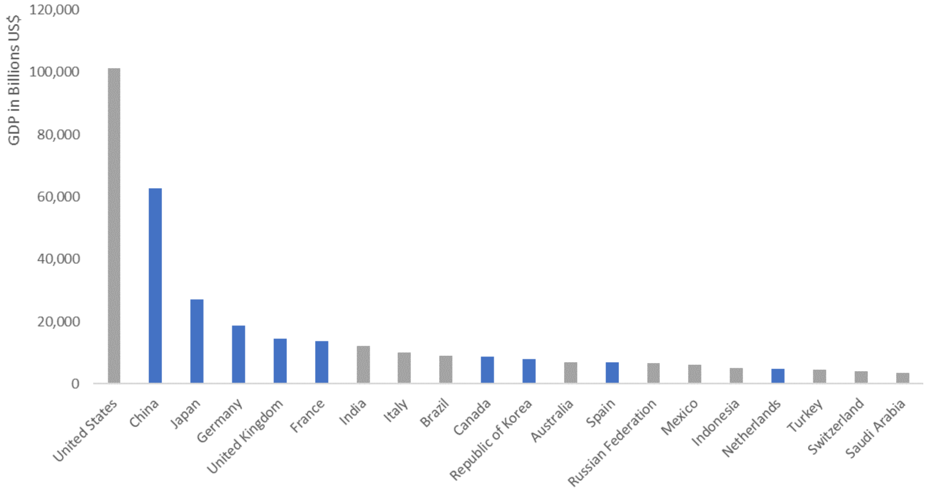

Figure 13 – Top 20 countries by 2016 GDP. Highlighted are the ones in this research – own work with data from (UNSTATS, 2018)

Secondly is the USA, who is one of the main trade partners of nearly all countries in the world (certainly of all the countries interested in artic shipping). Although we realize the potential for the USA to use the NWP for various trades with European, Asian and even internal flows, and knowing that its massive economy is important to any throughput analysis, it will not be a subject in this research. There are two main reasons: 1) it is very difficult to assess the precise origin of a trade within a country and this would lead to wrong conclusions if we consider potential volume that would never take place via the artic (the obvious examples are Asia-West Coast USA and Europe-East Coast USA); 2) the USA has access to both the Pacific and Atlantic Ocean and a well-developed inland transportation network of road and rail. It is easy and affordable for a shipper to move its cargo internally to a port in either coast and save in the maritime leg.

The third country that present similar traits as the ones discussed above is Canada. This is also an important trade partner with many of the subject countries and counts on shipping as its only resource to connect with all of them (except the USA). It does have access to both oceans but lacks the interconnectivity of inland transportation that the USA has, and it is ultimately divided between the two coasts in economic activity and population (see Figure 14), which brings a similar challenge of separating country-wide statistics into regional data. However, the Northwest Passage runs entirely across their territorial waters and may become not only a driver in international trade for Canada but also an internal connection between the two very distinct countries divided but a vast, rough and nearly empty territory. Therefore, Canadian trade will be taken into consideration for this research's analysis.

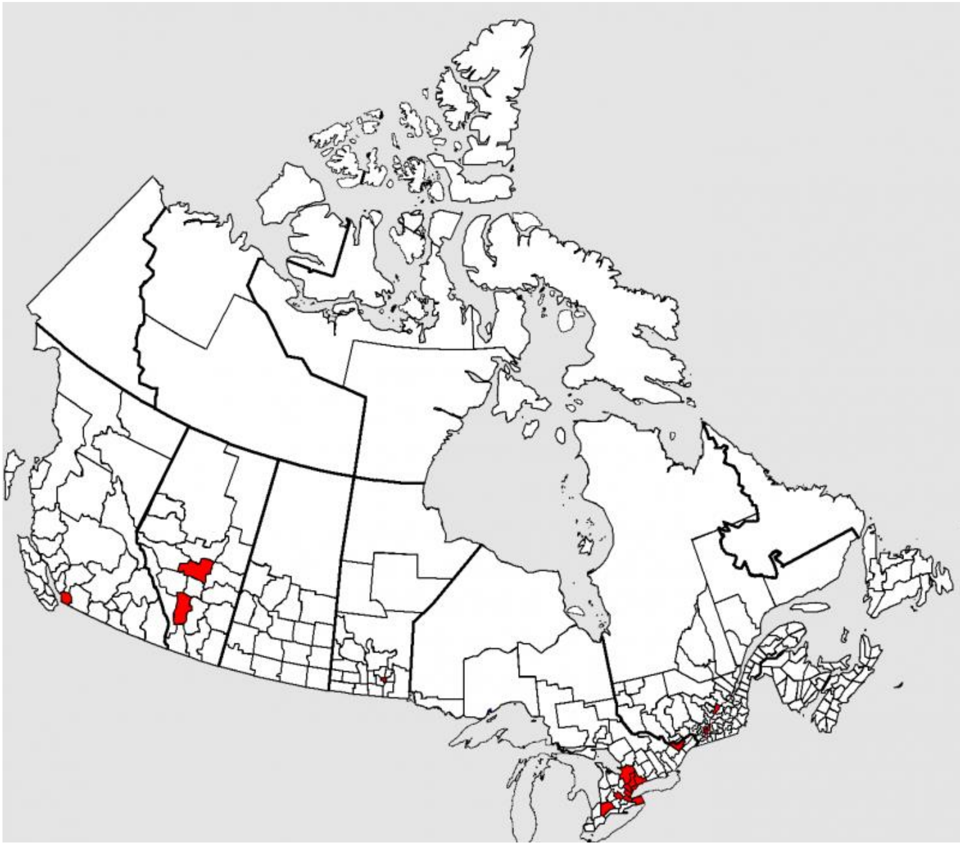

Figure 14 - Population distribution in Canada - 50% of the population lives in the highlighted areas. Source: (The Huffington Post Canada, 2016)

With these premises we start by identifying what are the macro relations, at country level data, between the targets. This is done with statistics on trade value between nations available from the United Nation's International Trade Statistics Database (COMTRADE), the largest such database in the world, with reports dating back to 1962 on hundreds of commodities and products categorized by the Harmonized System (HS). Because there is a clear imbalance in the number of countries considered in Asia (only 3) and Northern Europe (10+), the Asian countries will be considered the "reporters" of the data, while Europeans will be considered the "partners". Canada will be treated as a reporter as well, but in this case, it will also allow the Asian countries as partners. This limits the amount of data and analysis required while still taking into consideration every possible allowed combination.

This first step consists of ranking the biggest trade partners by total trade value, in US dollars and performing a Pareto analysis to narrow down the focus to the countries that combined represent 80% of the total of import and export values (see Figure 16). Considering both flows is important as there is no restriction on sailing in any direction and it also allows for all trade possibilities, thus eliminating one of the biggest constraints of the many of the available literature which is focusing solely in one commodity and many times in only one flow. The result is a new set of origin-destination pairs determined by the relevancy to the research (on the grounds of what was discussed prior) and their value (see Figure 17).

After analyzing these initial connections, we proceed to investigate each relationship deeper by sorting, for each pair of origin-destination identified, the most relevant commodities / products traded between them. The 2-digit HS level consists of 99 categories and is the most common categorization but is too detailed for our purpose. To summarize the figures analyzed we condense the classification down to the 1-digit HS proposed by the Atlas of Economic Complexity of the Harvard University. Table 4 presents the 10 categories used in this analysis and a few examples of sub-categories chosen here in no particular order but merely to illustrate what can be found in this level of categorization. Again, we use a Pareto analysis on the commodities categorized by 1-digit HS (high level classification) to prioritize the relevant categories and make a distinction between import and export for the same reasons stated previously.

Table 4 - 1-digit HS classification and sub categories

1-digit HS Category	Sub Categories
Electronics	Telephones Electrical transformers Transmission apparatus Electromechanical domestic appliances Electronic integrated circuits
Machinery	Pumps, compressors, fans Medical, surgical instruments Gas turbines Transmission shafts
Metals	Structures and their parts of iron or steel Aluminum plates Tubes or iron or steel Metal tools
Minerals	Iron ore and concentrates Petroleum oils, crude and refined Petroleum gases Zinc ore
Other	Commodities not specified
Stone and Glass	Jewelry Construction Stone Safety glass Glass fiber
Textiles and Furniture	Apparel, knit or not knit Footwear Lamps, seats, curtains Cotton
Transport Vehicles	Parts of motor Cars, trailers and semi-trailers Ships Rail locomotives
Vegetables and Foodstuffs	Soybeans, corn Vegetable oil Wood, pulp of wood, paper Coffee, tea and spices

This classification is sufficient to determine what type of cargo and, most importantly, the most likely vessel deployed for that trade. Figure 18 summarizes trade values and proportionate weight of each for all countries involved. It is the representation of the current situation of trade between countries that have an opportunity to benefit from sailing the NWP.

3.2 NWP parameters

In this section we will determine what are the fundamental parameters of the NWP that are crucial to decision the making process of a shipper or shipping company. These will be used to characterize the route.

Accessibility is likely the most significant trait of Arctic routes, and the one discussed more frequently as the defining factor in its success. With sea-ice being the obvious barrier to vessels, there are three main characteristics that determine its availability: the extent of coverage of sea-ice, its thickness / density and the duration of the ice-free season. If these aspects are known, and to some extent predictable, it is possible to determine the feasibility and plan a voyage through the passage.

These aspects have been discussed in literature review on the topic and are not a subject of this research given the high level of technical expertise required in analysis and forecasting. The volume of literature, the quality of peer-reviewed research and the acceptance of the results published give confidence in applying these findings into our study. In any case, there is no need to determine with pinpoint accuracy what the accessibility of the NWP will be like in the future, but rather establish the length of the season. We will focus on mid-century scenarios which are more reasonable to consider than end-century ones without accepting excessive bias in the forecasting.

Table 5 - Navigable window parameters

Study	Type of Vessel	Mid-Century Conclusions
Smith and Stephenson (2013)	Open Water	There will be a 53-60% probability of a successful voyage in September
Khon, et al. (2010)	Open Water	100 days window in the summer (+-35 days)
Melia, et al. (2016)	Both	60% success rate for September with OW; 100% for summer transits for PC6
Benassi, et al. (2016)	N.A.	80% of models predict low sea-ice concentration (<15%) in summers

Table 5 summarizes the findings recently reported for forecasting research on the Arctic Ocean cited in this study. It encompasses not only the navigable window, but also the ice-class restriction associated with it. As a conservative approach we will consider the 60% likelihood that a 3-month window will be open for navigation through the Northwest Passage as of mid-century for open water vessels. For ice-class ships of category PC6 or higher we will consider a 100% chance in this period, plus an extra 2-month extension of the window.

This has implications for trades that are sensitive to seasonality, for those who have a peak season in shipping may or may not have that season matching the one with good sailing conditions through the NWP. Additionally, the trades that have a high flexibility in terms of the vessels used may benefit from the occasional use of ice-strengthened ships when there is such an opportunity. On the other hand, well-structured trades with long-term fixed schedules (such as container liners) will not be well positioned to benefit from this, given additional costs of substituting a vessel in their rotation, unless investments are made in their fleet guaranteeing such capability. These issues will be discussed in Chapter 4.

No report was made, in the reviewed literature, towards any kind of navigability restriction in the NWP such as shallow depth or narrow passages. To the contrary, the NWP is seen as less restrictive than the competing routes, like the NSR (Arctic Council, 2009) where draft is an issue. Likewise, the canals present in the traditional alternatives (Panama and Suez) actually pose such restrictions, although they are so important in maritime trade that rarely a vessel is built without taking these into account

3.2 Decision Matrix

To determine we combine the results from the trade analysis, vessels and their characteristics with the restrictions and parameters of the Northwest Passage into a Weighted Decision Matrix that allows us to establish the highest scoring trade (the most suitable for NWP sailing). The trades (alternative options) will be compared against the routes specificities (criteria), therefore the weights, according to importance to decision making, will be applied to the route parameters and each trade will be scored, individually, according to how well it matches with each parameter. Going back to the research objective, this table will in a list of trades that have the best likelihood of being successful in sailing through the NWP and can be used by shipping companies to score their own individual case to help guide the decision-making analysis of whether or not to take this route.

The weights C_i will range from low impact (1), medium impact (3) and high impact (5). That means an individual route parameter weighted at 1 has low importance in the decision-making process, i.e., it does not affect significantly the decision and can be interpreted as a low restriction. Conversely, those with a weight of 5 are highly determinant of the success expected of the voyage and can make or break the possibility of the endeavor.

Table 6 - Criteria and weights applied to the matrix

Criteria	Impact	Weight
Availability and Seasonality	High	5
Contractual Flexibility	Low	1
Cost Sensitivity / Competitiveness	High	5
Ice Strengthening Requirement	Medium	3
Network Flexibility	Medium	3
Physical Restriction	Low	1

Table 6 summarizes the criteria selected and their respective weights according to the discussions in Chapter 2. Availability of the route is the factor with the highest impact given it is the most distinct aspect of the NWP, i.e., it is only projected to be physically possible to transit in a restricted amount of time every year. Therefore, trades that can take advantage of the opening score higher in this category.

Cost sensitivity measures if trades can absorb the additional financial burden expected of a typical voyage in the Arctic and remain profitable, including extra costs for hull reinforcements and ice-class certification, insurance premiums and other expenses particular to this voyage. Market competitiveness is a proxy for this parameter as when there are many players competing margins are usually lower (see Figure 15), acting as strong disincentive to increasing costs and risks. Container shipping, as an example, is very competitive and cost sensitive, whereas not many players exist in specialized and project cargo trades, which operates on much higher margins. These two criteria have the highest impact and significance to the analysis and therefore have a weight of 5.

The category Ice Strengthening Requirements does not consider the costs associated with strengthening the vessel, but whether the typical vessel in this trade is suitable for such high level of specialization. This can be measured by how specific the cargo is and the vessel needs to be to accommodate it. Dry bulk vessels are usually very flexible in the type of cargo they can manage so having specialized units in your fleet is not a big issue for shipping companies and may increase their market potential. It does not grant a weight of 5 because ice-strengthening is not an absolute requirement as we've seen in literature review, with some authors suggesting that even OW vessels will have a high likelihood of transiting the NWP by mid-century.

Figure 15 – Inter-industry profitability margin comparison - Source: McKinsey&Company (2016)

Network and contractual flexibility have some overlap in their analysis, assessing how possible it is for a shipping company to make changes in their schedule both from a client perspective (network) and a legal one (contractual). Container liners have a high commitment to their weekly schedules and usually negotiate their port stops on a semi to yearly basis and the current state of alliances has inserted an extra layer of complexity to the analysis (Notteboom, et al., 2017).

However, networks are harder and more expensive to adjust and have a higher impact on the financial success of a trade, whereas contracts can be negotiated more frequently, thus Network Flexibility has a weight of 3 and Contractual Flexibility weights 1. Physical constraints are weighted low, as it has been established that the Northwest Passage does not pose significant barriers to sailing for typical vessels apart from the presence of sea-ice, measured in a different category. It should still be considered because maneuvering through ice is likely to be a requirement in the beginning and end of the sailing season and longer vessels will have a harder task than shorter, more maneuverable ones (Arctic Council, 2009).

Individual scores A_j will range from 1-5 according to the fit between the alternative and the parameter being assessed. These scores will be discussed in Chapter 4. The final score will be calculated by the sum of the products of each weight multiplied by their individual score in that parameter (see Formula 1). This methodology allows for each significant aspect to be considered according to their relevance. It is a commonly used qualitative technique in Multi-Criteria decision analysis (MCDA).

Formula (1): $$Score = \sum_{i,j} C_i * A_{ji}$$

Where C_i is the weight the criteria and A_j the score of each alternative *j* to criteria *i*.

Chapter 4 – Analysis

In this chapter the results of the Decision Matrix will be presented and justified individually per alternative. Comparisons between trades will be made on specific criteria and overall to motivate the conclusions and discussions of Chapter 5. We start by determining the targeted trades resulting from the trade value analysis.

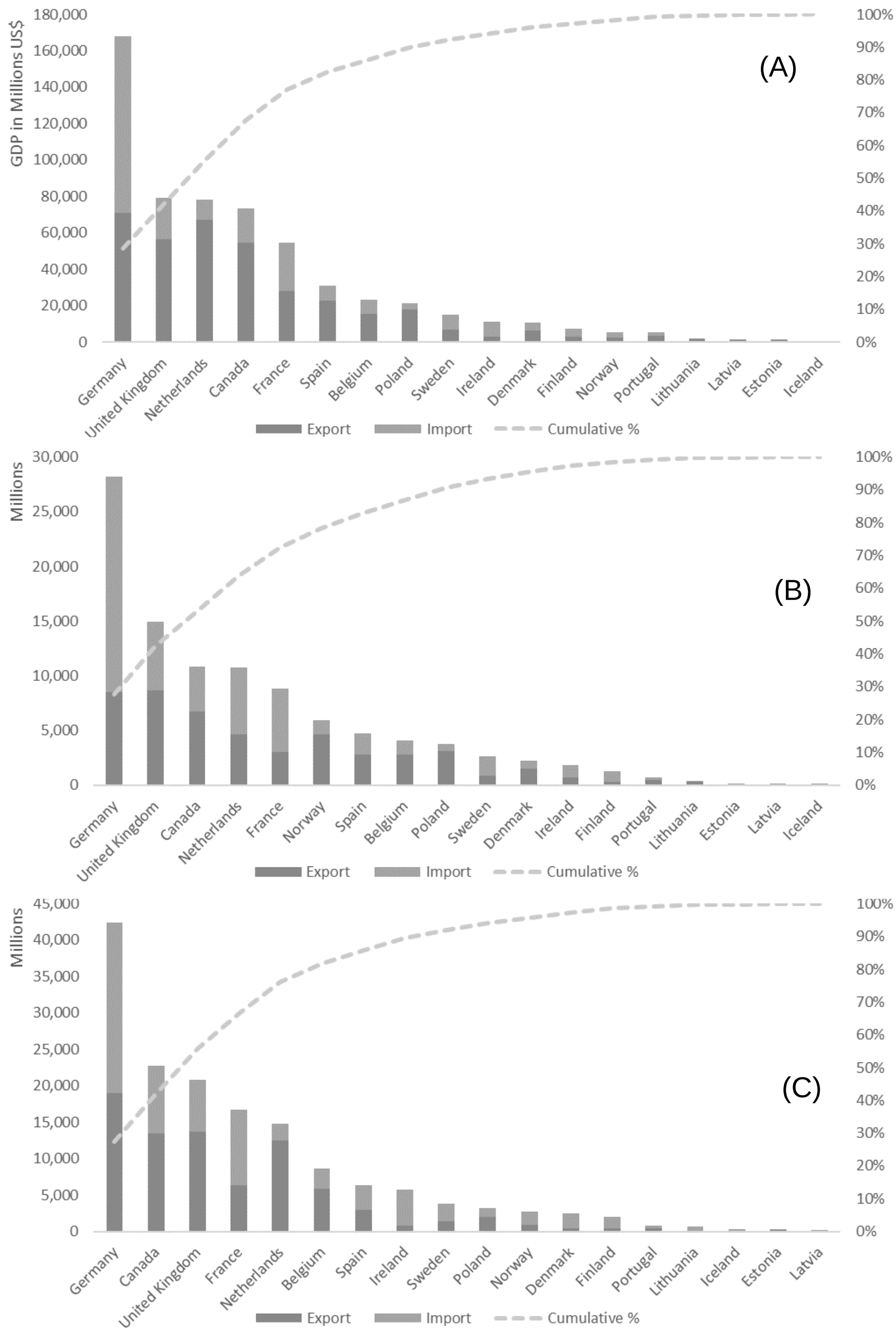

Figure 16 - Pareto analysis of total trade value (in US$ Million) for (A) China; (B) South Korea; (C) Japan broken down by import/export. Own work with data from (UN COMTRADE, 2018)

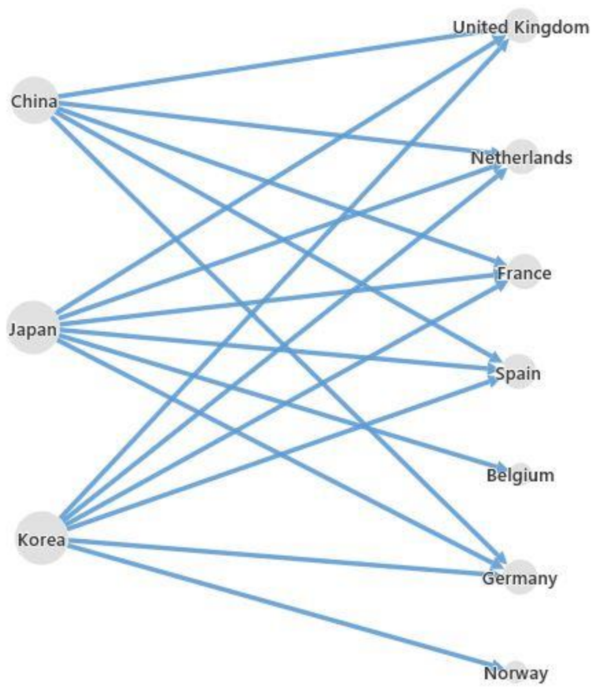

Figure 17 - Origin-Destination pairs selected - own work with data from (UN COMTRADE, 2018)

The analysis in Figure 18 reveals that most trade consists of high value, industrialized finished goods like machinery and electronic equipment. Nearly all of these goods are transported in containers given their high unit value and time sensitivity. There is a significant imbalance in the Electronics category, with 75% of trade value representing shipments from Asia to Europe.

Transport vehicles and vehicle parts / engines are very commonly transported via roll-on / roll-off vessels, which have a completely different shipping dynamic than containers. Noticeable in this category is the prevalence of Asia-Bound traffic (nearly twice as large as Europe-Bound shipments), due in most part to China importing a substantial amount of total traded value (43%).

The chemicals and plastics category present two different possibilities: finished goods, usually shipped in containers and raw chemicals used in various industries which are transported by specialized liquid bulkers, a very specialized trade. Similarly, the “vegetables and foodstuffs” category is split between finished, high-value goods such as beverages, but also contains wood and pulp products as well as grains that are transported as bulk cargo. Additionally, low figures for the “metals” and “minerals” category, where ores, petroleum by products and oils are registered, indicates not a lot of basic materials trades takes place.

The analysis allows us to determine the predominant vessels operating between these countries and consequently establish their basic characteristics.

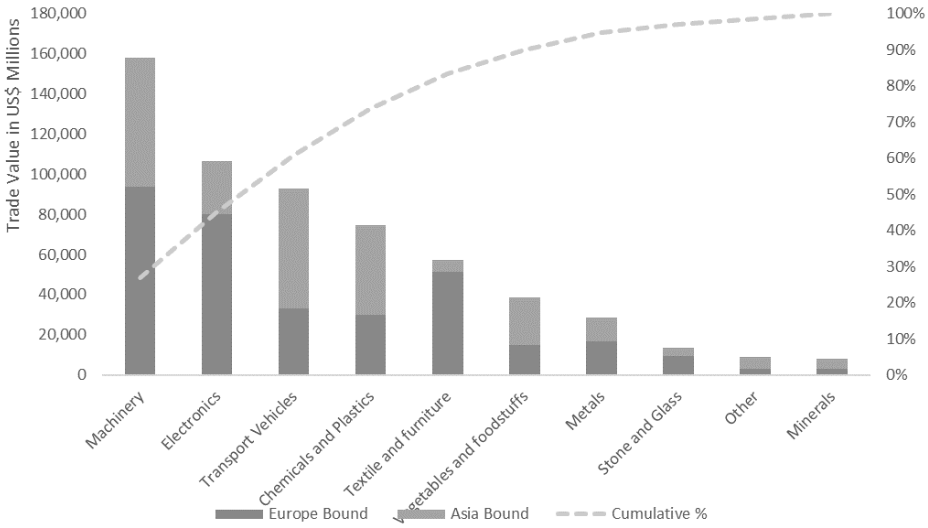

Figure 18 - 2-digit HS classification of products shipped between subject countries – own work with 2016 data from (UN COMTRADE, 2018)

4.1 – Dry Bulks

Table 7 - Results for Dry Bulks

Criteria	Weight	Dry Bulk	
		Score	**Total**
Availability and seasonality	5	2	10
Contract Type	1	4	4
Cost Sensitivity	5	3	15
Ice Strengthening Requirement	3	4	12
Network Flexibility	3	4	12
Physical Restriction	1	4	4
TOTAL		**57**	

The first trade analyzed is Dry Bulks. Although it does not represent a high percentage of the trade value between subject countries, it is vast in its scope and has high volumes in terms of tonnage, which makes it worthwhile to study. The average size of bulk vessels and total tonnage is presented in Table 8.

Regarding the first criteria bulks do not score high, not particularly because they are affected by the navigable window timing, but due to its duration. Bulks handling is time consuming and cycles are long because of it, which means limited shipments are possible in the span of 3 to 4 months, especially considering the voyage itself takes upwards of 20 days per leg. Unless major planning effort is given (which results in higher inventory costs), bulk trades will not be able to benefit too much form the window.

Bulk vessels are generic in design and flexible in nature, being able to handle anything from grains to iron ore with appropriate care being taken to cargo safety and quality (Stopford, 2009). This means shipping companies are more willing to invest in ice class certification because they can afford to have a share of their fleet available to these opportunities. Apart from the major trades of iron ore and coal, the average cargo size is not higher than 60,000 tons, which indicates a prevalence of medium sized vessels like Panamax granting it a high score in “Physical Restriction”.

In terms of contracts, there is a high incidence of voyage charters especially for more fragmented trades where there are many exporters. For trades such as iron ore, which are highly concentrated, long terms contracts are more common and sometimes shipping is handled by the cargo owner itself. However, these are often arranged as COAs, which leave the decision in the hands of the shipping companies (Stopford, 2009, p. 428). In this sense Bulks score high in the network and contract criteria.

Table 8 - Profile of Bulk trade – adapted from (Stopford, 2009)

Type of Cargo	Number of Cargoes	Total Tonnage	Average Size (tons)
Iron Ore	889	131,397,500	147,804
Coal	743	81,021,000	109,046
Grain	326	16,540,135	59,737
Heavy Grain	104	4,639,787	44,613
Coking Coal	72	3,114,500	43,257
Wheat	64	2,175,960	33,999
Sugar – bulk	116	1,981,400	17,230
Bauxite	20	1,097,000	54,850
Barley	15	554,000	36,933
Sugar - bagged	47	518,575	11,034

4.2 – Chemical

Chemicals represent 13% of trade value between the subject countries with a split of 40% being Europe bound and 60% destined to Asia (see Figure 18), and although a portion of it is represented by finished goods transported in containers (pharmaceuticals, for example) there is significant volumes of organic chemicals, hydrocarbon compounds, fertilizers and other products shipped in bulk. Figure 19 describes the chemical tanker transport model.

All the nations studied have a high level of industrialization and final production takes place in any of them. Organic / inorganic chemicals, vegetable oils and molasses are the most demanded categories of chemical transport needs and are usually traded in small consignments (average size 1,475 tons but can be as low as 500 tons) and transported in segregated tanks in vessels of 10,000 dwt (Stopford, 2009).

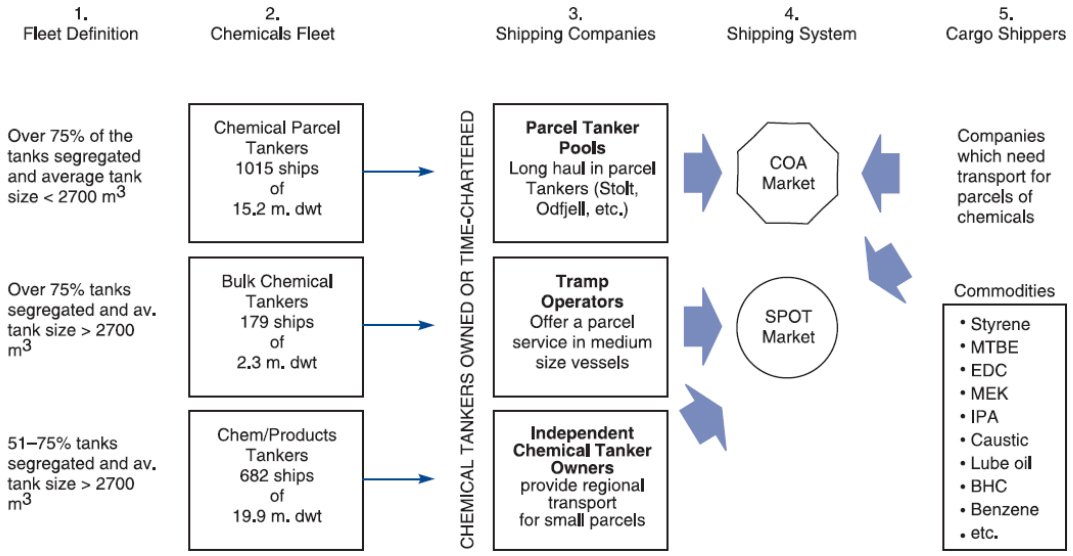

Figure 19 - Chemical transportation system model – Source: (Stopford, 2009)

From this description its clear this trade scores high in terms of contract flexibility with its preference for COA and spot charters. Additionally, small consignment and vessel sizes grant this trade high scores in physical restriction. There is no clear seasonality in this sector, supply and demand are stable. Moreover, these vessels can sail faster and handling at port is more efficient with the use of hoses and pumps (compared to bulk unloading), meaning there is much more opportunity to take advantage of available window and making more trips during that time.

The pulverized shipping market results in a medium score in cost sensitivity due to high competitiveness and reduced margins. The compartmentalization of the vessels is suitable for small parcels but also means a vessel may be carrying cargo for several different clients, making it hard for companies to make changes to their network without negative effects to their clients. Good planning is mandatory for shipping companies to take advantage of the cost savings brought by the NWP.

Table 9 – Results for Chemicals

Criteria	Weight	Dry Bulk	
		Score	Total
Availability and seasonality	5	4	20
Contract Type	1	4	4
Cost Sensitivity	5	3	15
Ice Strengthening Requirement	3	4	12
Network Flexibility	3	2	6
Physical Restriction	1	5	5
TOTAL		**62**	

4.3 – Container

Container shipping is the most studied trade recently because of its immense growth and importance to maritime trade and global economy, and that has been the case for research on Arctic shipping. It is responsible for most of the trade value between Asia and Europe being a very convenient, reliable and cheap way of shipping finished goods.

Table 10 - Results for Containers

Criteria	**Weight**	**Containers**	
		Score	**Total**
Availability and seasonality	5	4	20
Contract Type	1	2	2
Cost Sensitivity	5	2	10
Ice Strengthening Requirement	3	4	12
Network Flexibility	3	1	3
Physical Restriction	1	4	4
TOTAL		**51**	

This is a very competitive market with low operating margins (see Figure 15) where cost savings is the name of the game, so companies are not willing to risk an increase in costs resulting in a low score. Additionally, higher capital costs from ice strengthening is not attractive. However, since bunkering can represent more than 50% of the cost per TEU of a typical 11,000 TEU vessel, there is some incentive to save in fuel consumption by sailing shorter routes.

The charter market is not flexible, with long-term time contracts, which makes it harder to take advantage of opportunities like seasonal routes. Moreover, a typical liner has weekly stops on several port calls, so making any changes to this schedule is not a common occurrence and has considerable costs associated with it, which grants low scores in both criteria.

On the positive side there is some correlation between the period where the NWP is open and the peak of the container season, which takes place between August and October, in preparation for the holiday shopping season. Since this is a trade with over 6,000 ships in operation, with nine companies operating more than 100 vessels each and three of those with a fleet of over 500 ships (Alphaliner, 2018), there is the possibility of specializing a share of their fleet to ice-class certification without sacrificing capacity or flexibility, . Indeed, recent news have shown that companies are taking this route (Port Technology, 2018). Particularly these ice-strengthened vessels are suitable to arctic operations with their modest sizes not being a concern in terms of physical constraints.

4.4 – General and Project Cargo

This sector deals with cargo that is not efficiently transported and handled by bulk or container, either because of its dimensions (not confirming to container standards) or for being commonly handled as unit loads and not loose cargo (such as pallets, bags, bundles, etc.). Heavy equipment such as electrical generators or rail locomotives are high value items that render high freight rates but are not easily handled and transported by conventional vessels. Additionally, these are two examples that fit well with the profile of trade taking place between the subject countries of this research.

Stopford (2009) describes “specialized shipping” in five categories? 1) Chemical tankers (which was already analyzed); 2) Gas tankers; 3) Refrigerated ships; 4) Unit load vessels (where general cargo and Ro-Ro vessels are found) and 5) Passenger vessels. General cargo vessels come in all shapes and sizes, but apart from specialized heavy duty lifting or industrial use, these need to be somewhat flexible in design to be able to attend to a large spectrum of cargos. Additionally, since parcel sizes are not as big as bulk or crude shipping, general cargo vessel tend to be limited in size. Open hatch and multipurpose ships had an average size of 24,000 dwt in 2006 according to assessment made by Stopford (2009). This trade therefore receives a high score in the Physical Restriction criteria, losing points only due to unforeseen consequences of the harsh climate of the Arctic.

Table 11 - Results for General Cargo

Criteria	**Weight**	**General Cargo**	
		Score	**Total**
Availability and seasonality	5	5	25
Contract Type	1	4	4
Cost Sensitivity	5	5	25
Ice Strengthening Requirement	3	2	6
Network Flexibility	3	4	12
Physical Restriction	1	4	4
TOTAL		**76**	

Freight comes at a premium in this sector resulting from specialized handling requirements and occasional low ship occupancy due to odd sized cargo. Additionally, many general cargo vessels come equipped with handling equipment, and specialized design like hatches that open to the full width of the ship can increase capital costs from 25 to 50% compared to standard bulk design. The result is a high score for cost sensitivity.

Particularly for project cargo, which is the carriage of unique loads with unconventional dimensions and requirements, there is great potential in terms of network flexibility since these are rare and carefully planned operations which can take advantage of timely opportunities for cost savings. This also means a high performance in the window of navigation category. A common project cargo load traded between Asia and Northern Europe is equipment for container terminal handling, which are massive in size and are shipped in 4 to 6 units at a time.

Figure 20 - Quay Cranes at the end of their journey from China to London

Other examples involve the shipments of wind turbines for projects in the North Sea, as well as the vessels in charge of assembling these pieces at location. These are all odd sized cargos and ships that don't conform to usual shipping standards but are still significant to the trade between these countries. This market can take advantage of the window of opportunity of the summer periods in the Northwest Passage and have the potential to benefit greatly from its potential cost savings.

4.5 – Roll on / Roll Off

The final trade studied is the transport vehicles which account for 16% of trade value amongst our subject countries. There is a significant imbalance with Asia bound value being twice as large as the opposite direction. Germany alone exports almost US$ 13 billion worth of "cars" (which consists of small to large sized vehicles, diesel engines included), to China and an additional US$ 10 billion to Japan and Korea combined.

Roll On / Roll Off vessels are the to-go solution for vehicle haulage given their specialized design with multiple levels for parking and ramps to allow for vehicles to be rolled in and out of the decks (which explains its name). This greatly minimizes loading and unloading times and maximizes storage of these items which cannot be stacked or handled by cranes, but also severely restrict the vessel to basically one category of cargo. For this reason, they have low incentives to further specialized in ice strengthening, although there are examples of such vessels in regular services like ferries.

Like container liners, many Ro-Ro services run on fixed schedules with timely planned stops in their route, making it costly to change their network for a short amount of time. Several different consignments are carried in each voyage for various clients in different locations. Contracts are also rigid and long-term, giving low scores in both categories.

On the upside the trade is constant in its distribution throughout the year and cycles tend to be fast, which allows shippers to take advantage of the navigable window period if so desired. Additionally, although these can be very large vessels, their low-density cargo and no requirement to be serviced by ship-to-shore cranes leads to low draught requirements. The largest such ship at the time it was launched in 2011, the MV Tonsberg, had a draught of only 11m, resulting in high score for physical restriction criteria.

Table 12 - Results for Roll on / Ro off

Criteria	**Weight**	**Ro-Ro**	
		Score	**Total**
Availability and seasonality	5	4	20
Contract Type	1	2	2
Cost Sensitivity	5	4	20
Ice Strengthening Requirement	3	2	6
Network Flexibility	3	2	6
Physical Restriction	1	5	5
TOTAL		**59**	

4.6 – Results

Table 13 summarizes the findings and compares the final scores of each trade for every category.

The analysis shows General Cargo / Project Cargo trades are the ones with the characteristics that best fit with the potentials presented by arctic shipping in the Northwest Passage. Commercial players in this market sector should be considering the possibility of sailing through the NWP in their future endeavors from Asia to Northern Europe, or vice versa. The higher premiums on freight rate for special cargo and the contractual landscape of fully loaded voyage charters allow for decision makers to accept the still higher risks and indirect costs of arctic shipping while benefiting from reduction in voyage costs. Additionally, the use of the NWP may reduce total supply chain costs by shortening lead times and lowering inventory costs.

Chemical trades are also well positioned to benefit, however the market is pulverized and segregated between cargo owners and shippers. Those that are able to do full load shipments and would have lower or no costs in changing their routing network for a short period of the year will have a significant advantage in using the NWP.

Dry bulks have these traits but their larger consignments and increased handling times at port result in not being able to take full advantage of a limited window of opportunity. If more “optimistic” scenarios for the NWP are considered and the season is extended, or if ice-strengthened vessels are deployed in this trade, bulks will be benefited.

Although the most common target of the studies in economic feasibility analysis of the arctic routes, containers are not the most suitable for the voyage according to this methodology. Their networks are rigid, and it is costly to change them, especially twice a year to adjust to the sailing season. Additionally, the competitiveness of the trade leaves little margin for absorbing higher indirect costs. Ro-Ro trades have more room in the books to work with then containers, however they share the same characteristic of carrying cargo for multiple clients requiring many port visits, which is not conducive to network changes.

Table 13 - Conclusions from the Weighted Decision Matrix

Criteria	Weight	Dry Bulk	Chemical	Container	General	Ro-Ro
Availability and seasonality	5	10	20	20	25	20
Contract Type	1	4	4	2	4	2
Cost Sensitivity	5	15	15	10	25	20
Ice Strengthening Requirement	3	12	12	12	6	6
Network Flexibility	3	12	6	3	12	6
Physical Restriction	1	4	5	4	4	5
TOTAL		**57**	**62**	**51**	**76**	**59**

Chapter 5 – Conclusion

This study presents a thorough literature review of research on the state of the Arctic Ocean regarding the changing climate, warmer temperatures, sea-ice forecasting and the impact on the shipping industry. We establish that the NWP will be navigable by mid-century by open-water vessels for a 3-month window during summer months in the Arctic in 60% of the years. If ice-strengthened vessels of category PC6 are deployed, by mid-century the window is expended by 2 months and the success rate increases to every year.

The fundaments of economic and technical feasibility analysis are reviewed as it pertains to studying the viability of shipping through the Northwest Passage. The criteria identified as the most impactful to a successful transit (when the choice of sailing the NWP is more economically attractive than the alternative) are used to assess each trade on their own likelihood of using the NWP.

We discuss how analyzing the feasibility of a single voyage can be a limited approach. Using the shorter NWP can result in two different benefits for the supply chain: to reduce lead time and consequently inventory costs for cargo owners or simply reducing voyage costs by sailing at lower speeds without sacrificing lead time. In reality a mix of both is the most likely outcome with a reduction in voyage time and in sailing speeds resulting in benefits to both the cargo owner and the shipper. Companies that handle their own chartering and transportation can adjust this mix in a way that minimizes costs in their whole supply chain.

The study argues that, while both ways of analyzing this phenomenon are valid in their rights, combining the findings of the two not only is a unique approach but generates a set of conclusions of its own, with value to further research, to policy makers and commercial players with stakes in arctic shipping.

From the groundworks done in the literature review, the study proposes a weighted decision matrix as the methodology for combining, in one analysis, the two ways of studying the topic that has not been done before, thus contributing also to the theory on alternative route analysis. Parameters for the NWP were derived from scientific research of the physical conditions existing today and expected for the future in the Canadian Arctic. An analysis of trade patterns was conducted to determine the countries that have the potential to benefit from arctic shipping and the trades taking place between them currently. Characteristics of the most significant trades was presented. The decision matrix weights the fit between both the parameters of the NWP and characteristics of the trades to assess what trades are expected to benefit most.

Research on sea-ice forecasting is booming currently, with global warming and its consequences a focus of attention of many around the world. New findings from this particular field will fine tune this analysis and can have a significant impact on the weights applied and the conclusions.

Future research can find a way to differentiate trade flows to/from eastern and western USA and link them to the corresponding pair of origin/destination nodes identified here, enriching the Pareto analysis and possibly shifting the focus of the trades studied. Similarly, a distinction made in northern and southern China and eastern and western Canada will filter data that, as discussed, should not be considered in the analysis.

Decision makers can fine tune the parameters used to fit their individual characteristics and assess whether they are well positioned to benefit from this alternative route. Future research on the relation between sea-ice forecasting and shipping can focus their attention to trades that have a higher likelihood of using the route and save time and energy on studying ones with limited chances to succeed, thus bringing value to their findings.

Policy makers and commercial organization interested in supporting a route that saves overall costs and reduces shipping emissions by both sailing shorter distances and potentially at lower speeds may prioritize their policies on the findings of this research, maximizing legal and commercial efforts and optimizing resources. Many commercial enterprises may find a new business model based on the possibilities brought upon a new shipping network.

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