Development of Decision Making Techniques for Analysing the Designation of the Northern Sea Route (NSR)

Ahmad Fayas Ahmad Najib

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Abstract

The Northern Sea Route (NSR) located in the Arctic region is now open for the whole summer season due to the reduction of ice cover in the Arctic Ocean. As a consequence, one would expect that navigation in the Arctic region would become much easier. However, no parts of the NSR are entirely ice-free and there is no guarantee that merchant ships cruising along the NSR would complete their journey. Further to this uncertainty, there are also political, economic, technical, and safety issues to be dealt with. Despite that, the prospect of being able to shorten the route between Europe and the Far East using the NSR as a permanent shipping lane is attracting increasing interest. This is why the use of the NSR is now a major topic, especially in financial circles, amongst politicians, and shipping operators. Numerous assessments to determine the potential cost advantage of using the NSR as a transit route have been conducted throughout recent years. These are, however conflicting in their conclusions and a final answer to the question is therefore lacking.

The primary aim of this research is the application of decision-making tools to analyse the current routes of the NSR. Accordingly, this will lead to the development of decision-making techniques that will formulate a tool for shipping companies to select the most cost-effective route(s) for travelling between the Far East and European regions.

Four phases of research study have been undertaken. In the first phase, a model or hierarchical structure is developed using the pair-wise comparison technique of Analytic Hierarchy Process (AHP). This hierarchical structure contains every factor that influences the opening of the NSR. In the second phase, a decision making model is developed to select the most effective shipping transit route within the NSR. The model combines two different techniques which are the Evidential Reasoning (ER) method and a pair-wise comparison technique. In the third phase, a decision making model is proposed to select the best shipping transit route between the Far East and Europe by using Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS). A considerable body of high quality publications and reference materials are analysed to support the models. In the final phase, solutions to enhance the use of the NSR are proposed by using Soft System Methodology (SSM).

Most types of research conducted previously have only focussed on the quantitative or numerical aspects, neglecting to examine the qualitative aspects of the NSR. The proposed models in this research are efficient decision-making techniques which integrate both quantitative and qualitative aspects of the evaluated route. Accordingly, this can also be used to assess and support the decision whether to use the NSR or not.

Findings from this research imply that the decision making techniques presented can be used by shipping companies or any decision makers to determine the best shipping transit route between the Far East and Europe. The developed models are generic and can be tailored to facilitate other factors and decision modelling in other applications.

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Abbreviations

ABR	Arctic Bridge Route
AHP	Analytic Hierarchy Process
AIS	Automatic Identification System
AMSA	Arctic Marine Shipping Assessment
ANP	Analytical Network Process
ARCDEV	Arctic Demonstration and Exploratory Voyages
ARCOP	Arctic Operational Platform
CATWOE	Customer-Actors-Transformation-Weltanschhaung-Owner-Environment:
CI	Consistency Index
CLCS	Commission on the Limits of the Continental Shelf
CMs	Conceptual Models
CNPC	China National Petroleum Corporation
CO_2	Carbon Dioxide
CR	Consistency Ratio
DAS	Double-Acting Ship
DE	Distance
DWT	Deadweight Tonnage
EER	Escape, Evacuation and Rescue
EEZ	Exclusive Economic Zone
ELECTRE	Elimination and Choice Expressing Reality
EM	Emissions Factor
ER	Evidential Reasoning

FCS	Fleet Composition Strategies
FESCO	Far Eastern Shipping Company
FSICR	Finnish-Swedish Ice Class Rules
GeoMean	Geometric Mean
GIS	Geographic Information System
GLONASS	Global Navigation Satellite System
GMDSS	Global Maritime Distress and Safety System
GPS	Global Positioning System
GRT	Gross Tonnage
HAS	Human Activity System
HSA	Hard Systems Approaches
HSVA	Hamburg Ship Model Basin
IACS	International Association of Classification Societies
IB	Icebreaker
IBRU	International Boundaries Research Unit
IDS	Intelligent Decision System Software
IMO	International Maritime Organisation
INSROP	International Northern Sea Route Programme
JANSROP	Japan Northern Sea Route Programme
LNG	Liquefied natural gas
MAUT	Multi-Attribute Utility Theory
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
METAREA	Geographical sea regions for coordinating meteorological information

MODM	Multiple Objective Decision-Making
MOHQs	Marine Operations Headquarters
MoT	Ministry of Transport
MSC	Murmansk Shipping Company
NAVTEX	Navigational Telex
NEP	Northeast Passage
NIS	Negative Ideal Solution
NO_X	Nitrogen Oxide
NSR	Northern Sea Route
NSRA	Northern Sea Route Administration
NWP	North-West Passage
OAT	One-at-a-time
OBOR	One Belt One Road
OPEC	Organization of the Petroleum Exporting Countries
OR	Operational Research
P&I Clubs	Protection and Indemnity insurance
PC	Polar class
PIS	Positive Ideal Solution
PSMs	Problem Structuring Methods
PWCM	Pair-wise comparison matrix
RMRS	Russian Maritime Register of Shipping
SCR	Suez Canal Route
SE	Systems Engineering
SOP	Standard Operating Procedure

SO_X	Sulphur Oxides
SSM	Soft Systems Methodology
SWOT	Strengths, Weaknesses, Opportunities, and Threats
SY	Safety Factor
TC	Total Cost
TEU	Twenty-foot Equivalent Unit
TKR	Trans-Korea Railway
TOPSIS	Techniques for Order Preference by Similarity to Ideal Solution
TPP	Trans-Polar Passage
TS	Transport Services
TSR	Trans-Siberia Railway
TPSR	Transpolar Sea Route
TT	Transport Time
UAVs	Unmanned Aerial Vehicles
UNCLOS	United Nations Convention on the Law of the Sea
UNCTAD	United Nations Conference on Trade and Development
VIKOR	VlseKriterijuska Optimizacija I Komoromisno Resenje
WTO	World Trade Organisation

CHAPTER 1:
INTRODUCTION

Summary

This chapter presents background to the research and explanations necessary to justify the principal research aim and objectives. A broad and comprehensive literature survey is presented including justification of the study according to industrial and academic needs. A number of techniques and methods are highlighted for consideration and finally, the scope of the research study is presented.

1.1 Definition of the study area

First, a distinction should be made between the Northern Sea Route (NSR) and the Northeast Passage (NEP). The NEP is a historical term representing the transit route north of Russia linking the Northern Atlantic and Northern Pacific Oceans. It is a somewhat abstract term without strictly defined borders or end-points. Conversely, the NSR which is the term used by Russia – is a clearly defined entity. According to the official Russian definition, it stretches from the Novaya Zemlya islands in the west to the Bering Strait in the east. However, in this thesis, the term NSR also implies NEP which also has been used interchangeably by previous studies.

1.2 Background of the study

During the 16th Century, the search for alternative, shorter seaways to Asia began in earnest as European colonial powers expanded their empires and trade routes into East Asia. Several expeditions mainly organised by Great Britain and the Netherlands were sent out to the Russian Arctic to search for the route known as the Northeast Passage (NEP) (Ragner, 2008). Unfortunately, all these expeditions were either destroyed or forced to return due to severe and prevailing ice conditions. Thus, it was not until 1879 that the NEP was finally 'conquered', when the Finnish-Swedish explorer Adolf Erik Nordenskiold reached the Bering Strait following a full passage from Europe, and spending one winter along the way (Ragner, 2008).

Although Nordenskiold's passage through the NEP was considered a great historical achievement at the time, it was not to have any significant impact on world trade patterns. Despite Nordenskiold's success, it is evident that the severe ice conditions posed a significant obstacle and threat to sustaining commercial transit passages. However, it does highlight the changing climatic conditions that have been occurring in the Arctic region over recent years.

These changes have noticeably led to a reduction in the amount and extent of sea ice, its thickness as well as extending the navigation season for all vessels, including those of low ice classes or without ice strengthening capabilities. The prospect of being able to shorten the route between Europe and the Far East using the NSR as a permanent shipping lane is attracting increasing interest. Being able to use the NSR as a permanent marine shipping lane would bring enormous benefits to trade between Europe and the Far East. Notwithstanding, this is why the use of the NSR is now a major topic, especially in financial circles, amongst politicians, freight forwarders and shipping operators. A further reason behind the interest in the NSR as a marine shipping lane is due to the possibility of using the lane to transport hydrocarbons and other natural resources currently extracted in the Arctic region. Also important, is the possibility of using the NSR to transport resources from known resource deposits in northern Russia, which are currently not used due to the lack of viable transport options. Notably, this last point may cause significant changes in natural resources in global markets. Particular interest in the use of the NSR has also been demonstrated by the European Union, which recognised the lane's growth potential by taking this feature into account in developing its plans (Pastusiak, 2016).

There is no doubt that the reduction of ice cover in the Arctic Ocean has accelerated recently. As a consequence, one would expect that navigation in the Arctic region would become much easier, although, it is not entirely viable. According to Ragner (2000), no parts of the NSR are entirely ice-free even during the most favourable summer month (September). Indeed, this kind of information along with data on the extent of sea ice from year-to-year and the geographical variability of the ice indicates that there is no guarantee that merchant ships cruising along the Northern Sea Route (NSR) would complete their journey. Further to this uncertainty, there are also political, economic, technical, environmental and safety issues to be dealt with. Also, due to the high variability and challenging ice-conditions present along most of the NSR, the optimal route choice for vessels navigating the NSR will vary. Depending on seasonal, regional and annual variations in ice-cover, vessels will sometimes need to select routes closer to the mainland. Whereas, at other times, routes may be chosen to transit through the many archipelagos, and sometimes routes north of them. Based on many of these conditions and decisions that need to be made, vital questions are raised. Is it profitable to use the NSR as a trading route? What factors need to be considered? Can a shorter route outweigh the risks and safety of the vessels? Most types of research conducted previously have only focussed on the quantitative or numerical aspects, neglecting to examine the qualitative aspects of the NSR.

However, not all of these studies ignored the qualitative aspects, but instead, failed to integrate these aspects into their model and decisions.

Accordingly, this research is aimed at decision-makers and commercial companies facing the dilemma of whether to engage in trade or shipping along the NSR and what degree of uncertainty needs to be considered when making important long-term decisions. Therefore, it is important to apply an efficient decision-making technique which integrates both quantitative and qualitative aspects of the evaluated route. Accordingly, this can also be used to assess and support the decision to use the NSR or not. Also as a consequence, the different conclusions formed over recent years, following various assessments, can be surpassed along with a clear indication of the vessel's profitability using the NSR compared to the Suez Canal route (SCR).

1.3 Research Aim and Objectives

This research is primarily aimed on the application of decision-making tools to analyse the current routes of the NSR. This will develop the decision-making techniques in formulating a platform for shipping companies to select the most cost-effective route(s) for travelling between the Far East and European regions in summer season. The objectives of the research programme are:

1. To identify through a literature review factors that will influence the opening of the NSR.
2. To rank and prioritise the factors by using one of the modern decision-making methodologies.
3. To investigate a number of routes along the NSR and select the most effective shipping transit route by using one of the modern decision-making methodologies.
4. To select the best shipping transit route between the NSR and the conventional routes by using one of the modern decision-making methodologies.
5. To find solutions for enhancing the use of the NSR by using one of the modern problem structuring methodologies.

The key finding of research is a clear understanding of the NSR in terms of its environmental characteristics, political, economic, social, legal and other aspects in its current situation. Then, the next key finding is to list and rank the important aspects of NSR for shipping companies to consider before it is used for shipping operations.

Another key finding is the choice of shipping routes within the NSR. All available routes within the NSR are compared by using the decision-making methodology to help the decision makers choose the best route. In doing that, all relevant factors will be identified and put into a model, which is another key finding of the research.

Next key research finding is the selection of the best shipping route between the NSR and conventional maritime routes, such as SCR, Cape of Good Hope route, Trans-Siberian Railway and through air transportation. The key findings will be the factors identified and model for selecting the best route between the Far-east and Northwest Europe in summer season.

The last key finding is the structuring of the NSR problems and solutions to the problems. This is done by using one of the many problem structuring methodologies.

1.4 Justification of the research

The Northern Sea Route (NSR) is located along the Russian Arctic Coast with some areas free of ice for about three months of the year (Xu *et al.*, 2011). However, due to climate change, the Arctic Circle and ice is gradually reducing, and the NSR in future may be free of ice at least throughout the summer season (Ragner, 2000; Liu and Kronbak, 2010). Therefore, it is vital for shipping companies to consider using the NSR as an alternative route as it offers shorter distances especially between the Far East and Europe. Asia to Europe trade today is dependent on the shipping route via the Suez Canal. The current alternative to Europe is via the Cape of Good Hope, although the NSR can be one of the alternatives for the same trade route. The navigation distance between a Northwest-European port and the Far East via the NSR is approximately 40 % shorter compared to the Suez Canal route (Schoyen and Brathen, 2011). Furthermore, the economy of China is moving at a fast pace to become Asia's economic centre of gravity from the Southeast to the North. Among the 15 largest container ports globally (2015), 12 ports are Asian, and 8 of these are Chinese (World Shipping Council, 2016). Further, Asian mother ships are gradually leaving Southeast Asia for Northern China. By this geographical change, it would appear sensible to transfer part of the shipment from the Suez route to the NSR.

The Arctic Ocean has been dramatically affected by climate change (Liu and Kronbak, 2010). Future predictions indicate an even more drastic reduction of the Arctic ice cap which will expose new areas for exploration of natural resources and maritime transportation. Indeed, this situation may present a very convenient and efficient export corridor for the movement of Russian natural resources. Enormous reserves of various metals, oil, gas, timber and coal are located close to the shore of the Russian Arctic Ocean or along the rivers that flow into it.

Previous studies have defined the NSR as a series of different routes, and the sailing course frequently depends on the prevailing ice conditions (Eide *et al.*, 2010; Erikstad and Ehlers, 2012). The NSR is not a clearly defined linear route; it is the whole sea area north of Russia. Due to the high variability and challenging ice conditions along most of the NSR, the optimal route choice for vessels navigating through the NSR will vary (Ragner, 2008; Blunden 2010). Hence, many route options can be employed in the NSR, and it is essential for shipping companies to choose which route is best. Consequently, by selecting the most cost-effective route, shipping companies can gain benefits in operating their vessels along the NSR. For example; 1) reduction of bunker fuel costs, 2) reduction of gas emissions, 3) saving in port fees, agent fees and pilotage fees, 4) shorter distance between Far East and European trade, 5) reduction in total journey time, 6) increase round trip voyage (in a given period) and 7) reduction in the ships' operational and voyage costs

1.5 The Scope of the study

The scope of the study is illustrated in Figure 1.2. Four major Arctic shipping routes have emerged resulting from the reduction of sea ice namely; 1) North-West Passage (NWP), 2) Northern Sea Route (NSR), 3) Transpolar Sea Route (TPSR) or Trans-Polar Passage (TPP) and 4) Arctic Bridge Route (ABR). The focus and scope of this study is on the NSR, given it has the highest potential compared to the other Arctic routes. There are two types of shipping; Liner (containership) and Tramp (bulk and tanker). The shipping operations between the two are noticeably quite different, for instance, their operations and shipping costs. In this research, both types of shipping will be highlighted with the use of simulations and modelling.

The scope of the research is centred upon the rationale for undertaking this thesis, which is, a shipping route assessment and decision-making for the route selection. This study intends to emphasise the application of several decision-making tools or techniques and their potential to offer attractive features, not always achievable by traditional means. Therefore, this thesis only examines and explains the relevant methods and techniques to achieve the aim and objectives of the study as mentioned.

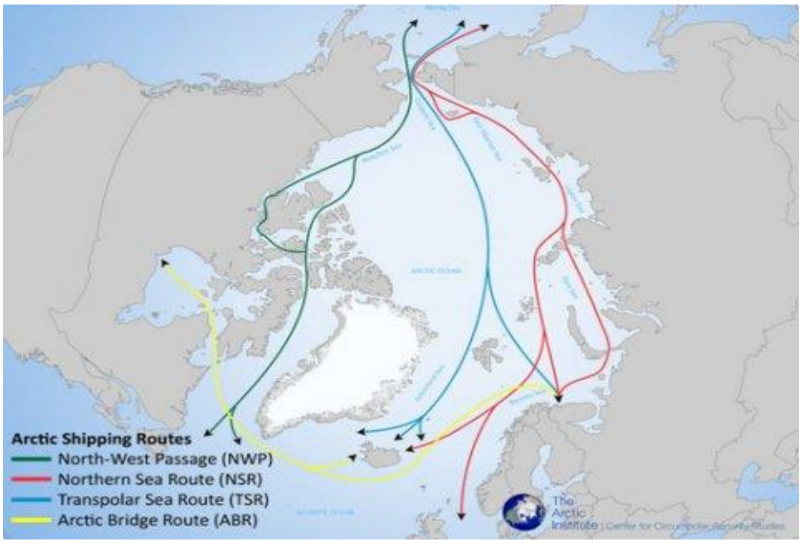


Figure 1.1**:** Map of the major Arctic shipping routes (Humpert and Raspotnik, 2012).

1.6 Conclusions

This chapter provides the basis for undertaking the research by introducing the background to the problem and research objectives. The justification for the research is presented along with the scope of the study.

CHAPTER 2:
LITERATURE REVIEW

Summary

In the first part of the chapter, major factors influencing the opening of the NSR are identified and discussed to increase the level of understanding about this new shipping route. The literature has been divided into eight main factors, namely; 1) Political, 2) Legal, 3) Economic, 4) Environmental, 5) Social, 6) Technological, 7) Safety and 8) the advantages of the NSR in comparison with other routes. Then, in second part, a number of decision making techniques are also presented.

2.1 Introduction

Throughout many years, the NSR has evolved from an internal shipping route into international shipping route. Before the NSR can be used for commercial shipping, the situation in the NSR needs to be reviewed. In this chapter, all major factors are identified from relevant journals, books, international reports, theses and websites. The definition of major factors will be first clarified. This is to ensure that the identified factors are grouped in the same and correct order. Factors defined are mostly provided by PESTLE analysis. PESTLE is a strategic planning tool used to evaluate the impact of political, economic, social, technological, environmental and legal factors that a project may have on a project. These definitions provided by PESTLE analysis were modified to suit this study. Eight major factors are introduced and presented in the next part of this chapter.

Multi-criteria decision making (MCDM) techniques will be employed in the next chapters. Therefore, some relevant MCDM techniques, such as AHP, ER, TOPSIS, ELECTRE, PROMETHEE and VIKOR will be reviewed. The problem structuring methods (PSM) will also be reviewed in this chapter.

2.2 The factors that influence the opening of the NSR

There are eight major factors that influence the opening of the NSR as follows:

2.2.1 Political Factor

Political factors determine the extent to which a government may influence the economy or a certain industry (Abdul Rahman et al., 2014; businessdictionary.com, 2019). For example, a government may impose a new tax or duty in which the entire revenue generating structures of organisations may change. Political factors include tax policies, fiscal policy, and trade tariffs that a government may levy around the fiscal year. Moreover, it may greatly affect the business environment. In terms of the NSR situation, a political factor is any activity related to government policies and its administrative practices can affect all parties involved in the NSR.

In 1991, the NSR was formally opened for foreign shipping (Moe and Jensen, 2010, Ostreng, *et al*. 2013). Notably, since this time, the Russian government has continued to promote the international use of this new route (Blunden, 2012). Russia is currently promoting year-round maintenance of the entire route as a means of bringing hard currency into the country (Mulherin, 1996). According to Moe and Jensen (2010), substantial investment is needed to make the NSR a viable transport route, and the absence of Russian state investment means that the operational condition of the route may continue to decline despite the improvement of ice conditions. Russia has invested 910 billion Roubles (13.99 million Pounds Sterling) towards the development of ten search and rescue centres along the NSR as an attempt to reduce open water rescue response times (Erikstad and Ehlers, 2012). Also, Russia's Arctic policies mentioned that it would build and develop infrastructure, including ports, customs facilities and marine checkpoints along its 17,500 kilometre Arctic coastline between 2011 and 2015 (Blunden, 2012). However, this is not happening because, according to Staalesen (2019), a massive development of new industry and infrastructure is still needed to develop the NSR. A total of 10.5 trillion Roubles (126 billion Pounds Sterling) of investment must be made in the region over the next ten years (Staalesen, 2019).

Regarding collaboration between the Russian government and other countries, Russia is willing to allow international participation in the management of the NSR (Blunden, 2012). In 2010, the Chinese began to collaborate with Russia where the China National Petroleum Corporation (CNPC) signed a strategic agreement with Sovcomflot, a Russian Maritime Shipping company, where the companies will coordinate their efforts in the utilisation of the NSR (Barents Observer in Blunden, 2012). The agreement envisages trans-Arctic shipment during the summer season and will cooperate in the shipping of hydrocarbons from Russia's offshore fields, while at the same time training Chinese mariners in Arctic Navigation. South

Korea is also playing a growing role in Arctic economic development by operating an Arctic research station at the Ny-Alesund research base. However, the interest of South Korea in the Arctic is purely commercial (Blunden, 2012). In news recently reported by Staalesen (2018), leaders of Russia's Vnesheconombank (VEB) and the China Development Bank met to sign one of their countries' biggest bilateral investment deals ever. The agreement includes the provision of more than 600 billion Roubles ($USD 9.5 billion) of Chinese investment money to the state-controlled VEB. It is aimed at creating a financial mechanism for joint integration processes on the area of the Eurasian Economic Union and the Chinese Belt and Road initiative (OBOR). The NSR is presented as a priority because of the approximately 70 projects that will be covered by the new agreement it was the only route specifically mentioned by name in the press release from the Russian bank (Staalesen, 2018).

The Northern Sea Route Administration (NSRA) is an institution responsible for the procedures for shipping in the area, including the introduction of security and environmental measures (The Northern Sea Route Administration, 2014). However, there are several issues regarding the administrative procedures of the NSR. According to Verny and Grigentin (2009), the NSRA imposes a heavy administrative burden that could drive away maritime companies. For example, local inspection of the vessel is mandatory even though the vessel fulfils the requirements. Ragner (2000) mentioned in his report that Russia's right to carry out inspections in the exclusive economic zone is to ensure compliance with Russian regulations being questioned by shipowners. This is because, vessels with sufficient ice-class and insurance coverage should be able to proceed without hindrance. The inspection process, as well as tariff negotiations, requires planning two months in advance with a potential reduction in this process of around one month for subsequent journeys. Compared to the 48 hours' notice that is required plus one day waiting at the Suez Canal this represents a significant hurdle, which in future needs to be improved (Erikstad and Ehlers, 2012). However, according to Liu and Kronbak (2010), shipowners should submit their requests to use the NSR at least four months in advance to the NSR Administration (NSRA) in Moscow, with a copy submitted to the NSRA representatives in Murmansk or in Vladivostok, depending on the entry point of the NSR. At present, a ship is not allowed to deviate from its route without permission granted from the Marine Operations Headquarters (MOHQs), but a revision to this restriction and control may be considered in the future (Ragner, 2000).

The Service of Marine Transport under the Ministry of Transport (MoT) is responsible for organising all NSR activities centrally. However, the overall supervision of NSR affairs is entrusted to the Northern Sea Route Administration (NSRA) (Ragner, 2000). Actual operations, including scheduling, route assignment, navigational support, pilotage and so forth are controlled by two marine headquarters (MOHQs). Their areas of authority divide at longitude 125º. The ships and shipments originating at the western end of the route are directed by the MOHQ located at Dikson on the Kara Sea coast. The formerly state-owned Murmansk Shipping Company (MSC) operates the Dikson MOHQ. For traffic originating at the eastern end, the corresponding authority is the Far Eastern Shipping Company (FESCO). FESCO's administrative offices and MOHQ are located in Vladivostok and at the East Siberian Sea port of Pevek, respectively. The MOHQs also act as centres for search and rescue, emergency ship repairs and the enforcement of safety and pollution-prevention measures (Mulherin, 1996; Ragner, 2000).

The Russian regulations set out that all vessels wishing to enter the NSR (including all areas within the Russian 200 nm exclusive economic zone) should notify the NSRA beforehand and submit an application for an ice-breaker escort (Ragner, 2000). The application must contain information on guaranteed payment of NSR fees and adequate insurance documentation to cover environmental pollution damage. Further, the vessel must also meet special ice-class requirements. Indeed, there is a range of minor technical requirements, including compatibility with the Russian ice-navigation technique of close towing, requiring increased strengthening in the bow and the ability to fasten towlines. Such requirements, in fact, exclude the use of vessels with bulb bow design (Ragner, 2000).

To arrange transit of the NSR, the following must be included in the request: (Liu and Kronbak, 2010).

- Name of the vessel, flag, address, port of registry and communication numbers of the shipowner.
- Gross/net tonnage and displacement of the ship.
- The ship's principal dimensions (length/breadth/draft), engine output, speed, age and propeller material and design.
- Type of bow construction (bulbous or knife).
- Ship's class including ice class, the name of society and date of the last examination.
- Expected date of the voyage.

- Presence of a certificate of insurance or other financial security concerning civil liability for environmental pollution damage.
- Purpose of the voyage (cargo transport-state port of loading /discharging).
- Owners preferred place of inspection by the administration's inspector.

Upon preliminary approval, the ship and its equipment will be inspected for ice worthiness by agents of the MSC or FESCO. It is assumed that the shipowner will pay all costs associated with delivering the ship to the respective port where a FESCO or MSC agent resides.

After passing the inspection, a ship is granted "Permission for leading through the seaway of the NSR". Depending on the capabilities of the ship and the ice-breaking resources at hand, the MOHQ will then schedule the date and determine the route of the voyage. The MOHQS are the full-service providers for any authorised usage of the NSR (Liu and Kronbak, 2010).

Erikstad and Ehlers (2012) mentioned that the corresponding political risks and uncertainties involved are considered very severe because the NSR is in Russian territorial waters. The rising military presence in the Arctic is increasingly justified by the need to project Russia's national influence and sustain claims over the region's sea-lanes and natural resources (Mortimer, 2017: Kaczynski, 2013). Regarding the international political configuration between the Arctic coastal states, international cooperation in the North Pole may continue. For instance, in March 2014, Government officials from the eight members of the Arctic Council held a summit in Canada. The Council on Foreign Relations published a very helpful guide on the jostling among the countries to capitalise on the shipping routes and energy resources that could be unlocked as the Arctic gradually melts. The main players are the countries with Arctic Ocean coastlines, namely; Canada, Denmark (Greenland), Norway, Russia, the United States (Alaska), and, to a lesser extent, Finland, Iceland, and Sweden. These nations have generally agreed to work together in principle to resolve any territorial and environmental issues (Friedman, 2014).

According to the international-law professor Michael Byers, The Russians have been quite cooperative in the Arctic during the past decade, probably because they realise how expensive it would be to take another approach, especially one involving militarisation (The Canadian Press, 2014). Kaczynski (2014) also mentioned that there might not be any piracy or terrorism in the NSR but the unpredictable behaviour of the Russian government about the selected prospective users of the NSR might be an important constraining factor. However, Russian authorities have signalled a flexible attitude towards foreign vessels wishing to use the route (Ragner, 2000).

2.2.2 Legal Factor

According to Rastogi and Trivedi (2016), legal factors included current and impending legislations that might affect the industry in areas, such as employment, competition, health and safety. Therefore, all legislations and regulations with regard to use of the NSR by shipping companies and other parties are mentioned next.

The United Nations Convention on the Law of the Sea (UNCLOS) is the primary legal source governing the issues of sovereignty over the world's oceans. UNCLOS is a comprehensive treaty dealing with a multitude of international law issues relating to the high seas and territorial and coastal areas, including navigation rights, natural resource exploitation and environmental responsibilities. Accordingly, the treaty sets various boundaries extending from the coast to the high seas; internal waters, territorial waters, contiguous zone, exclusive economic zone, continental shelf limit and international waters, designating certain rights to the coastal nations accordingly. The region of the Arctic without national sovereignty consists mainly of the ice-covered ocean rather than land. Thus, the UNCLOS governs this particular region (Isted, 2009).

The legal regime of the Arctic was not established through international agreements, unlike the Antarctic regime. Instead, it was defined by national legislation of the Arctic States, primarily Russia and Canada, which have the longest coastlines of the Arctic States (Ragner 2000; Bentzen & Hall, 2017). The present Russian regime for NSR shipping (as set out in the 1991 Regulations for Navigation on the Seaways of the NSR), is based on Article 234 of the UN Convention on the Law of the Sea. Article 234 states that a coastal state has the right to unilaterally adopt and enforce laws and environmental regulations in its exclusive economic zone where ice coverage causes exceptional hazards to navigation, and where the environment is especially vulnerable.

There are eight Arctic States, but only five have coastlines bordering the Arctic Ocean: Russia, the United States, Canada, Denmark, and Norway. Each of these five States has staked legal claim to territory in the Arctic based on historical claims of discovery and use, effective occupation, national identity, geographic proximity, Native use, and scientific data (Watson, 2009). The nations' overlapping claims and varied legal positions support the need for a new legal framework under an Arctic treaty. In August 2007, Russian parliamentary deputy and Arctic explorer placed a Russian flag close to the North Pole, declaring that 'the Arctic is ours and we should manifest our presence' (Pranjic & Unverdorben, 2016). Other Arctic states, such as Canada and Denmark, soon followed suit by announcing they would explore extending their State's sovereignty. In the upcoming years, tensions de-escalated, as the eight Arctic States reaffirmed their commitment to the UNCLOS in the 2008 Ilulissat Declaration. Furthermore, academics seems agree on the view that all states involved have more to gain from cooperation within the existing international legal framework than from escalation. This notion was reaffirmed by the resolution of a 40-year dispute between Norway and Russia over the Barent Sea in 2011, which saw an equal division of the contested territory (Castonguay, 2017). However, considerable territorial disputes in the region remain unresolved and the effectiveness of UNCLOS in this regard is debatable. Moreover, the extent to which states will respect the existing international legal framework cannot be known with certainty, in particular when taking into account deteriorating relations between Russia and the West (Pranjic & Unverdorben, 2016).

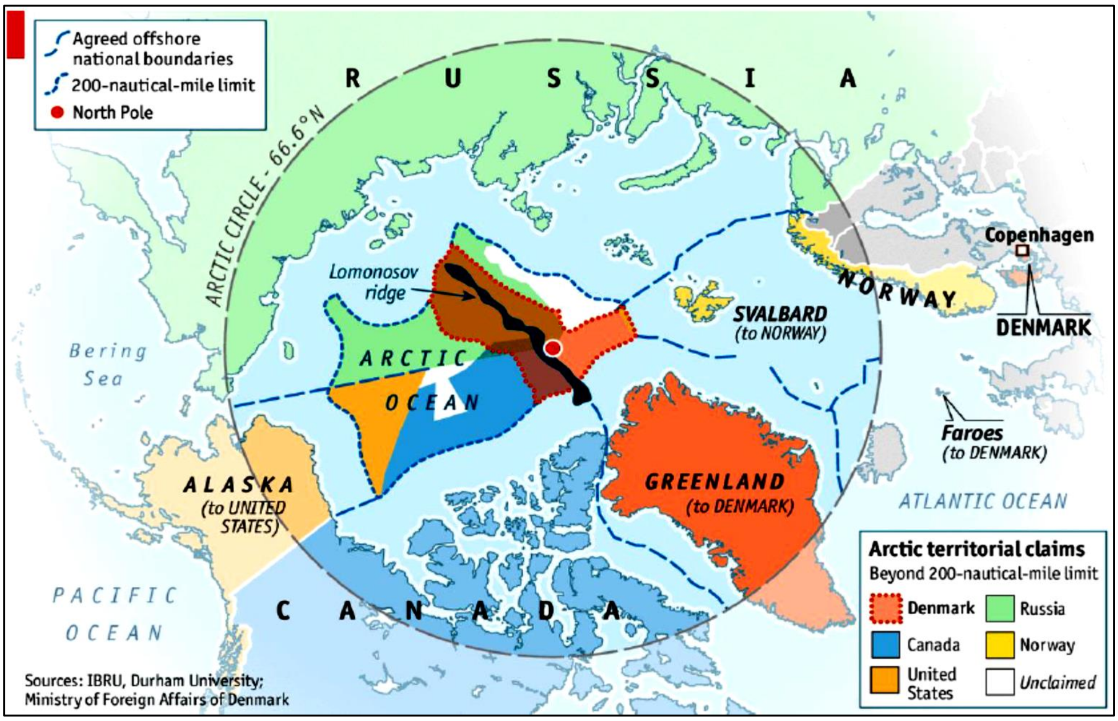


Figure 2.1: Arctic territorial claims (source: IBRU, Durham University)

Despite these existing unresolved territorial issues, the biggest potential security risk arises from extended continental shelf claims over the Lomonosov Ridge. After having collected scientific data, Canada, Denmark and Russia all have presented to the Commission on the

Limits of the Continental Shelf (CLCS), which include this underwater mountain range stretching across the Arctic Ocean. Overlapping continental shelf claims, combined with Russia's increasing assertiveness, have sparked concern over potential new or rekindled disputes. Figure 2.1 shows the territorial claims between Arctic States.

Russia has declared the straits along the NSR to be internal water under the Russian coastal region (Ragner, 2000; Watson 2016). The present regulations demanding permission to enter the exclusive economic zone part of the NSR and the mandatory ice-breaker escort in the central NSR straits, in effect make it impossible for vessels to transit any NSR route without the permission of Russian authorities, or without paying NSR fees. While this may not appear reasonable; strict enforcement of environmental standard is extremely important in the Arctic. Further, it will be difficult to use the NSR without using Russian infrastructure, and understandably, the Russian regulations are not universally accepted. Based on this principle, the US, as well as several non-Russian International Northern Sea Route Programme (INSROP) experts, have challenged Russia’s claim. In the view of the US, the NSR straits should be considered international straits, with the implication that foreign vessels use them for innocent passage without notification or application to the Russian authorities. Also, Russia’s right to perform inspections in the exclusive economic zone to ensure compliance with Russian regulations is being challenged as vessels with sufficient ice-class and insurance coverage should be able to proceed without hindrance (Ragner, 2000, Paulson, 2009). At present, this dispute is considered more of a legal issue rather than an actual issue, as Russian authorities have signalled adopting a flexible attitude towards foreign vessels wishing to use the route. Potential foreign users of the route are likely to comply with the Russian regulations, as they depend on Russian ice-breaker escort (Ragner, 2000).

Historically, the route for many decades has been one of the most contentious political issues in US-Soviet/Russian Arctic relations. The US labels the ice-covered straits of the route international and subject to the right of transit passage. Whereas, Russia claims that they are internal waters based on several theories, including historical references, closed by straight baselines. Legally speaking, the two statements are apparently on opposite ends of the continuum as both statements invoke national security as one of the more important interests substantiating and warranting their respective stands (Brubaker and Ostreng 1999).

Initially, there are no internationally legally binding requirements for ship design or ice class specific for ships traversing the Arctic Ocean. The International Maritime Organisation

(IMO) was planning to issue updated voluntary Guidelines for Ships Operating in Polar Waters (IMO, 2009). The updated guidelines will address construction provisions, as well as recommendations for equipment, operational guidelines including crew training and environmental protection and damage control (Eide *et al*., 2010). Finally, this guidelines or Polar Code (PC) entered into force on 1 January 2017 (IMO, 2019). From a set of voluntary safety guidelines, the PC gradually developed into today's sophisticated, legally binding catalogue of rules whose stated objective is not only to make shipping in polar waters safer, but also to mitigate its impacts on Arctic and Antarctic environments (Schopmans, 2019). However, PC was doing too little to prevent shipping accidents and pollution with potentially catastrophic consequences for polar environments (Bennet, 2017; Bognar, 2018; Schopmans, 2019).

Further reading concerning the legal issues of the NSR can be found in Dunlap, W.V., (1996), Transit Passage in the Russian Arctic Straits, International Boundaries Research Unit, Maritime Briefing, vol. 1(7).

2.2.3 Economic Factor

According to Rastogi and Trivedi (2016), economic factors are determinants of an economic performance that directly impact a company and have resonating long-term effects. For example, a rise in the inflation rate of any economy will affect the way companies' price their products and services. This definition is more of macroeconomic perspective. According to Alanzi (2018), for a business the key economic factors include labour costs, interest rates, taxes, transportation cost, energy cost, raw material cost and management. Therefore, in this study the definition of economic factors include both microeconomic and macroeconomic factors.

The NSR is an important and integrated part of the Russian Arctic infrastructure and economy and is increasingly used for shipments to many indigenous, industrial, military and scientific settlements in the Arctic, as well as an export route for timber, ores, and other products (Ragner, 2008). Russia has developed a series of active commercial ports and a busy seaway along the Siberian coast that relies on the escort of many powerful nuclear and diesel icebreakers. Interestingly, the western part of the route, between Murmansk and Dickson, was opened to year-round navigation after 1980 (Mulherin, 1996).

The NSR has incurred higher building costs for ice-classed ships (Liu and Kronbak, 2010, Kazcynski, 2012). Costs of building and operating ice-strengthened vessels suitable to transit the NSR are considerably higher compared to ordinary vessels. Where vessels only operate part of the year, of course, the capital costs will be higher (Moe and Jensen, 2010). Shipping companies need to use ice-strengthened vessels with an icebreaker backup vessel available most of the year. All this amounts to serious cost factors (Moe and Jensen, 2010). Both capital cost and depreciation costs are applied to yearly repayment and yearly depreciation of the capital, based on the building cost of the new ship (Furuichi and Otsuka, 2013). To finance the procurement of these ice class ships, ship-owners make use of bank loans from companies such as Credit Suisse Ship Finance and many other financing institutions. Generally, bankers will propose to ship-owners, before or after delivery, loans covering between 60 % and 80 % of the market value of a new vessel (Verny and Grigentin; 2009). Without a doubt, the ice-strengthened vessel is more expensive than the non-ice class vessel. For example, ships sailing through the NSR are required to satisfy NK register ice-class IA or better, which may bear a 10-30 % additional cost to build (Liu and Kronbak, 2010, Omre, 2012).

According to Erikstad and Ehlers (2012), the ice class level is assumed to influence the cost and operational factors of the vessel in the following way:

- The NSR sailing window. The annual savings using the NSR option will be more or less proportional to the number of trips per year using this route.
- The initial investment cost of the vessel. Higher ice class leads to higher costs.
- Operational cost will increase as a result of the higher resistance to ice as well as in open water.
- Voyage cost. The dominant part of the voyage cost will be the savings due to reduced fuel consumption resulting from slow-steaming through the NSR.
- Lost opportunity cost. For weight constrained vessels, the additional steel weight resulting from the ice strengthening will reduce the cargo carrying capacity of the vessel.

At present, the NSR requires an ice-class ship even for summer shipping navigation. Currently, there are three main sets of ice class rules, namely; Finnish-Swedish Ice Class Rules (FSICR), the Russian Maritime Register of Shipping (RMRS) ice rules and the unified Polar Class (PC) of the International Association of Classification Societies (IASC) (Riska in

Sorstrand, 2012). The Finnish-Swedish ice class rules have been adopted by the majority of classification societies except for RMRS and have been described as the industry standard for first-year ice, even though they are only intended for the Baltic (Riska in Sorstrand, 2012).

The classification societies have also acquired their own ice class rules, which cover mandated technical standards that must be fulfilled for respective ice classes. These mainly cover the strengthening of the hull, rudder, propeller and shaft to account for the shear forces resulting from ice impact. Some rules also include the performance of the vessel in ice, where the requirements are specific for different ice conditions, such as the FSICR. Furthermore, the ice class rules define several different ice classes depending on the severity of the ice conditions. Regarding the national ice class rules, there are national rules, such as the Finnish, Swedish and Canadian sets of rules. The national requirements often overlap with the ice class rules of the classification societies (Juurmaa, 2006).

The RMRS ice class rules have nine different ice classes, and additionally four ice classes for icebreakers. Like the FSICR ice class rules, the RMRS consists of three parts; hull, machinery and power requirements (Riska in Sorstrand, 2012). The approximate equivalent of ice-class classification systems (RMRS, FSICR and IACS) are shown in Appendix A.

It would appear that the minimum polar class (PC) required for independent navigation along the entire NSR would be PC2 for year-round operation and PC5 for spring/summer transits. The RMRS ice class may be dictated by powering and icebreaking performance rather than by the strength level (Nyseth and Bertelsen, 2014). It is anticipated that PC2 vessels of adequate power and manoeuvrability would transit in polar packed ice all year round. In summer, PC3 would be structurally adequate to undertake cautious voyages independently (Nyseth and Bertelsen, 2014). Appendix B shows the equivalent of PC with other classification societies.

Marine insurance covers three main categories; hull, cargo and marine liability. The hull and cargo insurances, cover the ship and the goods it is carrying. Commercial insurers manage these insurances whereas liability insurance is provided for 90 % of vessels by mutual companies known as P&I Clubs. The cargo insurance is purchased by the shipper and the ship-owner purchases the other insurances. The marine insurance depends on multiple factors such as the vessel’s gross tonnage, the insured value of the vessel, time of sailing and climate conditions, historical records of the owner of the vessel, the competition level in the insurance market (Mulherin, 1996), the condition and equipment of the vessel and the availability of an ice-breaker convoy (Chernova and Volkov, 2010). According to Lassere (2014), among the factors considered for the risk assessment and the rate of marine insurance are the experience of the crew in Arctic shipping; the availability of rescue units (icebreaker or else); the distance to a port in case of damage; the ice class of the ship; and the prevalence of fog and ice along the route considered.

The insurance premium for such an extreme journey through the NSR is quite high (Verny and Grigentin, 2009; Chernova and Volkov, 2010; Kazcynski, 2012). For instance, with a high probability of hull damage, the insurance companies would probably increase their premiums for cargo carried through such a hazardous area. The machinery and hull insurance will no doubt also be much higher (Liu and Kronbak, 2010). However, some have reported that the insurance premium is comparable to the Suez Canal Route (SCR). For instance, Erikstad and Ehlers, (2012) reported that the insurance cost for similar vessels has so far been equal to the SCR insurance including the addition covering piracy for the Gulf of Aden. According to Raza and Schoyen (2014), underwriters do not charge extra P&I insurance premium for the trans-arctic shipping between Europe and Asia via the NSR. However, this may be because accidents have not been recorded or by omitting major insurance claims along the NSR. The insurance companies adopt the wait-and-see position in this case. Thus, they may respond to possible accidents in the future with increased premiums (Erikstad and Ehlers, 2012).

The manning or crew cost is one of the major cost components for any shipping operation. The crew cost for the NSR shipping is higher than for conventional shipping because the NSR requires a high level of technical training for the officers (navigation in glacial waters) (Verny and Grigentin 2009). Seafarers, who have already worked in the extreme weather conditions of the Arctic, consequently receive higher wages compared to conventional routes (Verny and Grigentin 2009).

Fuel on board ships, commonly referred to as "bunkers", has become the most significant cost item of a ship’s operational expenses accounting today for almost 50 % of the voyage cost, which is higher than the crew’s wages, (Stopford, 2009: Lasserre, 2014). According to Liu and Kronbak (2010), fuel cost is one of the main factors that influence the competitiveness of the NSR. This is because cost savings for fuel may appear as a key driver to explore the NSR for commercial transits (Schoyen and Brathen, 2011). Also, reduced fuel consumption for ship propulsion by sailing via the shorter NSR could emerge as a driver to improve energy efficiency and savings (Schoyen and Brathen, 2011). The NSR has the potential to shorten lead times and reduce energy consumption in the supply chain

There are two parameters associated with fuel costs; the type of fuel used and the fuel consumption rate (Lassere, 2014). However, according to Tan (2013), fuel consumption for shipping navigation in the NSR is not necessarily lower than the conventional route because, in tough ice, the resistance is increased, the speed is reduced, and therefore the required power is higher compared to open water. In fact, higher fuel consumption might occur at high speed and low ice conditions as well as in tough ice at lower speed.

The level of interest in designing a fuel efficient ship is directly related to the fuel price (Wijnolst and Wergeland, 2009). According to Bialystocki and Konovessis, (2016) between 1970 and 1980, the fuel oil price rose significantly (almost ten-fold), leading to ships with high fuel consumption being laid up. Then, during 1985-2000 prices of fuel oil fell, with research and development on energy efficiency receiving limited attention from the maritime industry. However, from the year 2000 onwards, crude oil costs started to rise again, which drove engine manufacturers, shipyards and designers to reinvestigate design and operational solutions for reduced fuel consumption and energy efficiency (Bialystocki and Konovessis, 2016).

The Russian ice-breaking tariff or the NSR fees include payment for the assistance of an ice-breaker ship, meteorological forecasts and the use of communication systems (Verny and Grigentin, 2009; Liu and Kronbak, 2010; Gritsenko and Kiiski, 2016). Russia's mandatory ice-breaker fees are excessive, and the fees are not directly linked to the actual services rendered. For instance, during light summer ice conditions, an ice-strengthened vessel may be able to transit the NSR unescorted but will still need to pay a full fee (Ragner, 2008; Moe and Jensen, 2010). According to the new NSR rules for navigation, introduced in 2014, tariffs are published and applied on the basis of actual rendered services (Gritsenko and Kiiski, 2016). Notably, the fee system is a major obstacle or drawback to transit traffic, and since the opening of the NSR to foreign vessels in 1991, the Russian authorities have yet to design a system that encourages the use of the route even under otherwise ideal conditions (Ragner, 2008). For comparable ships, the NSR fees are about twice as expensive compared to the Suez Canal (Verny and Grigentin, 2009). Also, the NSR fees were high because with the reduced shipping activity the fees were increased to compensate for the decline in revenue (Moe and Jensen, 2010). Nevertheless, the tariff paid to the Russian Federation has been relatively low when compared to the actual operational cost of nuclear ice-breakers (Erikstad and Ehlers, 2012).

The current system of ceiling tariffs permits the NSR administration to apply rates lower than the official tariff level. According to Gritsenko and Kiiski (2016), between 1995 and 2002 a fixed ice-breaking fee existed only for cabotage whereas for import/export voyages and transit, the practice of a negotiated tariff with a service provider was in place. Further information regarding the NSR fees can be read from Gritsenko and Kiiski (2016). In addition to ice-breaking services, pilotage is compulsory. The Marine Operation Headquarters (MOHQs) will place two pilots on board the vessel, and the primary language used by the pilots and on board the icebreakers is Russian. Fees for piloting are assessed separately (Liu and Kronbak, 2010; Kazcynski, 2012).

The economic centre of gravity of the situations in both Europe and Asia is moving northwards (Blunden, 2012). It is also called the international 'geography of places', a new discipline describing the displacement of production centres and consumer markets (Verny and Grigentin, 2009). These shifts in economic geography are favouring the development of the NSR as a potential transit route linking Asia to the consumer markets of Europe. Notably, distance is an important factor in the balance of any advantages between the trade routes. Hong Kong is equidistant from Rotterdam and other ports in northern Europe via either the NSR or the SCR. The NSR is, therefore, shorter for all ports north-east of Hong Kong and longer for those south of it. In this context, it is significant that the economic centre of gravity in both Europe and Asia is moving northwards. In Europe, it is moving from the west to the north-east, with the development of Central and Eastern Europe and the German economic boom. In Asia, it is moving from the south-east to the north, with the growth of China (Verny and Grigentin, 2009; Blunden, 2012). Also, Asian mother ships that are providing facilities and supplies for smaller vessels are gradually abandoning South-East Asia for northern China (Verny and Grigentin, 2009). Shifts of this kind in economic centres of gravity favour development of the NSR and regular use of this route would further stimulate the economic growth of the northern European and Asian areas, in a self-sustaining feedback loop. By this new geography, it would seem worthwhile to transfer part of the containerised freight from the SCR to the NSR.

It is acknowledged in the literature, that the lack of major economic centres along the NSR affects the attractiveness of the route compared to the conventional route (Liu and Kronbak, 2010). About 2,500 nautical miles of Siberian coast between the Bering Strait and the Port of Murmansk is mainly uninhabited, so no stopovers are possible or feasible. The most important consequence of this fact is that regular container lines on the NSR cannot be optimised following the model used in SCR transport, which relies on a network of developed communication lines in the hinterlands of port cities (river transport and high-quality rail links for transhipment and feedering).

The oil and gas resource of Russia's Arctic regions constitute the world's largest energy reserve outside of OPEC countries (Blunden, 2012; Hille, 2016). For example, the US Geological Survey estimated that 70 % of the world's undiscovered natural gas – some 1,699 trillion cubic feet of gas and 44 billion barrels of natural gas liquids – lies in the Arctic, most of that is in Russia (Hille, 2016). These natural resources are driving the development of marine transport along the route. Russia's vast natural resources can be exported both east and west and make the NSR a very convenient export corridor for Russian natural resources (Ragner, 2000). Notably, in Russia, petroleum activities are moving northwards, and will soon go offshore. At the same time, climate change is having a significant impact on the extent of Arctic sea ice along the NSR. The increased petroleum activities will lead to unprecedented levels of shipping in and westwards from the Barents and Kara Seas. The diminishing sea ice cover will have even greater impact for shipping and will have implications for the entire Northern Sea Route (Ragner, 2008).

The increase in cruise vessel traffic is one of the key concerns for many Arctic countries (Ikonen, 2017). This is because, such vessels are growing in size and the number of passengers is likewise increasing. Besides cruise vessels, the Arctic has been a popular destination for private leisure boats which are not necessarily registered in the Automatic Identification System (AIS) and therefore are not subject to polar pilot requirements (Marchenko, 2015). However, marine tourism in the Russian Arctic has been at relatively low levels compared to some other Arctic countries. About three million tourists annually visit Alaska and pass by Russia's Far Eastern territories. This is also related to the lack of relevant domestic infrastructure (Arctic Info, 2015). Despite that, the Russian Federal Agency for Tourism managed to launch the first three Arctic cruises in 2015, from the Svalbard to the Frantz Josef Land and the potential market for such cruises is now up to 80,000 tourists a year (Arctic Info, 2015). Russian icebreakers also take tourists along the Northern Sea Route all the way to the North Pole (Iudin and Petrov, 2016). Tourist cruises in the Arctic are only profitable if there are no less than two to three cruises per season (RIA Novosti, 2011).

2.2.4 Environmental Factor

These environmental factors include all factors that influence or are determined by the surrounding environment. Factors of a business environmental analysis include weather, geographical location, global changes in climate, environmental offsets , ground conditions, ground contamination, and nearby water sources (Abdul Rahman et al., 2014; Alanzi, 2018). However, the factors are not limited to climate.

Arctic ice cover is diminishing, both in thickness and extent due to climate change (Ragner, 2000; Liu and Kronbak, 2009; Eide *et al.*, 2010; Xu *et al.*, 2011; Blunden, 2012). In September 2012, the Arctic sea ice extent reached a record minimum not observed since 1979, with a reduction of 45 % compared with the 1979-2010 climatology (Lei *et al.*, 2015). According to Eide *et al*., (2010), the ice cover in the Arctic is expected to continue reducing throughout the 21st century. This trend may lead to a longer navigation season, development of transportation routes, improved accessibility by ships, and increasing pressure to extract oil and gas resources in the Arctic region (Liu *et al*., 2009; Eide *et al*., 2010 and Shibata *et al*., 2011). The disappearance of summer sea ice will provide the NSR with more navigable days for shipping operations. This factor, the navigable time of the NSR together with the transit fees and the bunker prices are the most important factors that influence the use of the NSR (Liu and Kronbak, 2010).

The shrinking Arctic sea ice will also facilitate the seasonal use of the NSR and viability for transit container shipping (Xu *et al*., 2011). Summer shipping usually begins in mid-June and runs until mid-October (Otsuka and Furuichi, 2013). It is proven that the NSR can be used all year round if the vessel, at a minimum, is a PC2 ice-classed ship. However, this will incur high capital costs and affect the revenue of shipping companies. Notably, passage speed and the length of the navigation season were identified as the two main factors in determining whether voyages would be profitable. There are many variables behind these factors. The length of the actual routes can vary, depending on the ice conditions. As the navigation season advances, these can deviate as much as 2,100-3,400 n.m. (Drent, 1993). Summer and autumn are the safest and most economical seasons for marine activity; therefore, activities such as resource development, tourism or community re-supply will most likely increase in the summer months. However, there may be a few exceptions, where high commodities may drive year-round operations, but economics will drive that, and not the climate (AMSA Report, 2009).

According to Ragner (2000), the main physical constraints to NSR shipping are the shallow seas and straits along most of the route, in addition to the severe ice conditions. This is primarily why the shipping operation in the NSR cannot be entirely utilised. Consequently, the vessels have severe size restrictions, and therefore economies of scale cannot be realised, (max draft is 12.5 m, and max beam is 30 m, as vessels cannot be wider than an icebreaker). Therefore, this restricts the NSR vessel size to around 50,000 dwt (Brigham *et al*., 1999; Moe and Jensen, 2010). Although the minimum depth in most straits exceeds 20 m, the water in some areas is quite shallow. However, there is no draught limitation for more northern routes (Liu and Kronbak, 2010).

The physical parameters that pose challenges to the operations in the Arctic are mainly related to the high latitudes and low air and sea temperatures. Eide in Eide *et al*., (2010) listed all the operational conditions associated with NSR shipping:

- Sea ice and icebergs that represent hazards to the integrity of ship hulls and platforms.
- Icing from sea spray, precipitation, and fog, which raise both stability problems and other safety issues.
- Polar lows (small storms that are difficult to detect and predict).
- Wind chill, i.e. combinations of low temperatures and strong winds, which is a safety and health issue.
- Remoteness, with implications for rescue, emergency operations, and communications.
- Darkness in winter.
- Reduced visibility caused by fog and precipitation.
- Less reliable weather forecasts than in, e.g. the North Sea.
- In general, information on the meteorological and oceanographic conditions, like winds and waves, in parts of the Arctic with seasonal or all-year ice cover is poor (Eide *et al* 2010).

According to Molenaar (2014), marine shipping has the following actual and potential impacts on the marine environment and marine biodiversity as follows:

- Shipping practices and incidents leading to accidental discharges of polluting substances (cargo or fuel) or physical impact on components of the marine ecosystem (e.g., on the benthos and larger marine mammals).

- Operational discharges (cargo residues, fuel residues (sludge), (incineration of garbage and sewage), and emissions (CO_2, NO_X and SO_X).
- Introduction of alien organisms through ballast-water exchanges or attachment to vessels' hulls (e.g. in crevices).
- Other navigation impacts (noise pollution and other forms of impacts on, or interference with, marine species potentially causing, for instance, disruption of behaviour, abandonment, or trampling of the young by fleeing animals or displacement from their usual habitat).

The likelihood for some of these impacts, for instance, shipping incidents to occur is higher in some parts of the marine Arctic due to the presence of ice, lack of accurate charts, and insufficient experience in navigating ice-covered areas. Also, cold temperatures may affect machinery, and icing can create additional loads on the hull, propulsion systems and appendages (Molenaar, 2014). Eide *et al*., (2010) also reported concerns regarding the environmental issues. For example, oil spills, resulting from shipping accidents, occur regularly worldwide. Considering the added challenges of Arctic operations, the risk of accidents may increase in these waters. Presently, there are very few ways for recovering spilt oil from ice-covered waters. Therefore, these factors need to be addressed to avoid severe ecological and economic consequences. The remoteness of much of the marine Arctic, the limited available maritime safety information data, and the challenges of navigating therein also means that once shipping incidents do occur, a response will take a relatively long time and may be inadequate to address the impacts on the marine environment and marine biodiversity. According to Ho (2010), if global warming due to greenhouse gas accumulations is expected to be severe worldwide, it is enhanced in the Arctic regions, where a reduction in sea ice will result in the opening up of the NSR for ship transportation.

Laboratory studies have shown that polar bears may die if fouled by oil (Moe and Semanov, 1999). Fortunately, there is no relevant case history of such events occurring. Polar bears, however, live in close contact with the sea and tend to stay on the ice edge, along with leads (narrow, linear cracks in the ice) or in drift ice, and often enter the water and migrate over vast areas (Moe and Semanov, 1999; AMSA, 2009). These factors indicate that oil fouling is quite likely. According to Moe and Semanov (1999), the impact of shipping on the population level of polar bears seems not very likely. However, the polar bear is recognised as a symbol of the Arctic, and the perceived effects of even a few individual bears fouled may quickly evolve into a strong symbol of the overall environmental threat and damage of NSR activity.

Future shipping activity will certainly disturb the animals' peaceful existence. Already today in Chukotka during the navigation period in any harbour port it is possible to buy hides and bones of the polar bear or other fur animals (Yefimenko, 1999). Apparently, Zapovednik Wrangel Island is the only place in Russia where the polar bear is still under state protection (Yefimenko, 1999). Once the NSR is established, will this island be able to preserve bears, walruses and other species?

While Arctic marine species are few, each species has significant numbers. Advances in the melting of the Arctic ice have implications for zooplankton, fisheries, fish stocks, marine mammals and marine birds, which appear to be shifting northward (Eger, 2010). The number of species generally decreases with increasing latitude. The Arctic marine environment is also exposed to the potential impacts caused by maritime activity, such as shipping. Increased shipping in the Arctic may pose a potential threat to the Arctic ecosystem and on the population of different species as mentioned. Accordingly, a considerable number of species circulate throughout the Arctic to feed, mate, give birth, take care of their young and moult. As they follow their patterns of living, they are also exposed to various forms of disturbances and implications from shipping activity (Eger, 2010).

2.2.5 Social Factor

The social factor considers all events that affect the market and community socially (Abdul Rahman et al., 2014; Rastogi & Trivedi, 2016; Alanzi, 2018). Therefore, the advantages and disadvantages towards the community of an area in which a project is developing also need to be considered. These include cultural expectations, norms, population dynamics, health consciousness, career altitudes, and global warming.

According to Goodman (2014), the NSR shipping activities will affect the indigenous people of the Arctic region regarding the loss of food sources, loss of housing, loss of culture and bring disease to the people. However, there are positive advantages in supplying the Northern population with fuel, provisions, commodities and goods because it will bring much-needed specialists to the local communities and provide workplaces for the local communities (Ragner 2000). Nevertheless, historical evidence has shown that the conquest and modernisation of the North only brought destruction and discontent to the Arctic indigenous peoples (Ragner, 2000). The oil industry and transportation in the north is a relatively new branch of the economy in the Arctic region where reindeer herding, fishing, hunting, gathering and municipal services still have considerable significance for the economy and culture of the local population (Meschtyb *et al*., 2005). Reindeer herding, for example, is significant not only regarding employment and food consumption but also for the cultural identity of the indigenous peoples (Meschtyb *et al*., 2005).

The NSR places a more significant burden on rural villagers. Urban locals will experience a short-term gain from the NSR's trade and transit due to greater access to transportation and job employment in the oil fields. Although, rural locals will potentially suffer greater consequences as their food resources (elk, fish, and reindeer) instead are hunted to feed urban workers. Not only do we see the trend of short-term gain for long-term loss on an international level, but we also witness it on a domestic level (Meschtyb *et al*., 2005). The positive impacts are mainly attributed to increased revenues for local budgets, more job opportunities and improvement of the transportation connections to isolated settlements in the region. However, although the NSR does promote job employment, local companies often hire workers from other regions (Meschtyb *et al*., 2005). Therefore, there is no doubt that development of the oil extraction industry and expansion of sea transport operations in the Arctic can bring benefits as well as disadvantages to the local population.

2.2.6 Technological Factor

These factors pertain to innovations in technology that may favourably or unfavourably affect the industrial and market operations. These refer to technological awareness that a market possesses, which consider all events that are affected by technology.

Since 1978, Russian icebreakers and ice-strengthened carriers have maintained year-round navigation to the industrial complex at Noril'sk (Kaczynski, 2012). These ships are routinely plying the ice-covered waters of the Barents and Kara seas throughout the winter, a rare occurrence around Alaska and in the Canadian Arctic (Kaczynski, 2012). With a highly advanced fleet of icebreaking ships and a broad range of advanced marine technology, the Russians have the experience and technological capability to move ships virtually anywhere in the Arctic during the summer months (Mulherin, 1996; Ragner, 2000; Kaczynski, 2012). Much of this technology has been developed in Finland and Russia (Kaczynski, 2012).

The icebreaker fleet has overcome all the survival difficulties, and, in the long run, it is the icebreaker fleet that should be honoured for the opening, and exploration development of the NSR, that has enabled regular navigation to occur and to sustain its transport potential (Drent, 1993; Kaczynski, 2012). However, according to Ragner (2000) and Moe and Jensen, (2010), the ice-breaker fleet is ageing, and it seems unavoidable that Russia's icebreaking capacity will be reduced if not downgraded in the current decade. Nevertheless, in 2017, Russia launched a new icebreaker ship called the "Sibir" (Revesz, 2017). She is powered by two nuclear reactors and will be able to break ice fields up to three metres thick. Along with the "Arktika", placed into active service in 2016, and the "Ural", the three ships will become the "world's largest and most powerful nuclear-powered icebreakers", according to TASS Russian News Agency. Furthermore, Russia also plans to build another vessel called the "Leader", which will break through ice up to 4.5 metres thick and keep the NSR and Arctic coast open all year round (Revesz, 2017).

Ships using the NSR must have hulls capable of withstanding the shocks and friction of ice (Verny and Grigentin, 2009). However, new technological innovations and vessel design offer the icebreaking capacity to cargo ships, cruise vessels and research vessels extending their operational season and activity beyond the usual range (Ikonen, 2017). The use of the NSR is not only dependent on the length of the shipping season and reliability of service, incremental costs for insurance, pilotage and icebreaking; but whether vessels are suitable for the goods requiring shipment and the development of alternative routes. In the long term, new ship designs and improved techniques for ice navigation could become important (Drent, 1993). This was the first time a commercial LNG tanker has sailed across the NSR from Europe to Asia without the protection of an ice-breaker. The specially-built ship completed the crossing in just six-and-a-half days setting a new record (Mcgrath, 2017). This 300-metre-long Sovcomflot ship, the Christophe de Margerie, was carrying gas from Norway to South Korea (Mcgrath, 2017).

Most traditional icebreakers were capable of running astern in ice even though the vessels were not designed to do so (Juurmaa *et al*., 2002). It is possible that running astern could be considered as the main method of operation in heavy ice conditions. The key to this development is in the use of azimuthing podded propulsion, which provides the vessel with the benefits of both electric propulsion and excellent manoeuvrability (Juurma *et al*., 2002), combined for the first time. This Double-Acting Ship (DAS) concept is designed to operate ahead in open water and astern in heavy ice conditions. The actual bow form can be optimised for the selected route and the superior ice going performance when running astern reduces the need to use icebreaker assistance. The benefit from the freedom in bow form design is that the DAS has much better open water characteristics compared to conventional ice going vessels (Kurimo, 2011).

Ice conditions have always been a hindrance for smooth and safe navigation in the NSR. Simple technology, like the use of aerial drones to locate free and fast ice, should not be underestimated. Aerial drones are easy to fly and readily mounted with cameras that record the trip, adopting a bird's eye view. It is not just the recreational use of drones that has increased; also known as unmanned aerial vehicles or UAVs. Commercial drone use is rapidly expanding, with photographers, farmers, insurance firms and power line companies adopting the technology. Search and rescue and emergency response agencies also use drones to inspect broad areas and difficult terrain from the sky (Bruno, 2014).

2.2.7 Safety Factor

According to Merriam Webster Dictionary, the definitions of safety are as follows: 1) the condition of being safe from undergoing or causing hurt, injury or loss, 2) a device (as on a weapon or a machine) designed to prevent in advertent or hazardous operation and 3) to protect against failure, breakage, or accident. Therefore, in this study safety factors include all safety issues that may affect the risk the people's life and can create a financial loss to the company.

An extensive ports and shipping infrastructure including a cargo base currently exist along the NSR (Mulherin, 1996) (Appendix C shows all the seaports along the NSR). However, the state of infrastructure is incomplete and deteriorating (Kaczynski, 2012; Ho, 2011; Moe and Jensen, 2010). With the exception of Dudinka, there has been no modernisation of NSR ports since 1990 (Moe and Jensen, 2010). Erikstad and Ehlers, (2012) also reported that there is no land-based infrastructure, such as rescue centres or repair yards, along the NSR, especially when considering the draft limitations of larger vessels. The nearest Russian ports where repairs can be performed are located far away in Murmansk and Vladivostok which, practically speaking, is outside the NSR. As a result, should a vessel get into difficulties or suffer damage while navigating along the NSR, it must be repaired by the crew (Pastusiak, 2016). Waiting for outside help would cause substantial delays and be very expensive. Light search and rescue as well as ice-breaker support services, with seasonal and regional increased access, also need to be provided (Ho, 2011).

The present standards for Escape, Evacuation and Rescue (EER) will need to be modified in order to cater for the Arctic (Eide, *et al*., 2010). The uncertainty and the risk connected to the NSR are, among other factors, due to limited accident preparedness as a ship in distress might have difficulties in receiving assistance from rescue teams and icebreakers within a short time. Likewise vessel repair facilities may be located thousands of kilometres away as mentioned previously (Kitagawa, 2008; Ragner, 2000b; Ho, 2010; Verny and Grigentin, 2009). About 2,500 nm of Siberian coast between the Bering Strait and the Port of Murmansk are mostly uninhabited, so no stopovers are possible (Verny and Grigentin, 2009). However, Russia is building an early warning system in the Arctic, increasing the number of air patrols over the Arctic land and sea areas, particularly along the NSR. In 2014, the Russian Federation created four sea-air bases in the Arctic, officially for the purpose of emergency search and rescue operations (Kazcynski, 2014). Figure 2.2 shows the map of Arctic search and rescue agreement areas of application. All countries in the Arctic are responsible for any search and rescue operations that occur in their agreement areas.

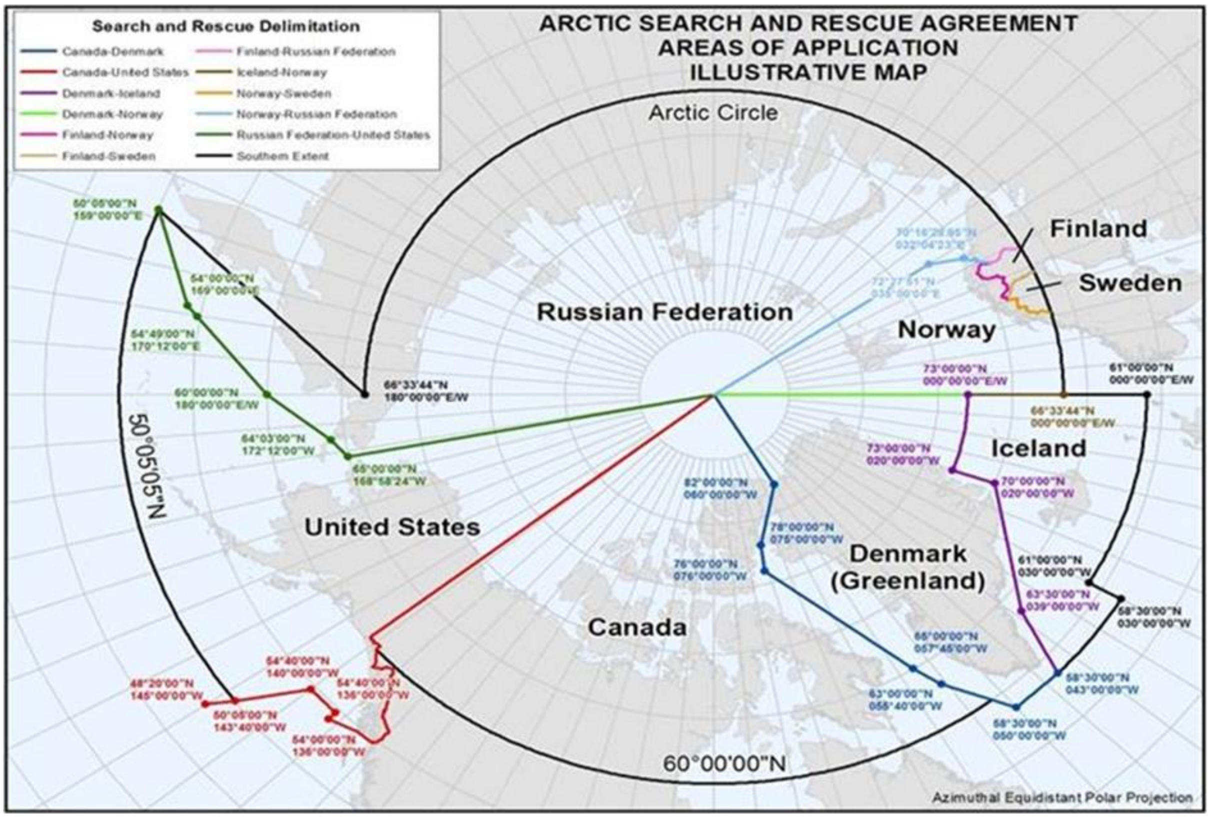


Figure 2.2: The Arctic Search and Rescue Agreement areas of application map.

(Source: CHNL information Office Centre - www.arctic-lio.com)

Sailing across the Arctic Ocean will require improvements in a suite of safety issues, including charting and monitoring, and the control of ship movements in the Arctic (AMSA, 2009). According to Liu and Kronbak (2010), electronic charts for larger parts of the route are presently being developed and made available. However, less than 10 % of Arctic waters are presently charted to modern standards even though five littoral countries have formed a regional hydrographic commission. Notably, the lack of charts will increase the probability of accidents or mishaps, and lack of good charts will definitely affect full insurability of shipping (Goodman, 2014).

Notwithstanding, navigational systems and hydrographical support are also in a critical condition (Moe and Jensen, 2010). Environmental monitoring, observational networks and forecasting services providing meteorological, oceanographic and sea ice information to support shipping all year round will need to be significantly enhanced in the NSR (Ho, 2011; Eide, at al., 2010). The NSR will further require the installation of sophisticated navigation systems on board vessels, for iceberg detection (Verny and Grigentin, 2009). For instance, precise satellite navigation provided by GPS and the Russian GLONASS system, satellite radio, telefax and data communication has improved significantly. However, satellite coverage along the route is still inadequate and incomplete. For example, a minor stretch along the route is not covered at all by satellites (Liu and Kronbak, 2010). The same situation was reported by Eide *et al*., (2010) regarding radio and satellite communications which are not satisfactory. The continued development of detailed (near) real-time ice information delivered directly to the vessel by satellite could realistically enable vessels to execute local and tactical navigation themselves in the future (Ragner, 2000). Communication between the Marine Operation Headquarters (MOHQs) and the vessel is presently only undertaken in the Russian language, which presents one of several practical obstacles for non-Russian vessels wishing to sail along the NSR (Ragner, 2000).

The NSR also requires a high level of technical training for the officers responsible for sailing the vessels (navigation in glacial waters) (Verny and Grigentin, 2009). Experienced mariners who are trained for Arctic operations are needed to operate the vessels (Ho, 2011). Seamen who have already worked in such extreme conditions will not find it difficult to profit from their experiences, consequently obtaining higher wages compared to conventional routes (Verny and Grigentin, 2009).

Pastusiak (2016) in his book, made a critical overview of the current status of transport and navigation infrastructure in the NSR. Table 2.1 shows the status of fuel provisions, emergency preparedness and rescue navigation infrastructure and availability of charts, nautical publications and information on current ice and hydro meteorological conditions in the NSR as reported by Pastusiak (2016).

Table 2.1: The current status of transport and navigation structure in the NSR (Pastusiak, 2016)

Facilities	**Status**
Fuel provisions	• Light and heavy fuel oil are available at a few ports along the NSR
Emergency and rescue services	• Partially supported by the already existing and planned icebreaker fleet and coastal emergency and five rescue stations • In remote areas, rescue services can only be provided by nuclear-powered icebreakers.
Navigation infrastructure	• Fixed aids to navigations (coastal devices) on the NSR are automatic, but function only during the navigation season. • Most beacons and leading beacons on the NSR are day marks (unlit after dark). They often look alike, which impedes navigation. Beacons are similar in colour to the snow which surrounds them, which may make them difficult to detect. • Buoys are of limited use due to a short navigation season during which there is no ice on the NSR. In summer season, there may be up to one thousand floating stakes on the NSR. Navigation buoys are automatic. They are put out for the duration of the navigation season, or from the moment when the sea is completely free of ice till the moment when first ice forms appear. After ice cover has disappeared, there may appear drift ice from the north, as a result of which buoys and floating stakes may be moved. If their function is to mark shoals and shallows, this may constitute a serious safety hazard. Therefore, buoys should not be relied on when it comes to establishing position. • It may be concluded that vessel positioning based on taking radio bearings does not function on the NSR, and the devices which are there are regularly excluded from service. There is, therefore, no positioning system available that could be used in order to verify position coordinates provided by GPS and GLONASS

Availability of Charts, Nautical Publications & Information on Current Ice and Hydrometeorological Conditions	• The navigation charts for the NSR are not reliable. This is because, the NSR has not yet been thoroughly surveyed. • The operational information regarding current ice and hydro meteorological conditions should be obtained from all available sources by means of the Global Maritime Distress and Safety System (GMDSS), radio information support system operating in coastal zones (NAVTEX) and from voice radio broadcasts. Current hydrometeorological information is collected by the Russian meteorological service (Roshydromet) and circulated in the form of official weather bulletins for particular forecast regions (SafetyNET) determined by the International Meteorological Organisation. In the Arctic, in the area belonging to the Russian Federation, there are two such regions known as METAREA regions: region XX in the western part of the NSR and region XXI in its eastern part. SafetyNET ice bulletins are released every day for both these regions (XX and XXI). While for region XX they are released throughout the year, for region XXI they only appear during the navigation season. This may create a major difficulty for vessels planning to cross the area outside the season. • Russia is planning to open two additional radio stations apart from the one in Tiksi. They are going to be located on both sides of Severnaya Zemlya and transmit information via the NAVTEX system. When combined with the SafetyNET service based on a satellite working in the region of the Indian and Pacific Oceans, three NAVTEX stations along the NSR should be able to ensure continuous access to navigational information. Such a system, however, will not guarantee information access on the transarctic route or complete coverage of the central section of the NSR. Information circulated by means of SafetyNET, NAVTEX and radio communication shows a high degree of generalisation. • Vessels navigating on the NSR must use weather and ice information from unofficial sources (outside SafetyNET system).

2.2.8 Advantages of the NSR in comparison with other routes

This factor is created because in most literature about NSR, its advantages were always highlighted, as compared to other routes. Therefore, this indicates the importance of this particular factor in regard to NSR issues.

The NSR provides a shorter distance between Europe, North America and Asia in comparison with other routes, which could translate into significant cost savings (Drent, 1993; Verny and Grigentin, 2009; Erikstad and Ehlers, 2012). This fact can be seen clearly from Table 2.2 below.

Table 2.2: Distance (in NM) between ports using various southern and Arctic routes (calculated from searoutes.com)

Route	**Panama Canal**	**Northwest Passage**	**NSR**	**Suez and Malacca**
London – Yokohama	12500	7593	7003	11203
Marseilles - Yokohama	12768	8649	8886	9477
Marseilles – Singapore	15909	11655	12773	6603
Marseilles – Shanghai	13393	9441	9679	8786
Rotterdam – Singapore	15645	10738	9741	8367
Rotterdam – Shanghai	13413	8377	7727	10550
Hamburg – Seattle	9159	7355	6630	16069
Rotterdam – Vancouver	8927	7346	7255	15324
Rotterdam – Los Angeles	7782	7998	7358	16053
Gioia Tauro – Hong Kong	13994	10438	10676	7432
Barcelona – Hong Kong	13514	9935	10173	8065
New York – Shanghai	10588	8314	9924	12355
New York – Hong Kong	11243	8985	10595	11605
New York - Singapore	12724	10327	11938	10172

Marginally longer route (blue)   shortest route (yellow)

According to Erikstad and Ehlers (2012), the benefits of a shorter route can be exploited in two different ways. First, to increase the number of round trips that can be made annually, thus increasing the freight income of the vessels. Secondly, the benefit can be taken by slow-steaming on the shorter distance, which will result in considerable fuel savings, as well as having the additional benefit of reduced emissions of CO_2. (Erikstad and Ehlers, 2012).

Eide *et al*., (2010), reported that for shippers to choose the NSR, the benefits must be substantial and outweigh the disadvantages. Accordingly, these benefits may be realised in less travelling distance, which can substantially reduce fuel costs, and shorter travelling time, which may translate into higher income due to lower inventory-holding costs and increased productivity. Emission reductions may also result in reduced costs, assuming that future external damage and costs incurred by ship emissions can be internalised (e.g. by the introduction of a tax regime or quota market) (Eide *et al*., 2010).

The NSR located high within the Arctic region with its distribution of sea ice and harsh environment will not incur piracy or threats of terrorism. Table 2.3 displays the piracy and terrorism threats related to global chokepoints. Notably, the various chokepoints also have limits relating to the ship size and weight. Also, while the Arctic routes have their challenges, the traditional trade routes also have their threats (Table 2.3) as some regions have experienced security hazards to shipping with threats of terrorism and piracy. Notwithstanding, the 1956 Suez Crisis showed how quickly passage through the region could be halted resulting from political instability. A repeat of similar events in the 21st century would force shipping to use longer routes via the Cape of Good Hope and the Panama Canal; if conditions permit, the far shorter trans-Arctic routes could provide an attractive option (Melia *et al*., 2017).

Table 2.3**:** Global chokepoints and its threat (Melia *et al*., 2017)

Chokepoint	**Location**	**Vessels per year**	**Capacity (DWT)**	**Threat**
Strait of Hormuz	Separates Iran from the Arabian Peninsula	50,000	Narrow	Regional instability and terrorism
Suez Canal	Egypt connects the Mediterranean and the Red Seas	17,228	200 k DWT, convoy limit	Terrorism
Bosphorus	Istanbul, Turkey, between the Mediterranean Sea and Black Sea	50,000	200 k DWT	Controls
Strait of Malacca	Separates Malaysia from Indonesia, connects the Pacific to the Indian Ocean	60,000	300 k DWT	Terrorism and Piracy
Panama Canal	Panama connects the Atlantic and Pacific Oceans	14,323	120 k DWT	N/A
Strait Bab El-Mandeb	Separates the Arabian Peninsula from the Horn of Africa, connects the Red Sea to the Gulf of Aden	22,000	Narrow	Terrorism and Piracy

A further advantage of the NSR is that there is no vessel size restriction further north of the NSR. While the coastal route of the NSR may limit the size of the ship, further north will provide a better choice for larger vessels to transit. However, further north of Russia experiences severe ice conditions compared to the southern route.

2.3 Multi-Criteria Decision Making (MCDM) methodology

Three out of five research objectives (Objective 2, Objective 3 and Objective 4) require a decision-making methodology for fulfilment. Therefore, multiple criteria decision-making (MCDM) will be employed in this research. MCDM is a branch of operations research (OR). It is also called as management science (MS) or decision science, and sometimes mentioned as a sub-field of mathematics (Mota et al., 2013). According to Hanne (1995), MCDM handles mathematical theory, methods and methodological issues and case studies (applications) for decision processes, whereby multiple criteria (objectives, goals, attributes) have to be (or should be) considered. The main objective of OR is to improve the decision-making process by providing mathematical tools of analysis, modelling and optimisation that help to make better decisions in empirical contexts.

MCDM has changed along with OR since the early 1970s. Nowadays, it has become a very important asset in decision-making processes (Mota et al., 2013). From the 1950s onwards, many refined MCDM methods were developed and they differred from each other in the required quality and quantity of additional information, methodology used, user-friendliness, sensitivity tools used, and mathematical properties that they verified (Zavadskas & Turskis, 2011). To facilitate a systematic research on MCDM, Hwang and Yoon (1981) suggested that MCDM problems could be classified into two main categories: multiple attribute decision-making (MADM) and multiple objective decision-making (MODM), based on different purposes and data types.

MADM is an approach employed to solve problems that involve selection among a finite number of alternatives. An MADM method specifies how attribute information is to be processed to arrive at a choice. MADM methods require inter-attribute and intra-attribute comparisons, and involve appropriate explicit trade-offs (Rao, 2007). The procedures of MADM can be summarized in five main steps as follows (Dubois and Prade 1980):

Step 1: Define the nature of the problem;

Step 2: Construct a hierarchy system for its evaluation;

Step 3: Select the appropriate evaluation model;

Step 4: Obtain the relative weights and performance score of each attribute with respect to each alternative;

Step 5: Determine the best alternative according to the synthetic utility values, which are the aggregation value of relative weights, and performance scores corresponding to alternatives.

If the overall scores of the alternatives are fuzzy, Step 6 is added to rank the alternatives for choosing the best one.

Step 6: Outrank the alternatives referring to their synthetic fuzzy utility values from Step 5.

On the other hand, MODM is aimed at optimal design problems in which several (conflicting) objectives are to be achieved simultaneously. The characteristics of MODM are a set of conflicting objectives and a set of well-defined constraints. Therefore, it is naturally associated with a mathematical programming method to deal with optimisation problems (Tzeng & Huang, 2011).

Simply, the MADM approach has all possible alternatives defined at the beginning of the decision-making process, while in MODM there is infinite number of possible solutions to the problem at the beginning of the process. In MADM the decision is based on predefined criteria which is the most preferred solution (from a set of predetermined ones), whereas MODM attempts to optimise a function based on a set of constraints. Therefore, in this study the MADM approach will be used because the criteria and alternatives are well-defined at the beginning of the decision-making process. The following are brief explanations of selected MCDM methodologies**. (**Later, the MCDM and MADM words are used interchangeably).

2.3.1 Analytical Hierarchy Process (AHP)

AHP is one of the more widely applied multi-attribute decision-making methods (Velasquez & Hester, 2013; Sitorus et al., 2019). AHP allows its users to decompose the decision problems into a hierarchy of sub problems which can then be independently analysed. Its methodology is based on pairwise comparisons of the defined criteria which are used to establish the weightage to assess the performance scores for alternatives.

For example, there are 10 students and the best student must be select based on six criteria. What AHP does is that it takes two students at a time and compare their criteria individually, which is called a comparison matrix. By doing so, AHP will find the best among the 10 students. The criteria also need some weightage because each criterion shall not contribute equally in choosing the best student.

AHP was proposed by Saaty (1977, 1980) to model subjective decision-making processes based on multiple attributes in a hierarchical system. Since then, it has been widely used in corporate planning, portfolio selection, and benefit/cost analysis by government agencies for resource allocation purposes. It should be highlighted that all decision problems are considered as a hierarchical structure in the AHP.

2.3.2 Simple Additive Weighting Method (SAW)

SAW can be considered the most intuitive and easy way to deal with MCDM problems because the linear additive function can represent the preferences of decision makers (DM). However, this is true only when the assumption of preference independence (Keeney & Raiffa, 1976) or preference separability (Gorman, 1968) is met. Churchman and Ackoff (in Tzeng & Huang, 2011) first utilised the SAW method to cope with a portfolio selection problem. The SAW method is probably the best known and widely used method for MADM. Because of its simplicity, SAW is one the most popular methods in MADM problems.

2.3.3 Evidential Reasoning (ER)

The ER approach is a general approach for analysing MCDM problems under uncertainties. Traditionally, MCDM problems are represented or modelled by decision matrices, including pairwise comparison matrices used in AHP (Saaty, 1980; Farkas & Rózsa, 2001) in which exact numbers without uncertainties are frequently used as their elements and are incapable of explicitly modelling uncertainties like ignorance. The subsequent outcomes from analyses based on such models appear to be free of uncertainties, which can be misleading to the inexperienced. Even to the experienced, although further sensitivity analysis can be carried out to reveal some of the uncertainty effects which are not modelled in the first place, the anchoring effects (Bazerman, 2005) of the outcomes can be significant and lead to biased decisions. Concurrently, sensitivity analysis is by far from ideal for identifying the combined effects of various types of uncertainty, which often co-exist in a decision-making problem.

2.3.4 TOPSIS

The technique for order preferences by similarity to an ideal solution (TOPSIS) method was proposed by Hwang and Yoon (1981). The main idea originated from the concept of compromise solution to choose the best alternative which is nearest to the positive ideal solution (optimal solution) and farthest from the negative ideal solution (inferior solution). Then, the best sorting is chosen, which will be the best alternative.

In case of TOPSIS, all students will be taken at a time as alternatives and they will be given a score based on criteria, which is called the decision matrix. By using TOPSIS method from the decision matrix, the best alternative can be determined. The calculation part is reduced as the best alternative can be computed from the decision matrix. But one problem that is encountered in TOPSIS or other MCDM method is computation of the criteria weightage. This problem is tackled by various ways, such as AHP, cross-entropy, and fuzzy preference programming.

2.3.5 VIKOR

The VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method was developed for multi-criteria optimisation of complex systems. It determines the compromise ranking list, compromise solution, and weight stability intervals for preference stability of the compromise solution obtained with the initial (given) weights. This method focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria. It introduces the multi-criteria ranking index based on a particular measure of "closeness" to the "ideal" solution (Opricovic, 1998).

VIKOR is a helpful tool in MCDM, particularly in a situation whereby the decision maker cannot or does not know the way to express his preference at the beginning of system design. The obtained compromise solution can be accepted by the decision makers because it provides a maximum "group utility" (represented by min S) of the "majority" and a minimum of the individual regret (represented by min R) of the "opponent." The compromise solutions can be the basis for negotiations, involving the decision maker's preference by criteria weightage.

2.3.6 MAUT/SMART

Multi attribute utility theory (MAUT) is based on utility theory. It has had considerable success, especially in the United States. It is an additive method which multiplys the score for each alternative and criterion by the weight assigned to the criterion. Further, it proceeds with the summation of values found; the selected alternative is one that gets a higher value from this summation. According to Vincke (1992), MAUT was developed to consider uncertainty caused by lack of precise information or data; consequently, the model uses probabilities, in which case the probability of occurrence substitutes, for weightage.

Simple multi attribute rating technique (SMART) is the simplest form of MAUT. SMART was initially proposed by Edwards (1971). Since then, it has been widely used in business, management, and social sciences. This method is based on linear additive or simple multiplicative models for aggregating single criterion evaluation. The models are most suitable for the analysis of discrete alternatives (Smirnov, 2007). The SMART method shows good performance and requires less computation power, making the method appropriate for information technology security area. The main advantage of this approach is its simplicity in comparison with the other decision-making methods.

2.3.7 ELECTRE

The ELECTRE method is used to establish a partial ranking and choose a set of alternatives by eliminating less favourable ones while encountering few criteria with large number of alternatives in a decision-making problem. The ELECTRE method begins with pairwise comparisons of alternatives under each criterion. Its basic concept is to manage outranking relations by using pairwise comparisons among alternatives under each one of the criteria separately. ELECTRE method was evidently found to be used in the information security field.

Roy (1968) and Benayoun et al. (1966) in Tzeng and Huang (2011) originally used the concept of outranking relations to introduce the ELimination and Choice Expressing REality (ELECTRE) method. Since then, various ELECTRE models were developed based on the nature of the problem statement (to find a kernel solution or to rank the order of alternatives), degree of significance of the criteria to be considered (true or pseudo), and preferential information (weightage, concordance index, discordance index, veto effect).The ELECTRE I, ELECTRE II, ELECTRE III and ELECTRE IV models were developed over the years to improve the method.

2.3.8 PROMETHEE

The PROMETHEE method is one of the most frequently used methods of multi-criteria decisions based on mutual comparison of each alternative pair with respect to each of the selected criteria. These methods require very clear additional information that is easily obtained and understood by decision makers and analysts. PROMETHEE method had been widely used in various other fields, including information security for its mathematical properties and friendliness of use.

Brans et al. (1984a, 1984b, 1985) considered a new set of outranking methods called PROMETHEE (preference ranking organisation methods for enrichment evaluations) in solving MADM problems. These methods are based on a generalisation of the criterion notion. In this period, a basic concept of fuzzy outranking relation is first considered and built into each criterion by pairwise comparison measures for alternatives to different relation-degrees in each other. These different relation-degrees are then used to set up a partial preorder (PROMETHEE I), a complete preorder (PROMETHEE II), or an interval order (PROMETHEE III) on a finite set of feasible solutions. Another method called PROMETHEE IV is introduced for the case, whereby the set of feasible solutions is continuous. These results can be easily apprehended by the decision maker, as illustrated in a numerical application.

2.4 Problem Structuring Methods (PSM)

Problem Structuring Methods (PSMs) are qualitative approaches for making progress with ill-structured problems (Smith and Shaw, 2018). PSMs sit within Operational Research (OR) but represent an alternative paradigm for problem solving, distinct from ‘traditional quantitative OR’ (Smith and Shaw, 2018). According to Mingers and White (2010), PSMs are a family of interactive and participatory modelling approaches whose aim is to help groups of diverse composition to ease a complex, problematic situation of common interest. This situation is characterised by the existence of multiple actors, multiple perspectives, incommensurable and/or conflicting interests, prominent intangibles, and key uncertainties (Rosenhead and Mingers in Mingers and Rosenhead, 2004). Normally, the hardest and most demanding element in addressing such situations can be the framing and definition of the issues creating the problem (Mingers and White, 2010).

PSMs offer support in such situations through modelling and group facilitation with a view to stimulating dialogue and discussion about the problem domain, and reaching shared understanding and joint agreements with respect to it. Some of the PSM methods as listed by Mingers and White (2010) are interactive planning, social system design, and strategic assumption surfacing and testing. Possibly the most popular of the methods is Soft Systems Methodology (SSM) and its history and development run together significantly with PSMs in general (Mingers and White, 2010).

2.4.1 SSM

SSM is a general method for system redesign. Participants build ideal-type conceptual models (CMs), one for each relevant world view, and compare them with perceptions of the existing system to generate a debate about what changes are culturally feasible and systemically desirable (Mingers & Rosenhead, 2004). This methodology is more than just a process; Checkland (1999) and Wilson (2001) also developed a set of tools to help users carry out the steps. These include: Rich Picture, Conceptual Model and CATWOE analysis.

2.4.2 The strategic choice approach

Strategic choice approach (SCA) is a problem structuring method which is centred on the management of uncertainty and commitment in strategic situations, whereby strategic refers to the advisability of considering particular decisions in the context of others. Strategic occasions can occur at any level. The planning situation structure is elicited from stakeholders in a workshop format. This structure is built in a participatory manner with the aid of facilitators. SCA is a member of the problem structuring methods group; within that group it is notable for the variety of tools and techniques available to progress with the problem. It has been widely used in diverse public planning areas.

There are four modes of analysis within SCA (Friend & Hickling, 2004). Switching between modes, which may be recursive, is guided by the facilitator. The modes are:

The shaping mode phase decision makers are addressing concerns about the structure of a set of decision problems that they are now facing. The decision makers may be debate in what way the choices should be formulated, and to what extent one decision should be seen as being linked to another. In the designing mode phase, the members will be debating whether they have enough options in view, or whether there are technical design constraints that may restrict the scope for combining options from linked areas of choice in particular ways. In the next phase, which is the comparing mode, decision-makers will address concerns about the ways in which the implications of different courses of action should be compared. The actors may consider a variety of different criteria and debate in what way assessments of consequences should be made. The final phase, which is the choosing mode, the actors will focus on the way to agree commitment to actions over time. Therefore, this may mean considering not only whether there are some commitments to substantive action that can be undertaken immediately, but also on ways the future process may be managed. Similarities in the SCA model can be seen between this general model of a decision process and other more familiar models, in which a sequence of logical steps is defined, often with feedback loops to allow possible recursion to earlier stages. For more detail descriptions see: Friend (2001), Friend & Hickling (2004).

2.4.3 Strategic options development analysis (SODA)

The SODA method is an approach which is designed to provide consultants with a set of skills, a framework for designing problem solving interventions and a set of techniques and tools to help their clients work with messy problems (Ackermann & Eden, 2001). These problems may be those that demand the ability to use model building to work with quantitative and qualitative aspects of the problem. It is an approach that encourages the consultant to bring together two skills.

Firstly, the skills of a facilitator of the processes involved in helping a problem solving team to work together efficiently and effectively to reach workable and politically feasible agreements. Secondly, the skill to construct a model, and appropriately analyse, the content, such as interconnected issues, problems, strategies and options in which members of the team wish to address. The process management issues are not taken as independent of the content management issues. Rather, each aspect informs the way in which the other skill is best utilised.

2.5 Conclusion

Within this chapter, a cautious analysis of major factors that influence the opening of the NSR, such as political factor, legal factor, economic factor, environmental factor, social factor, technological factor, and safety factor. The advantages of the NSR as compared to other routes were identified. Therefore, a methodology for ranking and prioritising these factors must be developed. This is because with so many factors identified, it is very important for shipping companies to clearly understand which factor is the most vital for them before they use the NSR for shipping operations. Therefore, some MCDM methods were reviewed in this chapter to fulfil the research objective. Moreover, some of these MCDM methods together with PSM method will be applied to answer all the research study objectives.

Over the years, many MCDM methods were proposed in literature; these methods are different in the type of research questions they aim to address, types of problem, theoretical background, and types of outcome obtained. Since methods have been designed for specific cases, with their associated benefits and limitations, there is no particular MCDM method that can be applied to all types of problem .Therefore, selection of the most suitable MCDM method will be carried out in the next chapter. Moreover, the research framework, outline, expert judgments and data analysis will be explained in the next chapter.

CHAPTER 3:
RESEARCH METHODOLOGY

Summary

The purpose of this chapter is to explain the research study methods and methodology. Firstly, the chapter explains the selection of MCDM methods and the way it meets the aims and objectives set by this thesis. Then the chapter discusses the questionnaires, expert survey as well as data collection and data analysis. It concludes with a brief discussion on the sensitivity analysis conducted for each chapter involved.

3.1 Introduction

The methodological view to decision-making techniques adopted in the thesis is based on a requisite logical modelling, whereby related factors and decision models are first generated to support decision-making and then solutions to the problems are provided. Therefore, it is essential to first select and justify the selection of MCDM methodology. Then, the data collection and algorithm are conducted according to the selected MCDM methods. The chapters are divided based on the research objectives which are explained in Chapter 1. The thesis outline is presented.

3.2 Selection of MCDM methods

Many attempts were made to define a framework that links each selection problem to the most suitable decision method. This is an exhaustive, thorough, and nearly impossible procedure that must consider all decision process dimensions, decision maker's(DM) role, not to mention the extensive number and variety of methods, and available information (Mota et al., 2013). However, it is unquestionable that the selection problem is primal to the success of process (Eldrandaly et al., 2009), which explains some of the particular studies in this area (Guitouni & Martel, 1998; Guitouni et al., 1999).

Hwang and Yoon (1981) organised some decision methods on a diagram tree according to available information, providing the decision analysts and decision makers with a simple tool to choose a method. Nevertheless, it is a restricted approach and leaves out important aspects of the decision process as well as powerful methods that are not considered in the tree definition.

A study conducted by Baker et al. (2002) presented a state of the art of the existing approaches to select MCDM methods. This study considered nine different approaches and compared them with each other regarding their characteristics. Moreover, it pointed out four major facets with inner features, in which according to the study it guaranteed the characterisation of the decision problem in the selection context. Those facets are:

Problem facet – type of decision problematic, problem scale (workplace, department, enterprise, and corporation).

Potential Action facet – a number of alternatives, ability to consider new alternatives, incompatibility and conflict, organisation of alternatives, nature of alternative sets (discrete, continuous).

Criteria facet – data type, measure scale, criteria weightage, criteriainteraction.

Usage facet – tool (Software), Approaches for giving partial and final evaluations, ease of use, cost for implementing (purchasing tool, costs for training), decision maker preferences (DM understanding, skills and habits).

Guitouni and Martel (1998) proposed seven guidelines to choose an appropriate decision method within 29 possible multi-criteria aggregation procedures (MCAP):

G1: Determine stakeholders of the decision process.

G2: Consider DM's "cognition" when choosing a particular preference evaluation mode.

G3: Determine the decision problematic pursued by the DM.

G4: Choose the MCAP that can handle the input information properly.

G5: Consider the compensation degree of the MCAP method

G6: Consider the fundamental hypothesis of the method

G7: Consider the decision support system

The guidelines support the designing of a typological tree of discrete MCAP. The DM or analyst only needs to follow the branches of the tree according to the guidelines and one or several decision methods will be presented as possibilities for the decision-making situation (DMS) under consideration. This means that an unequivocal choice is not always the result of its use. But it represents a powerful tool for guiding the method selection and can be improved by adding new methods to the list or new branches to the tree following, for example, the four facets above or other relevant characteristics of the DMS. However, guidelines proposed by Baker et al. (2002) and Guitouni and Martel (1998) are considered very general, which means that many MCDM approaches can be applied to solve a selection problem.

Munier (2019) initiated a tool (Appendix D) for selecting the most appropriate MCDM method to solve a selection problem. By using the Microsoft Excel as the platform, he listed 54 characteristics of selecting the best MCDM method together with 10 MCDM methods, namely SAW, AHP, TOPSIS, VIKOR, PROMETHEE, MOORA, ELECTRE, ANP, LP and SIMUS.

The tool which displays in the matrix shows that the different MCDM methods are in columns. They are listed in increasing capacity from left to right for scenarios modelling, and thus SAW is the first with low capacity and SIMUS is the last with the largest capacity. There are three areas. The first area is ‘scenario characteristics', which details the different criteria or conditions that can exist in a scenario. The second area is the 'membership matrix' which matches the different MCDM methods with every criterion. It indicates each method by using a (1) if it could handle a certain characteristic. For instance, Characteristic 31, 'necessity to use resources' can be only handled by 'PROMETHEE', ''Linear Programing' (LP) and 'SIMUS'. The third area is the right column that informs the total number of methods that can handle or match each characteristic. For instance, Characteristic 15, which is 'using any normalisation procedure', can be handled only by SAW, LP and SIMUS. The first row below the 'scenario characteristics' indicates the total number of criteria chosen by the DM. The second row below the matrix shows the results or total number of requirements that can handle each method. The third row below the matrix shows the scores for each method. The lowest is considered the most appropriate for a determined scenario.

This tool is very powerful because it can recommend the most suitable MCDM method for any selection problems. Therefore, this tool can be used to select the suitable MCDM method for this study. Six out of 44 characteristics were then chosen, namely ‘single scenario’, ‘single objective’, ‘several DMs (group decision making)’, ‘qualitative criteria’, ‘quantitative criteria’ and ‘large number of criteria’, as these are the most relevant to this study. However, the results showed that all 10 MCDM approaches were considered suitable (all methods scored the same). Therefore, even with this tool, there will be more than one methods that can be used to solve a selection problem.

According to Dooley et al. (2005), the appropriate methods to use can become increasingly evident throughout the problem structuring and identification of alternatives and criteria stages. Therefore, method selection can be an on-going process. The study also suggested to develop a descriptive framework to assist select the most appropriate MCDM approach and methods for a given problem, taking the problem attributes, decision maker's requirements, method requirements and limitations into consideration.

To summarise, searching for the best MCDM method for selection problems may never end. Research in this area is critical and valuable. The studies presented here mostly suggested a very general procedure and did not really signify the best method for a selection problem. It is a common belief that there is no one method superior to another, albeit there is perhaps one that is more popular, but most of the time any of them can be used to solve a problem (Munier, 2011). Therefore, all relevant characteristics and requirements mentioned in previous studies will be used to find the most suitable MCDM method for all selection problems in this study.

The MCDM methods employed in this thesis are based on the research objectives (Chapter 1, Section 1.3). For Objective 2, the AHP were selected to rank and prioritise the factors that influence the opening of the NSR. In fact, the AHP through pairwise comparison technique was used to find the weightage of the criteria throughout the study. An analysis of literature on MCDM method applications indicated that one of the most popular and widely applied in practice is the AHP method (Podgorski, 2015). The method in question involves the determination of various levels of importance for the defined criteria; subsequently, an expert comparison and ranking of decision variants in relation to those criteria. With the given relatively low level of complexity, availability of relevant supporting software, and possibility of applying them to solve decision problems in many economic sectors and areas of science and technology (Podgorski, 2015). The AHP method has been widely employed in hundreds of documented cases, which is confirmed by literature reviews of applications, thereof as published by Vaidya and Kumar (2006), Subramanian and Ramanathan (2012), and Russo and Camanho (2015).

To fulfil Objective 3 of this research, ER was used to find the most effective shipping transit route within the NSR. The ER approach uses a belief structure to model an assessment with uncertainty, a belief decision matrix to represent an MCDM problem under uncertainty (Riahi, 2010), evidential reasoning algorithms to aggregate criteria for generating distributed assessments (Yang & Singh, 1994), and the concepts of the belief and plausibility functions to generate a utility interval for measuring the degree of ignorance. ER is suitable because of the high uncertainty in terms of ice conditions, safety and other characteristics of the NSR.

TOPSIS was used to fulfil Objective 4 of this research, which is to find the best shipping transit route between the Far-east and Northwest Europe. This is because one of strengths of TOPSIS is the ability to take input as any number of criteria and attributes (Gavade, 2014). This is important because the comparison made is not only between qualitative or quantitative criteria, but with many different inputs, such as costs, distances, and load factors, which many previous studies failed to consider because of this limitation.

For Objective 5, the SSM was used to find the solutions to enhance the NSR use. This is because SSM has offers more tools to structure the problems (rich picture, problem diagram, conceptual model) and finally to find the solutions. It also remains as the most widely used and practical application of systems thinking (Mingers & White, 2010). Therefore, Figure 3.1 shows the research structure of the thesis with selected MCDM methods.

3.3 Questionnaires and Experts Judgement

Generally, diversity is valued within the framework of the expert task. Multiple experts produce more meaningful distributions of qualitative opinions or of quantitative estimates than single experts can (Benini et al., 2017). Meyer and Booker (2001) recommended some optimal numbers of experts. These limits vary by elicitation methods. If a face-to-face meeting was involved, they recommend five to nine experts for each available interviewer to moderate the sessions. Fewer participants will not produce enough diversity; more will likely struggle with adverse group dynamics ("follow the leader"). Therefore, in this research, the minimum number of experts employed was three because each expert answered the questionnaire individually (not put together in one group). Then, geometric mean was used to aggregate all the expert judgements.

Questionnaires were design based on the selected method. For example, pairwise comparison approach (AHP) was used for all chapters that involve MCDM methods to find the weightage of all evaluated criteria (Chapter 4, Chapter 5 and Chapter 6). Then, one belief degree questionnaire for ER method was also conducted, which will be explained more in the chapters involved.

Mostly questionnaires were sent through emails and some were distributed in person. Experts from academic background were obtained from journals, books and any other publications published in relation with the NSR. The experts from industry were obtained from shipping related institutions, such as classification society and Arctic Institute. Most experts were not familiar with the pairwise comparison technique and the belief degree questionnaire but did not have any problem in answering because it was easy. More information about questionnaire design and experts background can be obtained in Chapter 4, Chapter 5 and Chapter 6 of this thesis.

3.4 Data collection and data analysis

Data collection and data analysis were conducted based on the MCDM methods selected. Each MCDM method has its own data requirements and calculations. Most data were obtained from previous literature and through calculations. These processes were shown in each chapter involved. Case studies were also designed and constructed in Chapter 5 and Chapter 6 to make the study more focused and within the research scope. For example, the type and size of ships used, the number of days for shipping navigation, and location of the ports.

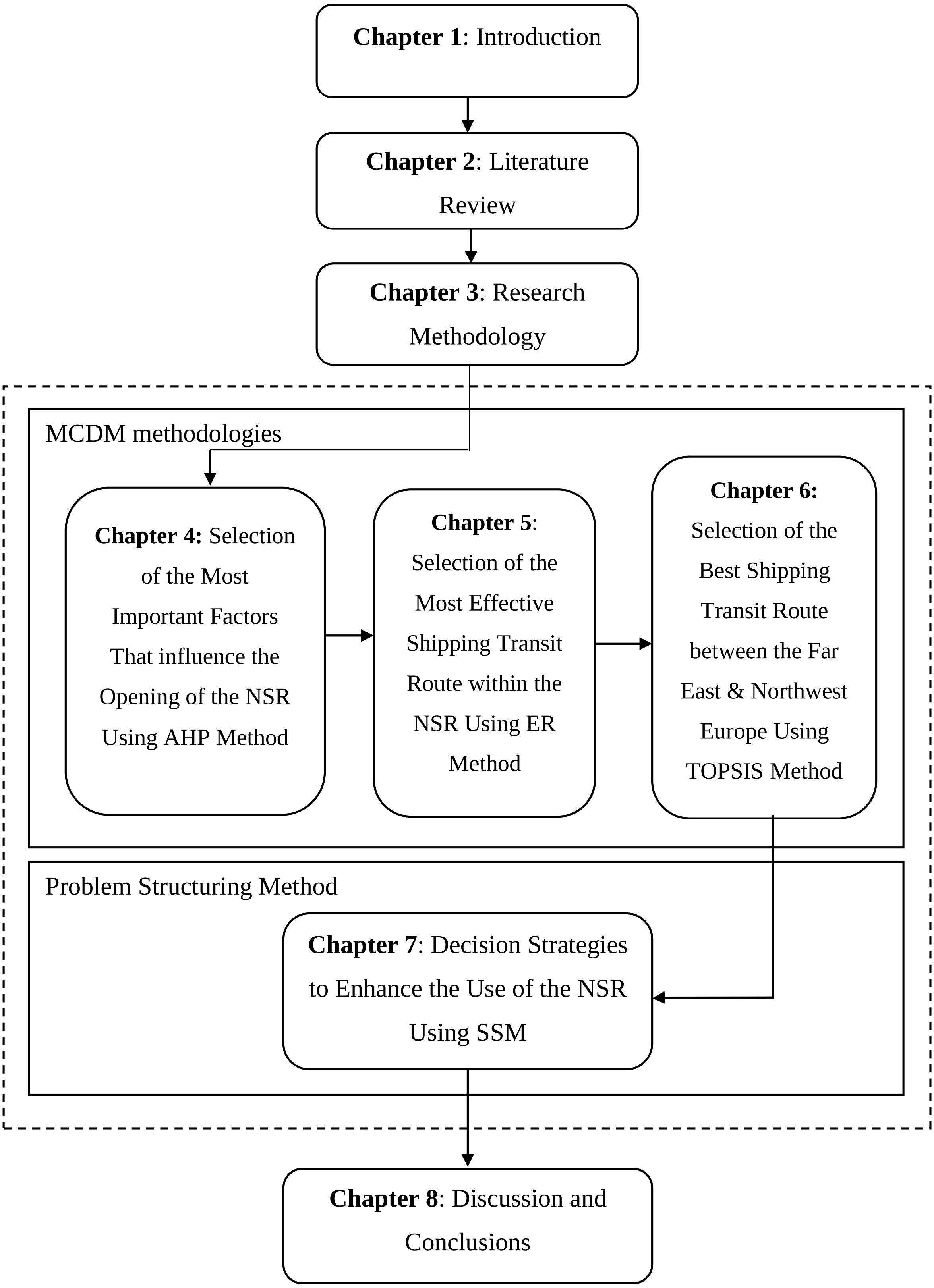


Figure 3.1: The research structure of the thesis

3.5 Sensitivity analysis

The solution to a decision problem, the global ranking of criteria or alternatives, may not provide enough information to the decision maker to make a final decision. There are several reasons why a sensitivity analysis should be conducted on the results. For instance, the judgements for some criteria may be subjective or there may be uncertainty in the data that leads to the preference value. In addition, the preference judgements may come from a group decision where there are different opinions. Moreover, different prioritisation methods may yield different results for the same pairwise comparison matrix. The sensitivity analysis provides more understanding about the problem, and in this way, the decision maker should be able to make a more informed decision.

According to Lucia and Mark (2001), parameter sensitivity is usually performed as a series of tests in which the modeller sets different parameter values to see how a change in the parameter causes changes in the model. Moreover, the sensitivity analysis helps to build confidence in the model by studying uncertainties that are often associated with parameters in the model (Lucia and Mark, 2001).

There are several methods to perform the sensitivity analysis on MCDM problems, but this research only focused on the numerical incremental analysis (Chen & Kocaoglou, 2008). This approach involved change in weightage values and calculating the new solution. The method, also known as One-at-a-time (OAT) (Leonelli, 2012), works by incrementally changing one parameter at a time, calculating the new solution and graphically presenting the way global ranking changes. This OAT method was used to all chapters involved.

There is no restriction on how much the increase/decrease in the number of percentage used on the weightage values or the output values of the methods involved. For AHP selection problems, Wu et al. (2007) used 20%, 25% and 30% increase in criteria weightage. On the other hand, Shand (2008), used 25%, 33.33%, and 100%. Meanwhile Chang et al. (2007) used 25%, 30% and 35%. For ER cases, Abdul Rahman (2012) applied -10%, -20% and -30% in his thesis. Pam (2010) used -20%, -40%, -60% and -80%. Ramin (2010) used both decrease and increase of 10%, 20% and 30% in the degree of belief values. For sensitivity analysis that involves TOPSIS method, Pam (2010) used both increase and decrease output values at 5% and 20%.

In this study, Chapter 4 (AHP) and Chapter 5 (ER), the percentages chosen were 10%, 20% and 30%, while in Chapter 6 (TOPSIS) the percentages used were 10%, 20%, 30%, 200%

and 300%. The variety of percentages chosen, especially in Chapter 6 had their own justifications which were explained in each relevant chapter.

3.6 Conclusion

This chapter selects and justifies the research methodology implemented in this thesis. The AHP, ER and TOPSIS were selected from many available MCDM methods. Meanwhile, the SSM approach was selected from many PSM methods. This selection of the MCDM methods and PSM method consequently fulfils the aim and objectives of research. Over recent years, MCDM was proven to be part of the decision-making in various components of a society that grows in complexity. The decision support has turned into a more solid, organised and widely used process. The other key research tools were questionnaire and data collection which were briefly explained in this chapter with more explanations in the next relevant chapters. The experts were carefully targeted and recruited based on their background. The results were manually analysed and with the help of intelligent decision system (IDS) software for ER calculation. The major results and findings of this research are discussed in the following chapter.

CHAPTER 4:

SELECTION OF THE MOST IMPORTANT FACTOR THAT INFLUENCES THE OPENING OF THE NSR USING ANALYTIC HIERARCHY PROCESS (AHP)

Summary

The Analytic Hierarchy Process (AHP) is introduced for selecting the most important factor that influences the opening of the Northern Sea Route (NSR). More than fifty factors have been identified from the previous chapter of Literature Review. These factors will be grouped into eight main factors in the format of hierarchical structure. All factors are measured using a pairwise comparison approach of AHP dealing with expert judgements. Then, the factors will be ranked based on the weight value calculated. A sensitivity analysis will be conducted to validate the results. The findings of the study include the identification of the factors and the ranking of the factors that influences the opening of the NSR.

4.1 Introduction

The NSR has been used as Russia's internal shipping transit since 1932, and in 1991, it was open for international use for the first time (Blunden, 2012). During that time, many countries did not show as much attention as they do today. Many believe it is the diminishing of ice in the Arctic due to climate change that has led to the opening of the NSR. However, there are many other factors as described in the previous chapter (Literature Review – Chapter 2) that are also affecting the use of the NSR. The eight main factors are political factor, legal factor, economic factor, environmental factor, social factor, technological factor, safety factor and the advantages of the NSR in comparison to other alternatives.

The NSR has attracted many researchers from all over the world with different fields and backgrounds to study this new shipping route. Some of the studies are geopolitics and policies (Kaczynski, 2013; Blunden, 2012), legal issues (Molenaar, 2009; Franckx, 2009), economic feasibility (Verny and Grigentin, 2009; Liu and Kronbak, 2010; Schoyen and Brathen, 2011), social (Meschtyb *et al*., 2005), technology (Kaczynski, 2012), and many other fields. All factors that influence the opening of the NSR are gathered from different published papers, institutional reports, news, and through interviews with experts. Despite all the researches described, there is no research using the MCDM approach to analyse economic feasibility, route selections, and many other aspects of the NSR. Furthermore, every time the

Arctic sea ice extent reaches a new record low, as it last did in September 2012 (as compared from 2012 until 2018), a host of new reports and studies predict a rapid increase in shipping activities in the Arctic (Humpert, 2013). Expectations are high that the NSR will rival traditional shipping routes and complement the Suez Canal route as a key waterway for trade to and from Asia by the middle of this century (Humpert, 2013). How true is this statement? What are the issues in the NSR shipping? Before answering all these questions, it is important to analyse the current state of the NSR by identifying all the factors that influence the opening of the NSR. Therefore, this chapter intends to analyse the most important factor that influences the opening of the NSR. By doing this, it is hoped that shipping companies will have more information about the NSR and reduce the risk of using it. Other parties of stakeholders of the NSR can also make adjustment and improve any deficiency of the NSR. An Analytic Hierarchy Process (AHP), which is one of the MCDM approaches, will be used to analyse the criteria that have been determined.

4.2 Literature Review

This chapter intends to identify and evaluate the factors and thus, no alternative is needed. The process to select the source of criteria must be determined as well. This particular type of AHP applications must be examined through the work of previous studies.

Vaidya and Kumar (2006) analysed different applications of AHP out of 150 application papers. These applications have been classified into three groups, namely (a) applications based on theme; (b) specific applications; and (c) applications combined with some other methodology. Themes in the first group are selection, evaluation, benefit-cost analysis, allocations, planning and development, priority and ranking, and decision making. Although a research article may be classified under two headings on the basis of the subject coverage, the best suited category is taken into account for the classification purpose to avoid duplication. The second group consists of the specific applications in forecasting, medicine, and related fields. The third group is AHP combined with quality function deployment and application areas such as personal, social, manufacturing sector, political, engineering, education, industry, government, and others. It is obvious that the AHP method can be applied into many different applications. Vaidya and Kumar (2006) affirmed that AHP is used to select from competing alternatives, allocation of scarce resources, and forecasting, but in the cases analysed, it is noticed that AHP was used mainly to weigh criteria ,select and rank alternatives. The selection of criteria by the decision makers depended on the problem type: in the selection, the criteria arose from the organisation's expertise; in the ranking of alternatives or of indicators, the literature was more used.

Russo and Camanho (2015) selected 33 articles in their study to analyse the criteria used in AHP. The object of all of these articles was the evaluation of specific real cases where the AHP method was adopted. All the articles refer to a case study. The articles selected were published from 2005 through to 2015. According to Russo and Camanho (2015), in general, the influence factors were denominated criteria. However, they also were called aspects, attributes, classes, dimension, families, index, and perspectives by the selected articles. Russo and Camanho (2015) analysed that, in most of the cases, the process to select the source of criteria was based on the literature; in another relevant number of cases, the process was based on selecting the criteria considered relevant for the organisation. Only in four cases was the source to select the criteria supported by external specialist contribution; with the exception of eight cases where no alternatives were reported due to the fact that the objective of the process was to identify and evaluate indicators. Regarding the ranking indicators, the literature was, once more, the main source. However, experts reviewed the criteria in many cases, in which the Delphi technique was used, and in one case, the organisational team provided the criteria.

Hence, in this study, the criteria are identified through literature review and discussion with experts. The AHP method will be used to weigh the criteria and then rank them accordingly.

4.3 Background of AHP method

The Analytic Hierarchy Process (AHP) is a problem-solving framework and a systematic procedure for representing the elements of any problem (Saaty, 1983). It has been developed by Thomas Saaty (1977, 1980), and has increased in popularity and is one of the most widely used MCDM approaches (Merwe, 2008; Saaty 1980). AHP is based on the experience gained by Saaty, while he was directing research projects in the US Arms Control and Disarmament Agency (Bhushan and Rai, 2004).

This technique is suitable for dealing with complex systems that involve making a choice from several alternatives and providing a comparison of the considered options. It is also capable of taking large quantities of decision-making criteria of quantitative and qualitative nature into consideration, and at the same time, facilitating the construction of a flexible hierarchy to address a decision-making problem (Cheng, 2002). Saaty established a consistent way of converting such pairwise comparisons (for example, ‘A’ is more important than ‘B’) into a set of numbers representing the relative priority of each of the criteria. In addition, AHP incorporates a useful technique for checking the consistency of the decision maker’s evaluations, thus reducing the bias in the decision-making process (Saaty, 1980). AHP has been applied to support decision making in different fields, for example, in engineering (Katarne *et al*., 2013; Triantaphyllou *et al*., 1995), healthcare (Pecchia *et al*., 2011), marketing (Wickramasinghe *et al*., 2009), and accounting (Apostolou and Hassell, 1993). AHP has also been accepted as a leading multi-attribute decision model both by practitioners and academics (Presley, 2006; Saaty, 2007).

The method is based on the subdivision of a problem into a hierarchical form, thus, helping analysts to organise the critical aspects of the problem into a hierarchical structure similar to a family tree. Here, the importance of each element (criterion) becomes clear (Saaty, 1980; Macharis *et al*., 2004). Other advantages of AHP over other multi criteria methods are:

- It supports group decision-making through consensus by calculating the geometric mean of the individual pairwise comparisons (Zahir, 1999).
- Its flexibility, intuitive appeal to the decision makers, and its ability to check inconsistencies (Ramanathan, 2001).
- AHP is a useful decision aid method in the sense that it would help the decision maker to make his/her decision using its advice without totally overriding the initial, tentative, choice (Ishizaka *et al*., 2011).

4.4 Generic Methodology

This research will be conducted by using the AHP method as shown in Figure 4.1. There are two parts of the methodology used in this study, which are Step 1 to Step 4 utilising the AHP method and Step 5 using a sensitivity analysis. The four main steps of AHP are explained in detail as follows:

Step 1: Define the problem and determine the kind of knowledge sought

The first step involves a definition of the unstructured problem. The decision analysts must have a clear understanding of the problem under investigation. Lack of understanding and wrong information will affect the whole structure of the problem.

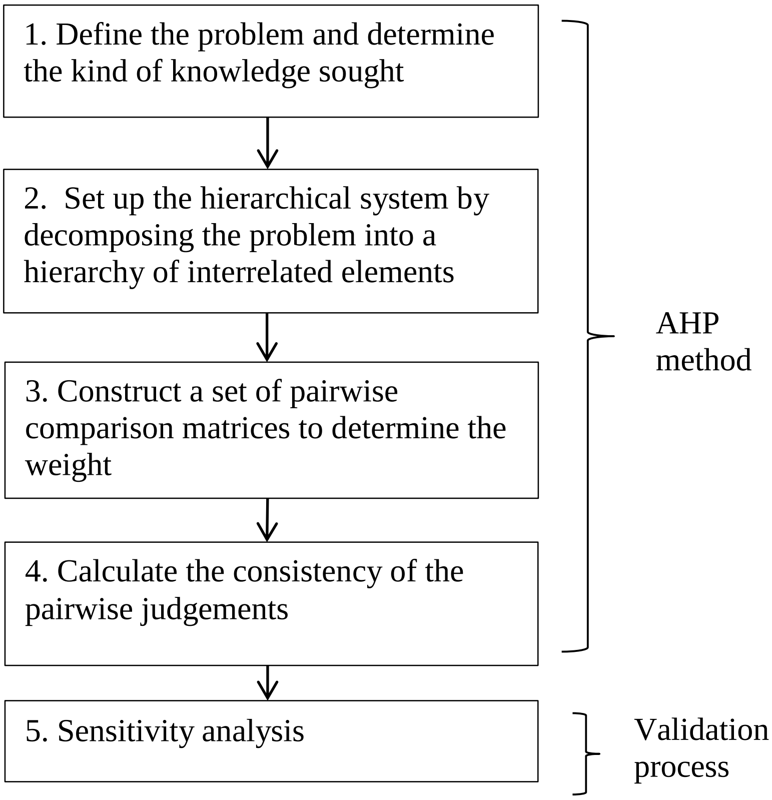


Figure 4.1: The flow chart of the research methodology

Step 2: Set up the hierarchical system by decomposing the problem into a hierarchy of interrelated elements

The second step is the decomposition of the problem into a systematic hierarchical structure. This process involves building a hierarchy, which is usually in a graphical representation of the problem in terms of the overall goal, criteria, and decision alternatives (Figure 4.2). Therefore, it is important that the experts involved in the process clearly define the problems and specify their judgements about the relative importance of each criterion of the subject matter. The formation of the hierarchy is based on two assumptions: (a) each element of a level in the hierarchy would be related to the elements at the adjacent levels; and (b) there is no hypothesised relationship between the elements of different groups at the same level (Cheng and Li, 2001**).**

A hierarchy is a model, and is not supposed to contain every item that can be identified (Tzeng and Huang, 2011). It is possible to clutter a model so much that it becomes useless for identifying truly relevant factors. If a hierarchy becomes too big, it is difficult to see the effect of making changes in judgements in any part of it as it becomes insensitive. A hierarchy should be large enough to represent the major concerns and small enough to be responsive to change (Tzeng and Huang, 2011).

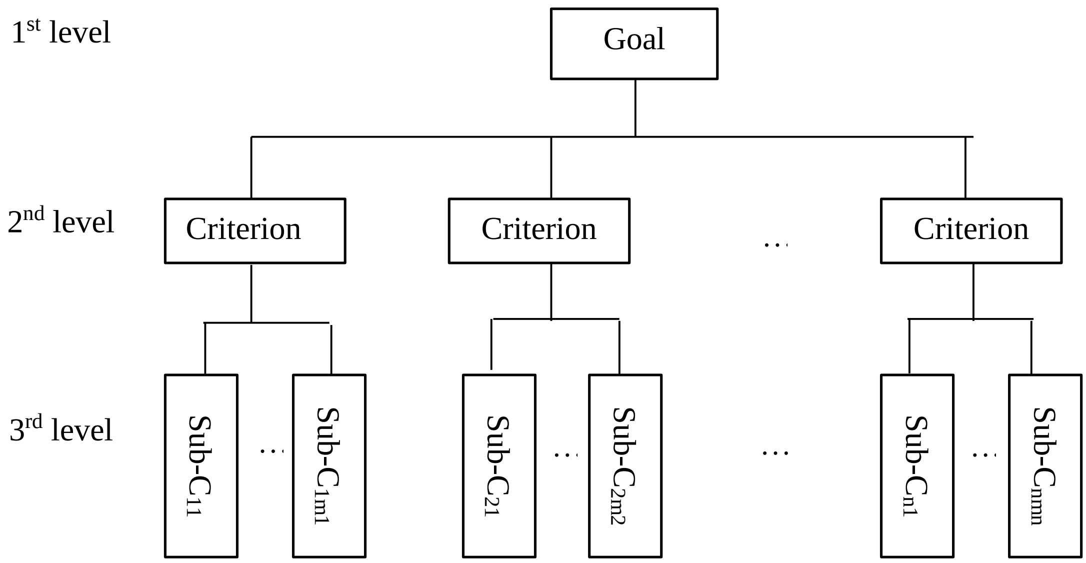


Figure 4.2: The hierarchical structure of the AHP (*Source*: Tzeng and Huang, 2011)

Step 3: Construct a set of pairwise comparison matrices and calculation of the weight

The third step is the identification of a preference or priority for each criterion in terms of how it contributes to the upper level event. Each element in an upper level is used to compare the elements in the level immediately below with respect to it. The process involves the employment of the pairwise comparison method to each group in the hierarchy to form a matrix and comparing each of the paired elements in the matrices. To construct the measurement, a set of questionnaires will be sent to a number of experts for analysing the priority of each evaluation parameter to another by incorporating the ratio scale of the pairwise comparison.

During this process, the experts are expected to specify how their judgements on a lower level criterion contribute to the formulation of the upper level criteria or top level event. To conduct the pairwise comparison matrix, firstly, set up n criteria in the row and column of a $n \times n$ matrix. Then, perform the pairwise comparison to all the criteria by applying a ratio scale assessment. The assessment scale is shown in Table 4.1 and each expert has to understand it before completing the pairwise comparison. This table contains two parts that describe the numerical assessment together with the linguistic meaning of each number. The first part is on the left side that explains “IMPORTANT”, while the right side is the second part of the table that describes “UNIMPORTANT” (Wu, 2007).

Table 4.1: The ratio scale of pair-wise comparison (Wu, 2007)

Numerical Assessment	**Linguistic meaning**	**Numerical Assessment**	**Linguistic meaning**
1	Equally important	1	Equally important
3	A little important	1/3	A little unimportant
5	Important	1/5	Unimportant
7	Very important	1/7	Very unimportant
9	Extremely important	1/9	Extremely unimportant
2,4,6,8	Intermediate values of importance	1/2, 1/4, 1/6, 1/8	Intermediate values of unimportance

The qualified judgements on pairs of attribute Ai and Aj are represented by a $n \times n$ matrix *A* as shown in Equation 4.1

$$A = (a_{ij}) = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a/a_{12} & 1 & \dots & a_{2n} \\ . & . & \dots & . \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \qquad (4.1)$$

where i,j=1,2,3,…,n and each a_{ij} is the relative importance of attribute A_i to attribute A_j.

For a matrix of order n, ($n \times (n{-}1)/2$) comparisons are required. According to Pam (2010), the weight vector indicates the priority of each element in the pair-wise comparison matrix in terms of its overall contribution to the decision making process. Such a weight value can be calculated using Equation 4.2.

$$w_k = \frac{1}{n} \sum_{j=1}^{n} \left(\frac{a_{kj}}{\sum_{j=1}^{n} a_{ij}} \right) \quad (k = 1,2,3,\dots,n) \qquad (4.2)$$

where a_{ij} stands for the entry of row *i* and column *j* in a comparison matrix of order *n*.

This study is using a group decision making. Therefore, the judgements of all experts will be combined together. It has been proven that the geometric mean, not the frequently used arithmetic mean, is the only way to combine the judgements of the group of experts (Saaty, 2008). The reciprocal property plays an important role in combining the judgements of several experts to obtain a single judgement for the group. The geometric mean equation can be calculated using Equation 4.3.

$$GM = (A1 \times A2 \dots \mathrm{An})^{\frac{1}{n}} \qquad (4.3)$$

where, *A1* is the first number, *A2* is the second number and *n* is the number of entries.

The arithmetic mean of a set of data is found by taking the sum of the data, and then dividing the sum by the total number of values in the set. A mean is commonly referred to as an average. The arithmetic mean equation can be calculated using Equation 4.4. If n numbers are given, each number denoted by a_i, where i = 1, …, n, the arithmetic mean is the [sum] of the a_i's divided by n or

$$AM = \frac{1}{n}\sum_{i=1}^{n} ai = \frac{1}{n}(a_1 + a_2 + \cdots + a_n) \quad (4.4)$$

Step 4: The calculation of the consistency of the pairwise judgements.

This involves carrying out a consistency measurement to screen out the inconsistency of responses. Comparisons made by this method are subjective and the AHP tolerates inconsistency through the amount of redundancy in the approach. If the consistency index fails to reach a required level then answers to comparisons may be re-examined. The weight values obtained in the pair-wise comparison matrix are checked for consistency purposes using a Consistency Ratio (*CR*). The *CR* value is computed using the following equations (Saaty, 1990):

$$CR = \frac{CI}{RI} \quad (4.5)$$

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (4.6)$$

$$\lambda_{max} = \frac{\sum_{j=1}^{n} \frac{\sum_{k=1}^{n} w_k a_{jk}}{w_j}}{n} \quad (4.7)$$

where n is the number of items being compared, λ_{max} stands for maximum weight value of the $n \times n$ comparison matrix, *RI* stands for average random index (Table 4.2) and *CI* stands for consistency index.

Table 4.2: Random Index (RI) values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

Source: Saaty (2013)

CR is designed in such a way that a value greater than 0.10 indicates an inconsistency in pair-wise comparison. If *CR* is 0.10 or less, the consistency of the pair-wise comparisons is considered reasonable (Saaty, 1980).

Step 5: Sensitivity Analysis

This research only focuses on the numerical incremental analysis (Chen and Kocaoglou, 2008) which was explained in Chapter 3. This is the most commonly used method in associated software tools, and according to Chen and Kocaoglou (2008), is also the most popular in the literature where AHP is used to solve problems.

4.5 Case study of selection of the important factors that influence the opening of the NSR

All four steps of the AHP technique discussed in Section 4.2 will be demonstrated together with the proposed model. The aims of this study are to select and rank the important factors that influence the opening of the NSR.

Step 1: Define the problem and determine the kind of knowledge sought.

During the Soviet era, the Russian Arctic Ocean was in practical terms closed to foreign shipping. This all changed in 1991, when the Soviet Union formally opened up the NSR to foreign vessels (Ragner, 2000). Being a new route for international use, the NSR certainly has brought more questions regarding its economy, legal, environmental, safety, and many other aspects to the shipping company. The lack of knowledge about the NSR will increase the risk of using it, and at the same time, the opportunity that the NSR has to offer cannot be overlooked. Furthermore, every time the Arctic sea ice extent reaches a new record low, many reports and studies predicted a rapid increase in shipping activities in the Arctic (Humpert, 2013). Unfortunately, the statistics have shown otherwise. For the years from 2011 until 2018, the transit statistics of ships through the NSR were 41, 46, 71, 31, 18, 19, 27 and 27 respectively (CHNL Information Office). The numbers are very small as compared to the other main shipping routes. Expectations are high that the NSR will rival traditional shipping routes and complement the Suez Canal route as a key waterway for trade to and from Asia by the middle of this century (Humpert, 2013).

Thus, it is important to analyse the issues or concerns regarding the NSR. All parties such as shipowners, government institutions, insurance companies and many others will have more information to equip themselves before using the NSR. Then, action can be taken to overcome any identified obstacles. All factors or any issues will be identified and grouped in the format of hierarchical structure, which will give more understanding of the problems.

Step 2: Set up the hierarchical system by decomposing the problem into a hierarchy of interrelated elements.

The second step is to construct the hierarchical structure of factors that influence the opening of the NSR. All the factors or criteria are gathered through the literature review (Chapter 2) and extensive brainstorming and discussion with an expert of the NSR. The expert specialises in comparative socio-economic and strategic studies of the marine resource use and human activities in the ocean space and in relation with developing coastal states. Besides his academic activities (teaching on strategic planning of marine economies, marine policy, international marine cooperation, and on Russian ocean policy in an American University) he is frequently engaged as a marine economic advisor by the World Bank, United Nations Food and Agriculture Organisation, United Nations Development Programme, United States Agency for International Development, Inter-American Development Bank, and other international donor organisations.

All factors were decomposed into a hierarchy of goal, main criteria, sub-criteria, and sub-sub criteria. This process can be classified into two sub-steps.

a) Identify all possible criteria

By using political factors as an example, the list of criteria that influence the opening of the NSR is shown in Table 4.3.

Table 4.3: The list of Political factors that influence the opening of the NSR

1.	The Russian government is anxious to promote its international use (Blunden, 2012)
2.	Year round maintenance of the entire route is currently being promoted by the Russians as a way of bringing hard currency into the country (Mulherin, 1996).
3.	South Korea is playing a growing role in Arctic economic development. It has since 2002 been running an Arctic research station at the Ny-Alesund research base (Blunden, 2012).
4.	The Chinese are beginning to collaborate with the Russians. The companies will coordinate their efforts in utilization of the NSR (Blunden, 2012).
5.	Russia's Arctic doctrines states that it will build and develop infrastructure, including ports, customs facilities and marine checkpoints (Blunden, 2012).
6.	The Russian Federation is currently intending to invest 910 billion roubles (13.99 million Pound Sterling) in the development of ten centres for search and rescue along the NSR as an attempt to reduce the rescue response time (Erikstad & Ehlers, 2012).

7.	In the absence of serious Russian state investment the operational conditions may continue to decline despite improved ice conditions (Moe & Jensen, 2010).
8.	A ship is not allowed to deviate from a route without Marine Operations Headquarters (MOHs) permission, but revision to this restriction and control might be considered in the future (Ragner, 2000).
9.	The inspection process as well as the actual tariff negotiations require at present two months of planning ahead, with a potential reduction for the subsequent journeys to one month (Erikstad & Ehlers, 2012).
10.	Ship owners should submit their requests to use the NSR at least 4 months in advance to the Administration of NSR (NSRA), Moscow, with a copy submitted to the NSRA representatives in Murmansk or in Vladivostok, depending on the area of entering the NSR (Liu & Kronbak, 2010),
11.	Russia's right to carry out inspections in the exclusive economic zone to ensure compliance with Russian regulations is being challenged. Vessels with sufficient ice-class and insurance coverage should be able to proceed without hindrance (Ragner, 2000)
12.	The corresponding political risks and uncertainties involved are considered very severe. This is because the NSR is in Russian territorial waters (Erikstad & Ehlers, 2012)
13.	The rising military presence in the Arctic is being increasingly justified by the need to project national influence and sustain claims over the region's sea-lanes and natural resources (Singh, 2013: Kaczynski, 2013).
14.	In terms of international political configuration between Arctic coastal states, the remarkable international cooperation in the North Pole may continue (Friedman, 2014)
15.	There might be no piracy or terrorism in the NSR but unpredictable behaviour of the Russian government in relation to selected prospective users of the NSR might be an important constraining factor (Kaczynski, 2014)
16.	Russian authorities have signalled a flexible attitude towards foreign vessels wishing to use the route (Ragner, 2000)

The possible criteria for the other seven factors are identified through the same process. All criteria mentioned in Chapter 2 of Literature Review are considered as possible criteria.

b) Construction of hierarchical structure

There are eight factors as grouped in the previous chapter of Literature Review. These eight factors will be considered as eight main criteria in this chapter. Again, using the political factors as an example, the process to construct the hierarchical structure is explained next. There are 16 factors or criteria under the political factor (Table 4.3) that have been identified in Step 2

(a) previously. However, these 16 factors are considered too many to evaluate and may bring difficulties during the pairwise comparison. Too many questions on the same things make people confused answering them. Hence, consistency problems may arise.

To solve this problem, all factors are clustered into relevant groups. By referring to Table 4.3, for factor numbers 1 and 2, they can be combined as 'Promotion by the Russians'. For factor numbers 3 and 4, they can be combined as 'Collaboration with other countries', while factor numbers 5, 6, and 7 are combined as 'Level of Russian state investment on the infrastructure'. Then, these three groups are grouped together as a 'Campaign effort'. Factor numbers 8, 9, 10, and 11, can be grouped as an 'Administration procedures' with factor numbers 9 and 10 being combined together. Political factor numbers 12 to 16 can be grouped as 'Foreign affairs', with a note that factor numbers 15 and 16 are combined together as 'Unpredictable behaviour of the Russian government in relation to selected prospective users of the NSR'. The new hierarchy model of the political factors is shown in Table 4.4.

Table 4.4: The hierarchy model of the political factors

Criteria	**Sub-criteria**	**Sub-sub-criteria**
Political Factor	Campaign Effort	Promotion by the Russians (factor numbers 1 and 2)
		Collaboration with other countries (factor numbers 3 and 4)
		Level of Russian state investment on the infrastructure (factor numbers 5,6 and 7)
	Administration Procedures	No ship deviation without Russian permission (factor number 8)
		Ship owners need to submit their request to use the NSR 4 months in advance (factor numbers 9 and 10)
		Mandatory local inspection of the vessel even though the vessels fulfils the requirements (factor number 11)
	Foreign Affairs	Political risks and uncertainties because the NSR is in Russian territorial water (coastal route) (factor number 12)
		Increasing militarization of the Arctic by the Russian Government (factor number 13)
		Changes in international political/strategic configuration and relations between major world actors and Arctic ocean coastal states (factor number 14)
		Unpredictable behaviour of the Russian Government in relation to selected prospective users of the NSR (factor numbers 15 and 16)

The same process was applied to other factors or criteria and shown in Appendix E. The wording for most of the criteria also has been changed to be more short, precise and general.

Table 4.5 shows the entire hierarchical model in the AHP framework consisting of the goal, main criteria, sub criteria and sub-sub criteria. The eight main criteria are 1) Political factor (PF), 2) Legal Factor (LF), 3) Economic Factor (EF), 4) Environmental Factor (VF), 5) Social Factor (SF), 6) Technological Factor (TF), 7) Safety Factor (FF) and 8) Advantages of the NSR in comparison to other alternatives (AF).

Table 4.5: The three level criteria that influence the opening of the NSR

	Level 1	**Level 2**	**Level 3**
The most important factor that influences the opening of the NSR	**Criteria**	**Sub-criteria**	**Sub-sub-criteria**
	Political Factor (PF)	Campaign Effort (PFA)	Promotion by the Russians (PFAA)
			Collaboration with other countries (PFAB)
			Level of Russian state investment on the infrastructure (PFAC)
		Administration Procedures (PFB)	No ship deviation without Russian permission (PFBA)
			Ship owners need to submit their request to use the NSR 4 months in advance (PFBB)
			Mandatory local inspection of the vessel even though the vessels fulfils the requirements (PFBC)
		Foreign Affairs (PFC)	Political risks and uncertainties because the NSR is in Russian territorial water (coastal route) (PFCA)
			Increasing militarization of the Arctic by the Russian Government (PFCB)
			Changes in international political/strategic configuration and relations between major world actors and Arctic ocean coastal states (PFCC)
			Unpredictable behaviour of the Russian Government (selected prospective users of the NSR) (PFCD)
	Legal Factor (LF)	Legal status of the NSR. Full Russian jurisdiction or some international status (LFA)	
		Border disputes in the Arctic (LFB)	
		Legal status of vessels and flags when transiting the NSR (LFC)	
		No international legally binding requirements for ship designs & ice class ship (LFD)	
	Economic Factor (EF)	Operating cost (EFA)	Capital costs (ice strengthened vessels) (EFAA)
			The NSR Insurance costs (EFAB)
			Ship depreciation (EFAC)
			Manning costs (EFAD)
		Voyage cost (EFB)	Fuel costs (EFBA)

			The NSR fees (Meteorological forecast & ice breaking) (EFBB)
			Ice pilot fees (EFBC)
		Commercial Aspect (EFC)	Shifts in economic geography (EFCA)
			Lack of major economic centre along the route (EFCB)
			Status of natural resources in Arctic (EFCC)
			Tourism industry (EFCD)
	Environmental Factor (VF)	Disappearing of summer sea ice (VFA)	More navigable days for shipping operations (VFAA)
			Possible extinction of Polar bears (VFAB)
			Some Arctic fisheries will be affected (VFAC)
		Challenges to operation (VFB)	Operational conditions like wind chills, darkness in winter, sea ice & ice bergs, high latitudes and etc. (VFBA)
			Seasonality of operations (Navigable for 2 to 4 months in eastern part of the NSR :without ice breaking assistance) (VFBB)
			Shallow seas & straits (Vessel size restriction in coastal route) (VFBC)
		Impact on the marine environment and marine biodiversity (VFC)	Accidental discharges of polluting substances (cargo or fuel) (VFCA)
			Operational discharges (cargo residues, fuel residues),garbage and sewage and emissions (CO_2, NO_2 SO_2) (VFCB)
			Navigation impacts (noise pollution and interference with marine species that cause disruption of behaviour and etc.)(VFCC)
			Introduction of alien organisms through ballast water exchanges or attachment to vessel hulls. (VFCD)
	Social Factor (Indigenous People) (SF)	Loss of food source (SFA)	
		Loss of housing (SFB)	
		Disease (SFC)	
		Loss of culture (SFD)	
		Stimulation of economic activity of people in the north region (SFE)	
	Technological Factor (TF)	Advanced ice breaking technology (TFA)	
		New ship technology/design (TFB)	
		Aerial drones will be used to spot free and fast ice (TFC)	
	Safety Factor (FF)	Status of shipping and port infrastructure (FFA)	Status of search and rescue facilities (FFAA)
			Status of availability of international port along the route (FFAB)
			Status of ships repair and maintenance facilities (FFAC)
		Status of navigational aids facilities (FFB)	Charting and monitoring (FFBA)
			Radio and satellite communications and emergency response (FFBB)

			Observational networks and forecast for weather, icing, waves and sea ice(FFBC)
		Training for crew for Arctic operations (FFC)	
	Advantages of the NSR in comparison to other alternatives (AF)	Shorter route (AFA)	Saving in time(AFAA)
			Saving in expenses (AFAB)
			Increase the number of round trips (AFAC)
			Reduced air emissions from ships (AFAD)
		No piracy/terrorism threat (AFB)	
		No vessel size restriction for further north route of the NSR (AFC)	

Step 3: Construct a set of pair-wise comparison matrices to determine the weight.

The weight for each criterion will be determined using a pair wise comparison technique. The experts will judge and analyse the priority of each criterion to another by incorporating the ratio scale of pair-wise comparison in Table 4.1. There are three levels of criteria that need to be evaluated and analysed. Level 1 is known as the main criteria, level 2 is called sub-criteria and level 3 is called sub-sub-criteria. A set of questionnaires (Appendix F) has been constructed and sent to the selected experts (20 experts). Consequently, there are seven experts involved in this data collection. The seven experts are from the shipping industry and academia (university Professor). Detailed background of the experts can be found in Appendix G.

Firstly, geometric mean (GeoMean) is calculate to combine the judgements of seven experts by using Equation 4.3. By using a pair-wise comparison of expert judgements (Table 4.6) between Political factor (PF) and Legal factor (LF) as example, the geometric mean is calculated as follows:

Table 4.6: The expert judgements score on the importance of Political factor over Legal factor

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7
How important is the PF compared to the LF?	7	3	7	3	1/5	7	3

GeoMean of seven expert judgements (Equation 4.3)

$= (7 \times 3 \times 7 \times 3 \times \frac{1}{5} \times 7 \times 3)^{\frac{1}{7}}$

= 2.9296 [This answer can be seen in Table 4.7 (row PF, column LF]

From Table 4.6, all experts agreed that the PF is more important compared to the LF except expert 5. This will not be a problem as long as the consistency ratio is less than 10% which will be explained later. Referring to the eight main criteria as an example association with Equation 4.1, an 8×8 pair-wise comparison matrix is developed to obtain the weights of these criteria. *A* $A(P_F L_F E_F V_F S_F T_F F_F A_F)$ is a pair-wise comparison matrix expressing the consolidated judgement (GeoMean) with regard to the relative priority of PL, LF, EF, VF, SF, TF, FF, and AF (Table 4.7).

Table 4.7: Pair wise comparison matrix for the main criteria

$A(P_F L_F E_F V_F S_F T_F F_F A_F) =$

	PF	LF	EF	VF	SF	TF	FF	AF
PF	1.0000	2.9296	0.7335	2.3796	2.2679	1.0776	0.6963	0.4202
LF	0.3413	1.0000	0.3749	0.8420	0.8020	0.4982	0.3218	0.3822
EF	1.3632	2.6671	1.0000	2.9177	3.9910	2.1552	1.3007	1.6013
VF	0.4202	1.1877	0.3427	1.0000	1.5856	0.8361	1.2190	0.3880
SF	0.4409	1.2469	0.2506	0.6307	1.0000	0.3859	0.2680	0.3070
TF	0.9280	2.0072	0.4640	1.1960	2.5910	1.0000	0.9437	0.6792
FF	1.4361	3.1078	0.7688	0.8203	3.7318	1.0596	1.0000	0.9351
AF	2.3796	2.6167	0.6245	2.5776	3.2570	1.4724	1.0694	1.0000
Sum	8.3094	16.7630	4.5590	12.3638	19.2264	8.4851	6.8190	5.7130

The performance ratio rate of $A(P_F L_F E_F V_F S_F T_F F_F A_F)$ is calculated as follows:

Table 4.8: The performance ratio of main criteria

PF	1÷8.3094 =0.1203	2.9296÷16.763=0.1748	0.7335÷4.559=0.1609	2.3796÷12.3638=0.1925	2.2679÷19.2264=0.1180	1.0776÷8.4851=0.1270	0.6963÷6.819=0.1021	0.4202÷5.713=0.0736
LF	0.3413÷8.3094=0.0411	1÷16.763 =0.0597	0.3749÷4.559=0.0822	0.8420÷12.3638=0.0681	0.8020÷19.2264=0.0417	0.4982÷8.4851=0.0587	0.3218÷6.819=0.0472	0.3822÷5.713=0.0669
EF	1.3632÷8.3094=0.1641	2.6671÷16.763=0.1591	1÷4.559 =0.2193	2.9177÷12.3638=0.2360	3.9910÷19.2264=0.2076	2.1552÷8.4851=0.2540	1.3007÷6.819=0.1908	1.6013÷5.713=0.2803
VF	0.4202÷8.3094=0.0506	1.1877÷16.763=0.0709	0.3427÷4.559=0.0752	1÷12.3638 =0.0809	1.5856÷19.2264=0.0825	0.8361÷8.4851=0.0985	1.2190÷6.819=0.1788	0.3880÷5.713=0.0679
SF	0.4409÷8.3094=0.0531	1.2469÷16.763=0.0744	0.2506÷4.559=0.0550	0.6307÷12.3638=0.0510	1÷19.2264 =0.0520	0.3859÷8.4851=0.0455	0.2680÷6.819=0.0393	0.3070÷5.713=0.0537
TF	0.9280÷8.3094=0.1117	2.0072÷16.763=0.1197	0.4640÷4.559=0.1018	1.1960÷12.3638=0.0967	2.5910÷19.2264=0.1348	1÷8.4851 =0.1179	0.9437÷6.819=0.1384	0.6792÷5.713=0.1189
FF	1.4361÷8.3094=0.1728	3.1078÷16.763=0.1854	0.7688÷4.559=0.1686	0.8203÷12.3638=0.0663	3.7318÷19.2264=0.1941	1.0596÷8.4851=0.1249	1÷6.819 =0.1466	0.9351÷5.713=0.1637
AF	2.3796÷8.3094=0.2864	2.6167÷16.763=0.1561	0.6245÷4.559=0.1370	2.5776÷12.3638=0.2085	3.2570÷19.2264=0.1694	1.4724÷8.4851=0.1735	1.0694÷6.819=0.1568	1÷5.713 =0.1750

The weight values of all main criteria are determined using Equation 4.2. Given the criteria "PF" as an example, the weight value is computed as follows:

$$W_{PF} = \frac{0.1203+0.1748+0.1609+0.1925+0.1180+0.1270+0.1021+0.0736}{8} = 0.1336$$

where the weight value of the criterion "PF" is known to be 0.1336. In a similar way, the weight calculation algorithm is applied to all other main criteria. Table 4.9 summarises all the output values of the weight value calculation.

Table 4.9: The weight value of evaluation criteria

									Weight value
PF	0.1203	0.1748	0.1609	0.1925	0.1180	0.1270	0.1021	0.0736	0.1336
LF	0.0411	0.0597	0.0822	0.0681	0.0417	0.0587	0.0472	0.0669	0.0582
EF	0.1641	0.1591	0.2193	0.2360	0.2076	0.2540	0.1908	0.2803	0.2139
VF	0.0506	0.0709	0.0752	0.0809	0.0825	0.0985	0.1788	0.0679	0.0881
SF	0.0531	0.0744	0.0550	0.0510	0.0520	0.0455	0.0393	0.0537	0.0530
TF	0.1117	0.1197	0.1018	0.0967	0.1348	0.1179	0.1384	0.1189	0.1175
FF	0.1728	0.1854	0.1686	0.0663	0.1941	0.1249	0.1466	0.1637	0.1528
AF	0.2864	0.1561	0.1370	0.2085	0.1694	0.1735	0.1568	0.1750	0.1828

Therefore, the criteria is ranked according to the weight value obtained from Table 4.9 as shown in Table 4.10.

Table 4.10: The ranking of the main criteria

Criteria	Weight value	Ranking
EF	0.2139	1
AF	0.1828	2
FF	0.1528	3
PF	0.1336	4
TF	0.1175	5
VF	0.0881	6
LF	0.0582	7
SF	0.0530	8

Table 4.10 shows that the Economic Factor (EF) is the most important factor that influences the opening of the NSR. The second rank is the Advantages of the NSR in comparison to other alternatives (AF), followed by Safety Factor (FF) in third place. Political Factor (PF) (4^{th}), Technological Factor (TF) (5^{th}), Environmental Factor (VF) (6^{th}), Legal Factor (LF) (7^{th}) and Social Factor (SF) (8^{th}) respectively.

Step 4: The calculation of the consistency of the pairwise judgements.

Next, the calculation of the consistency ratio of the pair-wise comparison is conducted. Firstly, each value in the column of the pair-wise comparison matrix (Table 4.7) is multiplied by the weight value of each criterion (Table 4.9) as follows:

	PF		LF		EF		VF		SF
	1.0000		2.9296		0.7335		2.3796		2.2679
	0.3413		1.0000		0.3749		0.8420		0.8020
	1.3632		2.6671		1.0000		2.9177		3.9910
0.1336	0.4202	+0.0582	1.1877	+0.2139	0.3427	+0.0881	1.0000	+0.0530	1.5856
	0.4409		1.2469		0.2506		0.6307		1.0000
	0.9280		2.0072		0.4640		1.1960		2.5910
	1.4361		3.1078		0.7688		0.8203		3.7318
	2.3796		2.6167		0.6245		2.5776		3.2570

	TF		FF		AF
	1.0776		0.6963		0.4202
	0.4982		0.3218		0.3822
	2.1552		1.3007		1.6013
+0.1175	0.8361	+0.1528	1.2190	+0.1828	0.3880
	0.3859		0.2680		0.3070
	1.0000		0.9437		0.6792
	1.0596		1.0000		0.9351
	1.4724		1.0694		1.0000

Thus, Table 4.11 summarises the calculation of pair-wise comparison matrix (PWCM) multiplied by the weight value of each criterion.

Table 4.11: The total value of the calculation of PWCM multiplied by the weight value

									Total
PF	0.1336	0.1705	0.1569	0.2098	0.1202	0.1266	0.1064	0.0768	1.1008
LF	0.0456	0.0582	0.0802	0.0742	0.0425	0.0585	0.0492	0.0699	0.4783
EF	0.1822	0.1552	0.2139	0.2572	0.2115	0.2532	0.1988	0.2928	1.7647
VF	0.0562	0.0691	0.0733	0.0881	0.0840	0.0982	0.1863	0.0709	0.7262
SF	0.0589	0.0726	0.0536	0.0556	0.0530	0.0453	0.0409	0.0561	0.4361
TF	0.1240	0.1168	0.0992	0.1054	0.1373	0.1175	0.1442	0.1242	0.9687
FF	0.1919	0.1809	0.1644	0.0723	0.1978	0.1245	0.1528	0.1710	1.2556
AF	0.3180	0.1523	0.1336	0.1366	0.1726	0.1730	0.1634	0.1828	1.4323

By using Equation 4.6, the total value of each criterion described in Table 4.11 is divided with the weight value of the corresponding main criteria and then divided by the number of criteria.

The λ_{max} is calculated as follows:

$$\lambda_{max} = \left(\frac{\frac{1.1008}{0.1336} + \frac{0.4783}{0.0582} + \frac{1.7647}{0.2139} + \frac{0.7262}{0.0881} + \frac{0.4361}{0.0530} + \frac{0.9687}{0.1175} + \frac{1.2556}{0.1528} + \frac{1.4323}{0.1828}}{8} \right)$$

$$= \left(\frac{8.2373+8.2185+8.2506+8.2387+8.2292+8.2456+8.2163+7.8336}{8} \right)$$

$$= 8.1837$$

Next, the *CI* is computed using Equation 4.5 as follows:

$$CI = \frac{8.1837-8}{8-1} = 0.0262$$

Subsequently, the consistency ratio (*CR)* is calculated using Equation 4.4. There are eight criteria in Level 1, therefore the random index (*RI*) is 1.40 (Table 4.2) and the CR value of the main criteria is obtained as follows:

$$CR = \frac{0.0262}{1.4} = 0.0187$$

The *CR* value of the main criteria is known to be 0.0187. This means that the degree of consistency in the pair-wise comparison is acceptable because the *CR* value is less than 0.10. (Saaty, 2012)

The similar calculation process of the weighing vector described previously is applied to determine the priority of each sub-criterion compared to others at level 2 and 3.

The weighing vector values of all the sub-criteria under PFA's group are shown as follows:

$A\ (P_{FA}P_{FB}P_{FC}) =$

	PFA	PFB	PFC
PFA	1	1	2/3
PFB	1	1	$1\frac{7}{9}$
PFC	$1\frac{1}{2}$	4/7	1

The weight values of $A\ (P_{FA}P_{FB}P_{FC})$ are 0.2822 (PFA), 0.4070 (PFB), 0.3108 (PFC) and the CR value is 0.0855.

The weighting vector values of all the sub criteria under PFA's group are summarised as follows:

$A\ (P_{FAA}P_{FAB}P_{FAC}) =$

	PFAA	PFAB	PFAC
PFAA	1	$1\frac{2}{3}$	7/8
PFAB	3/5	1	5/7
PFAC	$1\frac{1}{7}$	$1\frac{2}{5}$	1

The weight values of $A\ (P_{FAA}P_{FAB}P_{FAC})$ are 0.3708 (PFAA), 0.2469 (PFAB), 0.3822 (PFAC) and the CR value is 0.0116.

The weighting vector values of all the sub-criteria under PFB's group are summarised as follows:

$A\ (P_{FBA}P_{FBB}P_{FBC}) =$

	PFBA	PFBB	PFBC
PFBA	1	5/6	7/9
PFBB	$1\frac{2}{9}$	1	1
PFBC	$1\frac{2}{7}$	1	1

The weight values of $A\ (P_{FBA}P_{FBB}P_{FBC})$ are 0.2848 (PFBA), 0.3444 (PFBB), 0.3708 (PFBC) and the CR value is 0.0001.

The weighting vector values of all the sub-criteria under PFC's group are summarised as follows:

$A\ (P_{FCA}P_{FCB}P_{FCC}P_{FCD}) =$

	PFCA	PFCB	PFCC	PFCD
PFCA	1	$2\frac{3}{8}$	$1\frac{5}{9}$	$1\frac{1}{5}$
PFCB	3/7	1	7/8	5/7
PFCC	2/3	$1\frac{1}{7}$	1	1
PFCD	5/6	$1\frac{2}{5}$	1	1

The weight values of $A\ (P_{FCA}P_{FCB}P_{FCC}P_{FCD})$ are 0.3511 (PFCA), 0.1732 (PFCB), 0.2237 (PFCC), 0.2520 (PFCD) and the CR value is 0.0074.

The weighting vector values of all the sub-criteria under LF's group are summarised as follows:

$A\ (L_{FA}L_{FB}L_{FC}L_{FD}) =$

	LFA	LFB	LFC	LFD
LFA	1	$1\frac{2}{9}$	1	$1\frac{2}{3}$
LFB	5/6	1	4/9	1/2
LFC	1	$2\frac{1}{4}$	1	2
LFD	3/5	$2\frac{1}{8}$	1/2	1

The weight values of $A\ (L_{FA}L_{FB}L_{FC}L_{FD})$ are 0.2919 (LFA), 0.1589 (LFB), 0.3353 (LFC), 0.2138 (LFD) and the CR value is 0.0513.

The weighting vector values of all the sub-criteria under EF's group are summarised as follows:

$A\ (E_{FA}E_{FB}E_{FC}) =$

	EFA	EFB	EFC
EFA	1	1	1
EFB	1	1	$1\frac{3}{7}$
EFC	1	5/7	1

The weight values of $A\ (E_{FA}E_{FB}E_{FC})$ are 0.3385 (EFA), 0.3681 (EFB), 0.2934 (EFC) while the CR value is 0.0

The weighting vector values of all the sub-criteria under EFA's group are summarised as follows:

$A\ (E_{FAA}E_{FAB}E_{FAC}E_{FAD}) =$

	EFAA	EFAB	EFAC	EFAD
EFAA	1	2	$2\frac{3}{8}$	$2\frac{1}{9}$
EFAB	1/2	1	$1\frac{1}{2}$	3
EFAC	3/7	2/3	1	$1\frac{3}{7}$
EFAD	1/2	1/3	5/7	1

The weight values of $A\ (E_{FAA}E_{FAB}E_{FAC}E_{FAD})$ are 0.4038 (EFAA), 0.2850 (EFAB), 0.1765 (EFAC) and 0.1347 (EFAD) while the CR value is 0.0345.

The weighting vector values of all the sub-criteria under EFB's group are summarised as follows:

$A\ (E_{FBA}E_{FBB}E_{FBC}) =$

	EFBA	EFBB	EFBC
EFBA	1	$1\frac{1}{2}$	3
EFBB	2/3	1	$2\frac{1}{3}$
EFBC	1/3	3/7	1

The weight values of $A\ (E_{FBA}E_{FBB}E_{FBC})$ are 0.4948 (EFBA), 0.3477 (EFBB), 0.1575 (EFBC) and the CR value is 0.0023.

The weighting vector values of all the sub-criteria under EFC's group are summarised as follows:

$A\ (E_{FCA}E_{FCB}E_{FCC}E_{FCD}) =$

	EFCA	EFCB	EFCC	EFCD
EFCA	1	1	1	$2\frac{3}{4}$
EFCB	1	1	$1\frac{1}{2}$	$2\frac{3}{5}$
EFCC	1	2/3	1	2
EFCD	1/3	2/5	1/2	1

The weight values of $A\ (E_{FCA}E_{FCB}E_{FCC}E_{FCD})$ are 0.2987 (EFCA), 0.3274 (EFCB), 0.2526 (EFCC), 0.1213 (EFCD) and the CR value is 0.0072.

The weighting vector values of all the sub-criteria under VF's group are summarised as follows:

$A\ (V_{FA}V_{FB}V_{FC}) =$

	VFA	VFB	VFC
VFA	1	$1\frac{2}{3}$	3
VFB	3/5	1	2
VFC	1/3	1/2	1

The weight values of $A\ (V_{FA}V_{FB}V_{FC})$ are 0.5111 (VFA), 0.3201 (VFB), 0.1688 (VFC) and the CR value is 0.0018.

The weighting vector values of all the sub-criteria under VFA's group are summarised as follows:

$A\ (V_{FAA}V_{FAB}V_{FAC}) =$

	VFAA	VFAB	VFAC
VFAA	1	$2\frac{2}{3}$	$3\frac{1}{2}$
VFAB	3/8	1	3/5
VFAC	2/7	$1\frac{2}{3}$	1

The weight values of $A\ (V_{FAA}V_{FAB}V_{FAC})$ are 0.5966 (VFAA), 0.1753 (VFAB), 0.2281 (VFAC) and the CR value is 0.0669.

The weighting vector values of all the sub-criteria under VFB's group are summarised as follows:

$A\ (V_{FBA}V_{FBB}V_{FBC}) =$

	VFBA	VFBB	VFBC
VFBA	1	1	$1\frac{1}{9}$
VFBB	1	1	1
VFBC	1	1	1

The weight values of $A\ (V_{FBA}V_{FBB}V_{FBC})$ are 0.3406 (VFBA), 0.3432 (VFBB) and 0.3161 (VFBC) while the CR value is 0.0006.

The weighting vector values of all the sub-criteria under VFC's group are summarised as follows:

$A\ (V_{FCA}V_{FCB}V_{FCC}V_{FCD}) =$

	VFCA	VFCB	VFCC	VFCD
VFCA	1	$1\frac{5}{8}$	5/6	$1\frac{5}{9}$
VFCB	3/5	1	5/7	$1\frac{1}{3}$
VFCC	$1\frac{2}{9}$	$1\frac{2}{5}$	1	$1\frac{2}{5}$
VFCD	2/3	3/4	5/7	1

The weight values of $A\ (V_{FCA}V_{FCB}V_{FCC}V_{FCD})$ are 0.2939 (VFCA), 0.2135 (VFCB), 0.3044 (VFCC) and 0.1882 (VFCD) while the CR value is 0.0090.

The weighting vector values of all the sub-criteria under SF's group are summarised as follows:

$A\ (S_{FA}S_{FB}S_{FC}S_{FD}S_{FE}) =$

	SFA	SFB	SFC	SFD	SFE
SFA	1	$1\frac{3}{7}$	3/4	$1\frac{2}{5}$	5/7
SFB	5/7	1	$1\frac{1}{6}$	$1\frac{3}{8}$	4/9
SFC	$1\frac{1}{3}$	6/7	1	$1\frac{1}{2}$	5/6
SFD	5/7	3/4	2/3	1	1/2
SFE	$1\frac{3}{7}$	$2\frac{1}{4}$	$1\frac{1}{5}$	2	1

The weight values of $A\ (S_{FA}S_{FB}S_{FC}S_{FD}S_{FE})$ are 0.1949 (SFA), 0.1714 (SFB), 0.2107 (SFC), 0.1355 (SFD), 0.2875 (SFE) and the CR value is 0.0144.

The weighting vector values of all the sub-criteria under TF's group are summarised as follows:

$A\ (T_{FA}T_{FB}T_{FC}) =$

	TFA	TFB	TFC
TFA	1	$1\frac{1}{9}$	$1\frac{1}{2}$
TFB	1	1	2
TFC	2/3	1/2	1

The weight values of $A\ (T_{FA}T_{FB}T_{FC})$ are 0.3799 (TFA), 0.3989 (TFB) and 0.2212 (TFC) while the CR value is 0.0212.

The weighting vector values of all the sub-criteria under FF's group are summarised as follows:

$A\ (F_{FA}F_{FB}F_{FC}) =$

	FFA	FFB	FFC
FFA	1	$2\frac{1}{8}$	2
FFB	1/2	1	$1\frac{1}{9}$
FFC	1/2	1	1

The weight values of $A\ (F_{FA}F_{FB}F_{FC})$ are 0.5018 (FFA), 0.2532 (FFB), 0.2450 (FFC) and the CR value is 0.0042.

The weighting vector values of all the sub-criteria under FFA's group are summarised as follows:

$A\ (F_{FAA}F_{FAB}F_{FAC})$ =

	FFAA	FFAB	FFAC
FFAA	1	2	$1\frac{3}{5}$
FFAB	1/2	1	$1\frac{3}{7}$
FFAC	5/8	5/7	1

The weight values of $A\ (F_{FAA}F_{FAB}F_{FAC})$ are 0.4702 (FFAA), 0.2850 (FFAB), 0.2448 (FFAC) and the CR value is 0.0393.

The weighting vector values of all the sub-criteria under FFB's group are summarised as follows:

$A\ (F_{FBA}F_{FBB}F_{FBC})$ =

	FFBA	FFBB	FFBC
FFBA	1	$1\frac{1}{5}$	$1\frac{2}{7}$
FFBB	5/6	1	$1\frac{2}{9}$
FFBC	7/9	5/6	1

The weight values of $A\ (F_{FBA}F_{FBB}F_{FBC})$ are 0.3830 (FFBA), 0.3326 (FFBB), 0.2844 (FFBC) and the CR value is 0.0017.

The weighting vector values of all the sub-criteria under AF's group are summarised as follows:

$A\ (A_{FA}A_{FB}A_{FC})$ =

	AFA	AFB	AFC
AFA	1	$3\frac{1}{3}$	$1\frac{5}{8}$
AFB	1/3	1	5/8
AFC	3/5	$1\frac{4}{7}$	1

The weight values of $A\ (A_{FA}A_{FB}A_{FC})$ are 0.5282 (AFA), 0.1736 (AFB), 0.2982 (AFC) and the CR value is 0.0074.

The weighting vector values of all the sub-criteria under AFA's group are summarised as follows:

$A\ (A_{FAA}A_{FAB}A_{FAC}A_{FAD})$ =

	AFAA	AFAB	AFAC	AFAD
AFAA	1	1	$1\frac{3}{7}$	$2\frac{2}{3}$
AFAB	1	1	$1\frac{4}{5}$	$2\frac{5}{6}$
AFAC	5/7	5/9	1	$1\frac{1}{2}$
AFAD	3/8	1/3	2/3	1

The weight values of $A\ (A_{FAA}A_{FAB}A_{FAC}A_{FAD})$ are 0.3234 (AFAA), 0.3483 (AFAB), 0.2027 (AFAC) and 0.1256 (AFAD) while the CR value is 0.0025.

Some of the expert judgements are not consistent (individually) but when it's been aggregated, the results shows that the score are consistent (less than 10%). This manual calculation also tally with the software calculation means that the calculation is correct.

Step 5: Sensitivity analysis

A sensitivity analysis was undertaken to test the outcome of the application of the AHP model, with the different weighting scenarios, as described in the following sections. The tables provided for each scenario indicates the outcome of the sensitivity analysis against the base case (original ranking as shown in Table 4.10) for comparative purposes. From the original weight values, a new set of weight values (Table 4.12) is obtained using the percentage increase of 10% 20% and 30%.

Table 4.12: A sensitivity analysis of 10%, 20% and 30% increases of weight value for main criteria

Criteria	0	10%	20%	30%	Ranking
EF	0.2139	0.2353	0.25668	0.2781	1
AF	0.1828	0.2011	0.21936	0.2377	2
FF	0.1528	0.1681	0.18336	0.1987	3
PF	0.1336	0.147	0.16032	0.1737	4
TF	0.1175	0.1292	0.141	0.1527	5
VF	0.0881	0.097	0.10572	0.1146	6
LF	0.0582	0.064	0.06984	0.0757	7
SF	0.053	0.0583	0.0636	0.0689	8

Table 4.13: Sensitivity analysis of 30% increased of weight values

Criteria	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking
EF	0.2781	1	0.2061	2	0.2073	1	0.2082	1	0.2089	1	0.2101	1	0.2114	1	0.2116	1
AF	0.1736	2	0.2377	1	0.1762	3	0.1771	2	0.1778	2	0.1790	2	0.1803	2	0.1805	2
FF	0.1436	3	0.1450	3	0.1987	2	0.1471	4	0.1478	4	0.1490	3	0.1503	3	0.1505	3
PF	0.1244	4	0.1258	4	0.1270	4	0.1737	3	0.1286	5	0.1298	4	0.1311	4	0.1313	4
TF	0.1083	5	0.1097	5	0.1109	5	0.1118	5	0.1527	3	0.1137	6	0.1150	5	0.1152	5
VF	0.0789	6	0.0803	6	0.0815	6	0.0824	6	0.0831	6	0.1146	5	0.0856	6	0.0858	6
LF	0.0490	7	0.0504	7	0.0516	7	0.0525	7	0.0532	7	0.0544	7	0.0757	7	0.0559	8
SF	0.0438	8	0.0452	8	0.0464	8	0.0473	8	0.0480	8	0.0492	8	0.0505	8	0.0689	7

Legend

The criterion with increased weight values (30%)

The changes of ranking

The sensitivity analysis was conducted by increasing the weightage of each criterion (whether by 10%, 20% and 30%) and then, the difference of that value (between new weight and original weight value) was divided by seven other criteria so that the total weightage value for eight criteria will be equal to 1. Referring to Table A4.16, (Appendix H) for 10% of weight increase, there are no changes of ranking, except for social factor (SF) which switched position with legal factor (LF) from number 8 to number 7. Nevertheless, the weight values between LF and SF were quite close with only 0.0009 separating them. It can be said that the changes were almost not happening because of the tiny differences in weight value. Any changes in expert judgement or adding more expert judgement may result in different ranking between the two factors. In conclusion, for 10% changes of weightage value, the ranking for each factor remained the same, except for SF.

Based on Table A4.17 (Appendix H), there are some changes in ranking. The changes are summarised as follows:

- When the weight value of AF increased by 20%, the AF has moved from number 2 to number 1 and EF has moved from number 1 to number 2.
- When the weight value of FF increased by 20%, the FF has moved from number 3 to number 2 and AF has moved from number 2 to number 3.
- When the weight value of TF increased by 20%, the TF moved from number 5 to number 4 and the PF has moved from number 4 to number 5.
- When the weight value of SF increased by 20%, the SF moved from number 8 to number 7 and LF has moved from number 7 to number 8

Referring to Table 4.13, for 30% of weight value increase, there are more changes of ranking. The changes are summarised as follows:

- When the weight value of AF increased by 30%, the AF has moved from number 2 to number 1 and EF has moved from number 1 to number 2.
- When the weight value of FF increased by 30%, the FF has moved from number 3 to number 2 and AF has moved from number 2 to number 3.
- When the weight value of PF increased by 30%, the PF itself moved from number 4 to number 3 and FF has moved from number 3 to number 4.
- When the weight value of TF increased by 30%, the TF moved from number 5 to number 3, PF has moved from number 4 to number 5 and FF has moved from number 3 to number 4

- When the weight value of SF increased by 30%, the SF moved from number 8 to number 7 and LF has moved from number 7 to number 8

To conclude, for 10% of sensitivity analysis conducted, it can be said that the model is quite robust but not for 20% and 30% increases. Sensitivity analysis should be performed to study the robustness of a choice. Sensitivity analysis indeed permits to understand the consequences of a change in the weights of criteria and sub-criteria. For instance, decision makers were likely to change their opinion about criteria over time because of an evolving context. In the case of multiple decision makers, disagreements when performing the AHP evaluations may involve future changes or some confidence intervals for the definition of the weightage. In the end, whatever the reason of doubts, sensitivity analysis improves the credibility and reliability of the AHP model and results.

4.6 Conclusion

The AHP modelling was conducted in this chapter to demonstrate the issues or uncertain situations faced by shipping companies in the NSR. The developed model was dynamic and able to be used in different situations faced by shipping companies. The sensitivity analysis confirmed the consistency of ranking of the test case, especially with the 10% change in weightage value. However, with the 20% and 30% increase in weightage value, only some factors remained unchanged. Nevertheless, the selection of evaluation of criteria, sub-criteria, and sub-sub-criteria can be improved from time to time based on the changes of situation of the NSR in the future. Therefore, the output will be different from this test case.

The ‘economic factor’ and ‘advantages of the NSR as compared to other alternative’ factors were the most important factors (ranking first and second by using AHP calculation). This result was very much predicted before conducting the pairwise comparison calculation, because shipping companies will always try to reduce the cost and maximise profit. The reduction of shipping cost, especially fuel cost, reduction of gas emission and increase in round trip voyage were all derived because of the shortest route offered by the NSR. Although the NSR was 40% shorter than the alternative routes, it did not mean that the cost was also 40% reduced. However, the cost is still less than the alternative routes as concluded by Liu and Kronbak (2010), Schoyen and Brathen (2011), Chang et al. (2015) and many others.

It is also interesting to mention that from the AHP ranking, the environmental factor was ranked at number 6 which was quite low, providing the sensitiveness of the Arctic Ocean. There are several explanations as to answer this situation. In terms of gas emission, shipping shares of emissions are lower than those of road and air transport (Statista, 2019) (Figure 4.3). The shipping industry is very well regulated and towards greener technologies as countries have reached agreements to improve the fuel efficiency of ships, mainly through ship design and efficiency standards (known as energy efficiency design index - EEDI). This measure could significantly reduce shipping greenhouse gas emission.

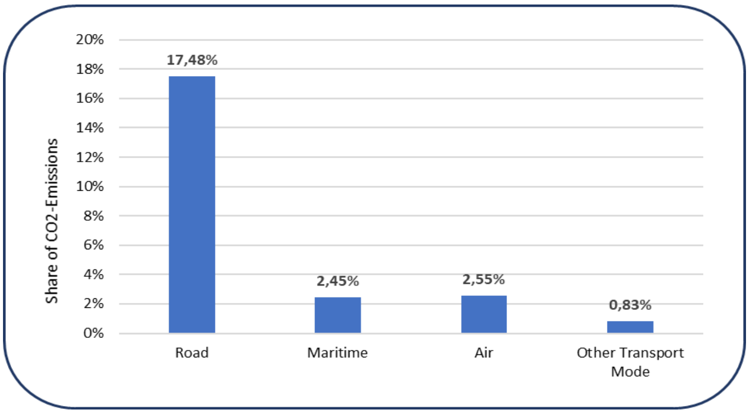


Figure 4.3: Share of transport modes in global CO2 emissions in 2014 (Source: Statista 2019)

The other reason was because there was no major accident that happened in the NSR that involved shipping and polar bear to this date. If a major oil spill happened in the Arctic or collision between ship and Arctic mammals (i.e. Polar bear), the results would be different. As mentioned earlier in Chapter 2, the NSR requires different classes of ship which needed extra strength at the ship hull, which means that oil spills is unlikely to happen in the Arctic. The NSR authority also conducted an inspection to the ship which are willing to use the NSR and many other documents and procedures need to be provided that will satisfy the NSR authority. All these will prevent major accident such as oil spill to occur in the NSR.

The pairwise comparison technique of AHP was very useful to find the rank of identified factor. However, the main contribution of the AHP technique was the way all factors were structured and put into one hierarchical form to represent the problem or in this case the factors that influenced the opening of the NSR. From this big hierarchical structure, it will narrow down to a smaller one which is suited to its relevant goal. In the next chapter, by using this hierarchical structure, the best shipping transit route within the NSR is set to seek.

CHAPTER 5:

SELECTION OF THE MOST EFFECTIVE SHIPPING TRANSIT ROUTE WITHIN THE NSR USING EVIDENTIAL REASONING (ER) APPROACH

Summary

In this chapter, a method is demonstrated for selecting the most effective shipping transit route within the Northern Sea Route (NSR). The method used for dealing with a multiple-criteria decision analysis under uncertainty is called the Evidential Reasoning (ER) approach. This method is able to consider both quantitative and qualitative criteria of a complex nature in the selection process. The calculation and aggregation processes are conducted using the Intelligent Decision System software (IDS). Before that, the pair-wise comparison technique is used for assigning the weights to each criterion and sub-criterion. The results of this study include the ranking of the shipping routes and indications of their strengths and weaknesses in the format of performance distributions. This information is very important in helping decision makers to select and be aware of any risk implication associated with the selection.

5.1 Introduction

Human beings are natural effort minimisers, especially when it involves moving around. Usually, they will try to choose the shortest path to go from one place to another. This action can easily be observed in pedestrians. If possible, a pedestrian will walk over a lawn, zigzag by cars in a parking lot, or in certain places, even a railroad track if the route selected allows them to reach their destination faster. Therefore, transportation, as an economic activity, replicates this process of minimisation, particularly by trying to minimise the friction of distance between locations (Rodrigue, 2013). Friction of distance can be expressed in terms of length, time, economic costs or the amount of energy used (Rodrigue *et al*., 2006). Shorter times and lower costs are looked at by individuals as well as by business corporations. For an individual, it is often only a matter of convenience, but for a company, it is of strategic importance as a direct monetary cost is involved. Under such circumstances, it is not surprising that numerous methods have been developed to deal with the often complex issue of route selection. For instance, some of the studies are by Jung and Rhyu (1999), who conducted a study for determining the most economical shipping route using the A* (A star) algorithm; Hsu and Hsieh, (2007) used the Pareto optimal solution; Park *et al*., (2004) and Choi *et al*., (2007), determined economical shipping routes using an 8-point Dijkstra algorithm; Roh, (2013) used an improved Isochrone method, which is based on the study by Hanssen and James (1960); and Kashiha *et al*., (2016) used a conditional logit model.

Since the first commercial transit of the NSR in 2009 (Kramer and Rerkin, 2009), there has been growing interest in its use as a transit route. However, shipping navigation in the NSR is not straightforward or similar to other routes. Located along the Russian coastline in the north, the NSR is really a challenging route for ship navigation. The NSR is also not a single shipping lane; it can be any number of routes or fairways as defined by the Russian authority. Therefore, numerous routes and a great variation of the NSR are possible. For safety reasons, the choice of route is recommended by the Marine Operations Headquarters of the West and East regions of the NSR (Ragner, 2000). They will give the routing recommendations based on the ice conditions. Nevertheless, in the past few years, the ice conditions have been getting better and now, even non-ice class vessels are allowed to navigate in the NSR at certain periods of time. The most favourable navigation routes in the Arctic regions essentially depend on distribution of the ice cover during the navigational season. However, the information on standard routes is a foundation for developing normative documents such as sailing directions for different seas and for future reference for shipping companies as the NSR becomes more navigable.

Choosing the best or most effective route definitely can reduce ship expenses, time, as well as emissions. Other than that, safety is an important element for the choice of route, particularly given the icy nature of the water of the NSR.

5.2 Literature Review

There are a few recently published studies about the selection of route within the NSR. Eide *et al*. (2010) listed four transit routes across the Arctic Ocean. Route 1 is close to the traditional NSR, passing largely within Russian territorial waters. Route 2 is a modified version of the first but avoids some of the shallow areas. Route 3 is designed to lead vessels mostly outside the Russian Exclusive Economic Zone (EEZ). Route 4 goes directly across the North Pole. In general, most of the studies of the NSR used these four options of route but with slight variations. The study adopted two types of scenarios: 1) All-year Arctic operation of 5000 TEU double-acting container vessels (bulbous bow and ice- breaking aft); and 2) Part-year Arctic operation of a fleet of identical 6500 TEU PC4 ice-classed container vessels (bulbous bow).

The PC4 ice-classed container vessel operates a liner service that transits the Arctic during the summer, when the ice cover is at its minimum, and uses the Suez Canal for the rest of the year.

PC4 is one of the Polar Classes (PC) that refers to the ice class assigned to a vessel by a classification society based on the *Unified Requirements for Polar Class Ships* developed by the International Association of Classification Societies (IACS). Seven Polar Classes are defined in the rules, ranging from PC1 for year-round operation in all polar waters to PC7 for summer and autumn operations in thin first-year ice.

The outcome of the study by Eide *et al*., (2010) has settled on Route 3 as the most profitable route after evaluating the combined effects of fuel consumption, transit time (speed of vessels), future ice conditions, and uncertainties in fee and tax regimes. Their study also predicted the ice conditions in the years 2030 and 2050 and again Route 3 was the best for both circumstances. Having said that, this study failed to include other input factors, such as gas emission from ship and safety factors.

Another study conducted by the Hamburg Ship Model Basin (HSVA) (2014) used a routing software ICEROUTE, to calculate the fuel consumption, transit time, and exhaust gas emissions for three types of vessels: 1) bulk carrier; 2) oil tanker; and 3) LNG carrier. The simulation was conducted for seven vessels, which are one bulker, four tankers, and two LNG carriers. Four different transit routes along the NSR were considered and the calculation was based on different ice conditions between 1960 and 2040, within the months of April to November. The results show that Routes 3 (High-Latitude route) and 4 (Transpolar route) are hard to pass in the present, since the results of calculations show the first arguable completed transits in 2040. The research also concluded that there is a clear relation between the ice situation (extent, thickness and coverage) and fuel consumption and exhaust emission.

Some findings can be obtained from the study by HSVA such as the most completed transits are recorded with Route 1. Moreover, there will be possible completions of Routes 3 and 4 in 2040, even if Route 4 shows the maximum time and fuel requirements. These findings are only for tanker ships. For the bulker ship, there are very few completed transits for all routes due to the lack of engine power and ice-breaking capability. Contrary to the LNG carriers, its high ice-breaking capability shows a high rate of completion for all routes. However, this study did not include the containership in the model, and this is a big gap in the study.

A study by Chang *et al*., (2015) is very different as compared to the other studies. They produced new navigation routes within the NSR using a 3D geographic information system (GIS), in particular Google Earth online. The criteria used to determine the route are water depths, sea ice distribution layers, and seashore topology. This study also implemented a higher-geometry maze router in ice zone areas to obtain the optimal route in relation to safety and costs.

Even though the study conducted by Chang *et al*., combined many quantitative and qualitative factors together to find the optimal route within the NSR, some factors such as radio and satellite coverage are not included in this study. This particular factor is very important because the coverage of radio and satellite in some Arctic areas is not very good at the moment as reported by Liu and Kronbak (2010) and Kaczynski (2012). This is especially true at higher latitudes up to the North Pole.

5.3 Background of methods used

This section explains the methods that will be used in selecting the most effective shipping transit routes within the NSR. Basically, there are two main methods to be applied in this study, namely 1) an Analytic Hierarchy Process (AHP) and 2) an Evidential Reasoning (ER) method.

5.3.1 AHP Methodology

The AHP approach will be used again to find the weight for each factor. The explanation about the background and algorithm of the AHP approach can be referred to Section 4.2 in Chapter 4.

5.3.2 ER Methodology

The Evidential Reasoning (ER) approach is a generic evidence-based multi-criteria decision making (MCDM) approach for dealing with problems having both quantitative and qualitative criteria under various uncertainties including vague data and randomness. The ER approach was first generated by Dempster in 1967 and extended and refined by Shafer in 1976 (Lee, 2008; Riahi, 2010). It is often referred to as the Dempster-Shafer theory of evidence or D-S theory (Abdul Rahman, 2012).

Sonmez et al. (2002) introduced an application of ER to solve multiple criteria contractor prequalification problems with uncertain, incomplete (imprecise) and/or missing information. The process of building a MCDM model of a hierarchical structure was presented, in which quantitative and qualitative information was represented in a unified manner through equivalent knowledge transformation. They used a similar set of decision criteria applied to those advocated by Holt et al. (1994d) and for simplicity, the same set of criteria weightages were used. When an alternative was evaluated on the criterion contractor's organisation, for example, there were sub-criteria (attributes) such as age, size, image, quality control policy, health and safety policy, and litigation tendency, which were used as the evaluation basis. Some of these sub-attributes can only be assessable by using subjective judgements while the remainder may be numerically assessed. The sub-criterion image is a qualitative attribute which requires subjective assessment, e.g. against a number of grades that can be used for this purpose. The following grades were applied: none, poor, average, and good.

The evaluations given by the DM were fed into the computer program IDS via evidential reasoning. The results can be described as distributed because each contractor, to some extent, has been assessed to more than one evaluation grade. Contractor K, for example, was assessed to be 22% worst, 36% bad, 23% average, 7% good and 4% excellent. Then, the final results showed that Contractor O was the best contractor.

It was shown that the ER approach could handle quantitative and qualitative data, which might be vague and/or incomplete. It can be used as a MCDM method, enabling a DM to give a judgement according to their knowledge, expertise, and available information at the time a decision was made. It is important to obtain the decision maker's true preferences in a decision-making problem to ensure that a rational decision can be made based on real DM preferences. The ER approach provides this by using the concept of degree of belief.

Shariatmadari and Azadi (2013) applied the ER approach for selecting knowledge management (KM) strategies. The strategies selection consists mainly of seven key sections, which are: 1) Definition of the KM problem; 2) Identification of possible KM strategies; 3) Identification of KM strategies assessment factors; 4)The ER distributed modelling framework for KM strategies' assessments; 5) Recursive and analytical ER algorithms for aggregating multiple identified KM strategies assessment factors, and 6) Utility-interval-based ER ranking method that is designed to systematically compare and rank alternatives/options. The set of criteria weights was calculated by using the pairwise comparison matrix method (or called AHP or Eigenvector method).

The case has three strategies: 1) Codification strategy; 2) Personalisation strategy, and 3) Blend strategy that were assessed in terms of six strategy factors, which were incentives, top management support, time, cost, culture and people, and communication. Some of these factors were only assessable by using subjective judgements, while the remainder were numerically assessed. For example, the factor "incentives" was a qualitative attribute requiring subjective assessment (e.g. against a number of grades that could be used for this purpose).

They classified the evaluated KM strategies into the following grades: "worst", "bad", "average", "good", and "excellent" at the top level. They also developed new sets of grades for other main criteria. For example, the DM used four grades for the criterion "communication" while the other main criteria were evaluated with a set of five grades each by using different wordings. The use of different grades facilitated data collection and allowed capture of the DM preferences, experience, intuition or beliefs, and implied that the DM was not manipulated by the method or decision analyst who might help during the decision process. This was because their own expressions were used to evaluate decision criteria.

The computer software IDS facilitated the implementation of the ER approach. The final ranking showed that codification strategy came first, followed by personalisation strategy and then blend strategy.

Researchers of this method avail themselves in a variety of applications such as Consumer Preference Prediction (Wang *et al.*, 2009), Assessment of E-Commerce Security (Zhang *et al.*, 2012), Performance Assessment (Fu and Yang, 2012), Ship Selection (Xie *et al.*, 2008), Construction Contractors (Sonmez et al, 2001), Maritime Security Assessment (Yang *et al.*, 2009), Port Selection (Abdul Rahman and Ahmad Najib, 2017) and many more.

The use of belief decision matrices for MCDA problem modelling in the ER approach results in the following features:

- It is capable of providing its users with greater flexibility by allowing them to express their judgements both subjectively and quantitatively (Riahi, 2010).
- An assessment of an option can be more reliably and realistically represented by a belief decision matrix than by a conventional decision matrix (Xu and Yang, 2001).
- It is capable of accommodating or representing any uncertainty and risk that is inherent in the decision analysis (Riahi, 2010).

- It accepts data of different formats with various types of uncertainties as inputs, such as single numerical values, probability distributions, and subjective judgments with belief degrees.
- As a hierarchical evaluation process, it is capable of offering a rational and reproducible methodology to aggregate the data assessed (Riahi, 2010).

Due to the advantages listed above, the ER approach is definitely a suitable methodology to find the most effective shipping transit route within the NSR.

In general, there are four methodologies of ER that will be applied in the study as follows:

i) The basic algorithm

Let E be a criterion to be assessed that is evaluated through L sub-criteria, denoted by

$E = \{e_1, e_2, \ldots, e_i, \ldots, e_L\}$

A particular route can be assessed on a criterion using a set of assessment grades $H = \{H_n, n = 1,\ldots, N\}$ with a set of associated belief degrees $B = \{\beta_n, n = 1,\ldots,N\}$. For example, in this study, the top criterion is assessed using the five grades: Very poor, Poor, Average, Good and Very good, i.e., for this criterion:

$N = 5$, H_1 = {Very poor}, H_2 = {Poor}, H_3 = {Average}, H_4 = {Good}, H_5 = {Very good}.

Each belief degree in the set B is associated with a corresponding grade in the set H. for example, β_n is associated with grade H_n, representing that an alternative is assessed to grade H_n, with a belief degree of β_n. Belief degrees are a type of subjective probability, and therefore they must satisfy the following relationship (Yang and Xu 2002):

$0 \le \beta_n \le 1$, $\sum_{n=1}^{N} \beta_n \le 1$, and $\beta_H = 1 - \sum_{n=1}^{N} \beta_n$

where β_H is the belief degree unassigned to any specific grade, representing the unknown or missing percentage of information in the assessment. If $B_i = \{\beta_{n,I}, n = 1, \ldots,N\}$ stands for the assessment of an alternative on sub-criterion e_i, the following equations can be used for mapping B_i to B.

Let $S(y)$ represent the assessment of a criterion y. Then, $S(E) = \{(H_n, \beta_n), n = 1, \ldots, N\}$ represents that a criterion E is assessed to grade H_n with degree of belief β_n, $n = 1, \ldots, N$. Therefore,

$S(e_i) = \{(H_n, \beta_{n,i}), n = 1,\ldots, N\} \qquad i = 1,\ldots, L$ (5.1)

Let ω_i be the weight criterion e_i to reflect its relative importance to its parent criterion E and *0* $0 \leq \omega_i \leq 1$,

$\sum_{i=1}^{L} \omega_i = 1$,

$m_{n,i} = \omega_i \beta_{n,i} \qquad n = 1,\ldots, N ; i = 1,2,\ldots, L$ (5.2)

$m_{H,i} = 1 - \sum_{n=1}^{N} m_{n,i} \qquad i = 1,2,\ldots, L$ (5.3)

$m_{n,i}$ is the basic probability mass representing the degree to which the *i*th sub-criterion e_i supports the hypothesis that the criterion E is assessed to the grade H_n. $m_{H,i}$ is the remaining probability mass unassigned to any individual grade and can be further broken down into two parts $\bar{m}_{H,i}$ and $\tilde{m}_{H,i}$ as shown in equations 4 and 5, respectively:

$\bar{m}_{H,i} = 1 - \omega_i \qquad i = 1,2,\ldots, L$ (5.4)

$\tilde{m}_{H,i} = \omega_i \left(1 - \sum_{n-1}^{N} \beta_{n,1}\right) \qquad i = 1,2,\ldots, L$ (5.5)

To obtain the assessment of the parent criterion, $S(E) = \{(H_n, \beta_n), n = 1,\ldots, N\}$, the assessment of all the sub-criteria are aggregated in the following recursive fashion. Firstly, $E_{I(i)}$ is defined as the subset of the first *i* sub-criteria as follows:

$E_{I(i)} = \{e_1, e_2,\ldots,e_i\}$

Let $m_{n,I(i)}$ be probability mass defined as the degree to which all the *i* criterion in $E_{I(i)}$ support the hypothesis that the assessed alternative is assessed to grade H_n on *E*; let $m_{H,I(i)}$ be the remaining probability mass unassigned to individual grades after all the assessments on sub-criteria in $E_{I(i)}$ have been considered. The relationships shown in equations 6 and 7 are correct when $i = 1$.

$m_{n,I(1)} = m_{n,1} \qquad \text{n} = 1,2,\ldots, \text{N}$ (5.6)

$m_{H,I(1)} = m_{H,1}$ (5.7)

Then, based on Equations 6 and 7, the following iterative calculation can proceed for $i = 1,2,\ldots, L-1$ to obtain the coefficients $m_{n,I(L)}$ and $\bar{m}_{H,I(L)}$, $\tilde{m}_{H,I(L)}$ (Yang and Xu 2002)

$$K_{I(i+1)} = \left[1 - \sum_{t=1}^{N} \sum_{\substack{j=1 \\ j \neq t}}^{N} m_{t,I(i)}\, m_{j,i+1}\right]^{-1} \quad (5.8)$$

where $K_{I(i+1)}$is a normalization factor and:

$$m_{n,I(i+1)} = K_{I(i+1)}\left[m_{n,i(i)}m_{n,i+1} + m_{H,I(i)}m_{n,i+1} + m_{n,I(i)}m_{H,i+1}\right] \; n = 1,2,\ldots,N \quad (5.9)$$

$$\tilde{m}_{H,I(i+1)} = K_{I(i+1)}\left[\tilde{m}_{H,I(i)}\tilde{m}_{H,i+1} + \bar{m}_{H,I(i)}\tilde{m}_{H,i+1} + \tilde{m}_{H,I(i)}\bar{m}_{H,i+1}\right] \quad (5.10)$$

$$\bar{m}_{H,I(i+1)} = K_{I(i+1)}\bar{m}_{H,I(i)}\bar{m}_{H,i+1} \quad (5.11)$$

$$m_{H,I(i)} = \tilde{m}_{H,I(i)} + \bar{m}_{H,I(i)} \qquad i = 1,2,\ldots, L \quad (5.12)$$

Finally, the combined degrees of belief in the assessment $S(E)$ can be calculated as:

$$\beta_n = \frac{m_{n,I(L)}}{1-\bar{m}_{H,I(L)}} \qquad n = 1,2,\ldots, N \quad (5.13)$$

$$\beta_H = \frac{\tilde{m}_{H,I(L)}}{1-\bar{m}_{H,I(L)}} \quad (5.14)$$

In this way, the assessment of the parent criterion can be obtained by aggregating the assessments of all its sub-criteria.

ii) The transformation between different sets of grades

If all criteria are qualitative and are assessed using the same set of grade H, then the algorithm previously mentioned can be directly used to aggregate assessment information from sub-criteria to parent criteria up to the very top criterion. However, it is likely that a sub-criterion and its parent criterion have different assessment grades. This issue can be dealt with by the following transformation calculations.

For a sub-criterion with assessment grades differing from those of its parent criterion, the equivalent relationship between the two sets of grades needs to be established. Suppose a sub-criterion e_i has N_i grades. Then $H_i = \{H_{l,i}, l = 1,\ldots, N_i\}$, $S(e_i) = \{(H_{l,i}, \gamma_{l,i}), l = 1,\ldots, N_i\}$ and a grade $H_{l,i}$ in H_i means a grade H_n in H to a degree of $\alpha_{n,l}$ ($n = 1,\ldots, N$). Then let

$$\beta_{n,i} = \sum_{l=1}^{N_i} \alpha_{n,l}\, \gamma_{l,i} \qquad n = 1, \ldots, N \quad (5.15)$$

where $\gamma_{l,i}$ is the degree of belief to which criterion e_i is assessed to $H_{l,I}$, and $\alpha_{n,l}$ is determined by decision makers subjectively or by rules. It is necessary to keep $0 \leq \alpha_{n,l} \leq 1$ and $\sum_{l=1}^{N} \alpha_{n,l}$ = 1 for any given *l*.

Based on Equation 15, $S(e_i) = \{H_{l,I}, \gamma_{l,i}), l = 1, \ldots, N_i$ can be transformed to $S(e_i) = \{(H_n, \beta_{n,i})$, $n = 1, \ldots, N\}$ in terms of value and utility equivalence (Yang, 2001).

iii) The transformation between numeric assessment and grade assessment

It is also common that there may be numeric sub-criteria in question. In this case, a numeric value can be transformed to an equivalent assessment using the grades of its parent criterion in the following way.

Let $h_{N,i}$ be the largest and $h_{1,i}$ the smallest feasible values, respectively, that any assessed option can take on the sub-criterion. Suppose a value $h_{n,i}$ for a quantitative sub-criterion is judged to be equivalent to a grade H_n, $n = 1, \ldots, N$. then, a value h on e_i is mapped to the grade set with degrees of belief by using Equations 5.16-5.18:

$$S\,(e_i(h)) = \{(h_{n,i}, \beta_{n,i}), n = 1, \ldots, N\} \tag{5.16}$$

$$\text{where } \beta_{n,i} = \frac{h_{n+1,i} - h}{h_{n+1,i} - h_{n,i}}, \beta_{n+1,i} = \beta_{n,i}, \text{ if } h_{n,i} \leq h \leq h_{n+1,i} \text{ and } n = 1, \ldots, N-1 \tag{5.17}$$

$$\beta_{k,i} = 0 \qquad \text{for } k = 1, \ldots, N \text{ and } k \neq n, n+1 \tag{5.18}$$

The assessment $S(e_i(h))$ transformed to the format of a belief structure as shown on the right hand side of Equation 16 can be used directly in the ER aggregation algorithm.

iv) Ranking the options

Theoretically, the ranking options can be carried out after all the assessments of each option on the sub-criteria are aggregated and its performance distributions on the top criterion *T*, denoted by $S(T) = \{(H_n, \beta_n), n = 1, \ldots, N\}$, become available. However, it is not straightforward in practice to rank options using their performance distributions in the format of $\{(H_n, \beta_n), n = 1, \ldots, N\}$. In this case, a utility function $u(x)$ can be defined for the *N* assessment grades so that a utility score can be calculated for each performance distribution and a direct comparison based on the scores can be made.

The utility function $u(H_n)$ is defined as the utility of the grade H_n and $u(H_{n+1}) > u(H_n)$ if $u(H_{n+1})$ is preferred to H_n. Taking the top criterion for instance, if $\beta_H = 0$, the utility of an option on the top criterion is then calculated by $u(T) = \sum_{n=1}^{N} \beta_n u(H_n)$. If $\beta_H \neq 0$, i.e., there is a degree of unknown which could be assigned to any grade, then the likelihood of an option being assessed to grade H_n on criterion T is belief interval $[\beta_n, (\beta_n + \beta_H)]$ for $n = 1,\ldots, N$.

The assessment based on a single scale of *u(T)* is obviously much easier and more intuitive for a decision maker to rank the options in question. To rank alternatives on utility intervals, the simplest way is to use the middle point in each interval, as a performance indicator can be calculated using following equation:

Utility intervals = $[(u_{min}(T) + u_{max}(T)]/2$ (5.19)

5.4 Generic Methodology

This is the generic methodology of selecting the most effective shipping transit route within the NSR. To conduct the research, a combination of decision-making techniques such as AHP and ER is used. AHP or in particular the pair-wise comparison technique is used to obtain all the weight of evaluated criteria and ER is used for selection problem. Again, sensitivity analysis is conducted for partial validity of the research. The proposed methodology in stepwise order is described next:

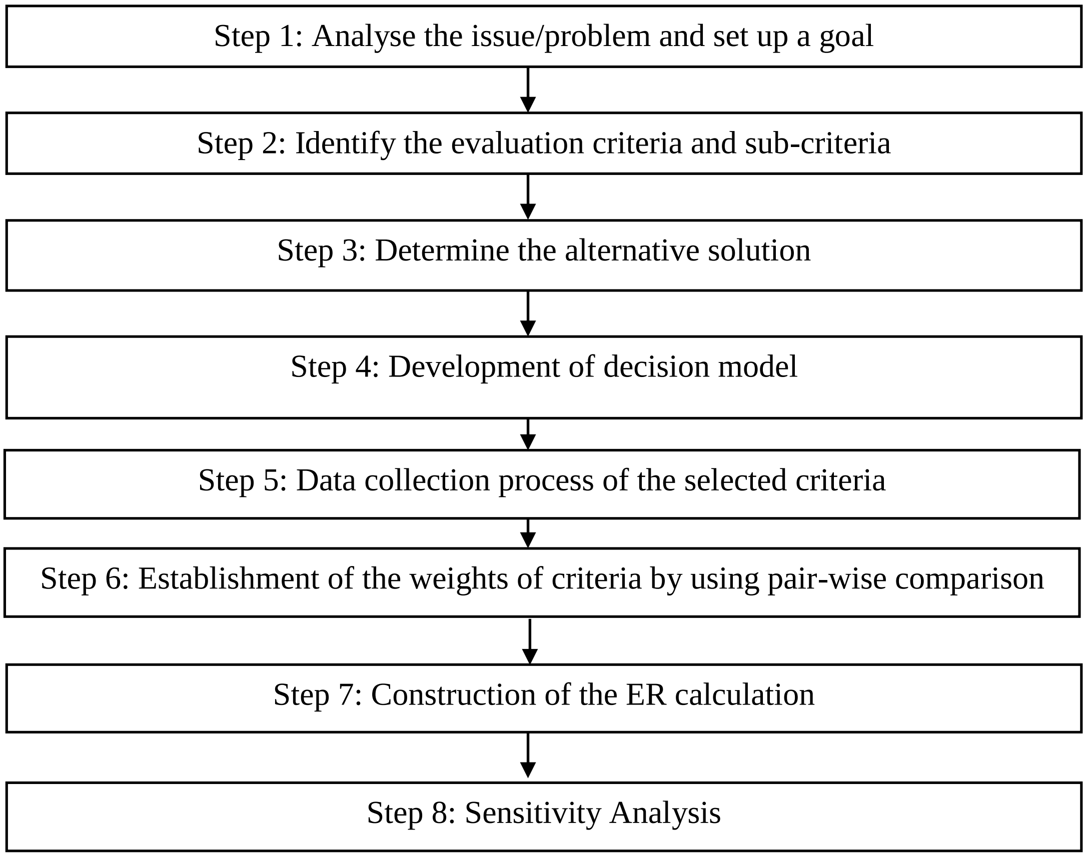


Figure 5.1: Flowchart of the methodology of selection of the most effective shipping transit route within the NSR

Step 1*: Analyse the issue or problem and set up a goal*

Hwang and Yoon (1981) suggested that Multiple Criteria Decision Making (MCDM) problems can be classified into two main categories: multiple attribute decision making (MADM) and multiple objective decision making (MODM), based on the different purposes and different data types. Therefore, decision makers have to study the problem and define the situation carefully, including as many relevant details as possible. Since this study focuses mainly on the evaluation problem, MADM is emphasised. The typical MADM problem examines a set of feasible alternatives and considers more than one criterion to determine a priority ranking for alternative implementation

Step 2: *Identify the evaluation criteria and sub-criteria*

The criteria and sub-criteria will be identified through literature review, discussion with experts, and brainstorming technique. Then, all criteria and sub-criteria will go through the filtering process as only significant ones can be chosen for use in this study. The research gaps found in the literature study can be used to improve the selection of parameters in this study.

Keeney and Raiffa (1976) suggested five principles to be considered when the criteria are being formulated, which are:

- Completeness (the criteria must embrace all of the important characteristics of the decision-making problems)
- Operational ability (the criteria will have to be meaningful for decision makers and available for open study)
- Decomposability (the criteria can be decomposed from higher hierarchy to lower hierarchy to simplify evaluation processes)
- Non-redundancy (the criteria must avoid duplicate measurement of the same performance)
- Minimum size (the number of criteria should be as small as possible so as to reduce the needed manpower, time, and cost)

Step 3*: Determine the alternative solution*

Referring to Section 5.2, there are a few types of shipping routes within the NSR conducted by other researchers, which can be used as the alternatives. These selected alternatives will be clarified with experts and will be the possible alternatives in this study. Decision makers must be able to incorporate the evaluation criteria with the alternatives in order to guarantee that the goal will be reached.

Step 4*: Development of decision model*

The model or hierarchical structure of the problem will be developed. This model consists of goal, criteria, sub-criteria, and the alternatives. Decision makers must be aware of some of the key concepts when trying to develop the hierarchy as listed below by Saaty (2012).

- In a functional hierarchy, complex systems are broken down into their constituent parts according to their essential relationships.
- The top level of the hierarchy – the focus (goal) – consists of only one element: the overall objective. The other levels contain several elements.
- There is no limit to the number of levels in a hierarchy.

- When the elements of a level cannot be compared readily, a new level with finer distinctions must be created.
- Hierarchies are flexible and can be altered to accommodate new criteria.
- A very successful way to structure a hierarchy is to brainstorm the subject in the presence of other participants, by listing all the relevant factors and alternatives that come to mind.

***Step 5**: Data collection process of the selected criteria*

The qualitative dataset will be obtained from selected experts using a set of questionnaires and interview sessions. During this process, the experts are expected to express their judgements on the issues discussed.

A numerical dataset will be obtained through literature reviews, institutional reports, online website, and any other sources. It is assumed that all criteria and their respective weights are expressed in crisp values or known precisely, which makes it possible to arrange them in a crisp ranking. If the available information is not enough to judge or when the crisp value is inadequate to model real situations, then, the application of the fuzzy set theory is justified when the intended goals or their attainment cannot be defined or judged crisply but only as fuzzy sets (Zimmermann, 1987).

***Step 6**: Establishment of the weights of criteria by using pairwise comparison approach*

All selected criteria will be assigned with a number of weights using the pairwise comparison approach of AHP. This step can be referred to Step 3, Section 4.2.1 in Chapter 4.

***Step 7**: Construction of the ER calculation*

The calculation process will be conducted using the Intelligent Decision System Software (IDS) (Yang and Xu, 2002) software tool. IDS is a window-based software package that has been developed on the basis of the Evidential Reasoning (ER) approach, a recent development in handling hybrid MCDM problems with uncertainties. For demonstrating purposes, a manual calculation will be shown using a number of examples. Further detail about the ER algorithm can be found in Section 5.4.

***Step 8:** Sensitivity Analysis*

A sensitivity analysis is conducted to partially validate the developed model. The objective of a sensitivity analysis when applied in a model verification process is to ascertain if the model output responds appropriately to changes in the model input. In this study the aim was to demonstrate the sensitivity of an assessment grade when the input values of the decision attribute changed.

5.5 Case study of the selection of the most effective shipping route within the NSR

The process of selecting the most effective shipping transit route within the NSR is as follows:

Step 1*: Set up a goal*

The NSR is not a single shipping lane. It is a large area in the sea north of Russia. The variations of shipping routes in the area are enormous. Since vessels are employed either in port-to-port navigation within the NSR or in transit navigation along the NSR, the choice of routes is also varied. It is also important to establish the specific time of navigation as for now, the NSR is very difficult to navigate during winter. Vessels with different ice classes have different levels of capability to sail based on the thickness of ice. This study only focused on summer time navigation and only for transit navigation with one particular vessel (same size, type, and capability) that sails through a number of routes within the NSR. This study will analyse and compare the shipping routes within the NSR with the aim of selecting the most effective shipping transit route.

Step 2*: Identification of the criteria*

a. Identify the possible criteria and sub-criteria

This study tries to find the most effective shipping transit route. Therefore, the general criteria of route selection must be identified in the first place. According to Rodrigue (2013), route selection tries to find or use a path minimising cost and maximising efficiency. It also implies that route selection must be the least damaging to the environment.

Therefore, the three parameters/factors that can be used to identify the evaluation criteria are as follows. Firstly, minimising cost, which means a good route selection should minimise the total costs of the transport system (Rodrigue, 2013). Secondly, efficiency maximisation. Even if a route is longer and more expensive to operate, it might provide better safety or services to the ship (Rodrigue, 2013). Thirdly, the route selection must be the least damaging to the environment. By examining the list of criteria from Table 3.5 in Chapter 3, the criteria related to cost minimisation, efficiency maximisation, and least damage to the environment are as follows: 1) economic factor (EF); 2) advantages of the NSR with comparison to other alternatives (AF); 3) safety factor (FF); and 4) environmental factor (VF). Hence, the political factor, legal factor, social factor, and technological factor are eliminated from this study. This process of selection and elimination for all factors can be found in Appendix I.

Consequently, Table 5.1 shows the three levels of criteria that are related to the factors of route selection.

Table 5.1: The list of criteria that related to the factors of route selection

Main criteria	**Sub-criteria**	**Sub-sub-criteria**	**Parameter**
Economic Factor (EF)	Shipping Operating costs (EFA)	Capital costs (ice strengthened vessels) (EFAA)	Fixed
		The NSR Insurance costs (EFAB)	Fixed
		Ship depreciation (EFAC)	Fixed
		Manning costs (EFAD)	Fixed
	Shipping voyage costs (EFB)	Fuel costs (EFBA)	Variable
		The NSR fees (Meteorological forecast & ice breaking) (EFBB)	Variable
		Ice pilot fees (EFBC)	Variable
Environmental Factor (VF)	Disappearing of summer sea ice (VFA)	More navigable days for shipping operations (VFAA)	Variable
		Possible extinction of Polar bears (VFAB)	Fixed
		Some Arctic fisheries will be affected (VFAC)	Fixed
	Challenges to operation (VFB)	Operational conditions like wind chills, darkness in winter, sea ice & ice bergs, high latitudes and etc. (VFBA)	Variable
		Seasonality of operations (Navigable for 2 to 4 months in eastern part of the NSR :without ice breaking assistance) (VFBB)	Variable
		Shallow seas & straits (Vessel size restriction in coastal route) (VFBC)	Variable
Safety Factor (FF)	Status of shipping and port infrastructure (FFA)	Status of search and rescue facilities (FFAA)	Variable
		Status of availability of international port along the route (FFAB)	Variable (but does not fit with the simulation)
		Status of ships repair and maintenance facilities (FFAC)	Variable (but does not fit with the simulation)
	Status of navigational aids facilities (FFB)	Charting and monitoring (FFBA)	Variable
		Radio and satellite communications and emergency response (FFBB)	Variable

		Observational networks and forecast for weather, icing, waves and sea ice(FFBC)	Variable
	Training for crew for Arctic operations (FFC)		Fixed
Advantages of the NSR in comparison to other routes (AF)	Shorter route (AFA)	Saving in time(AFAA)	Variable
		Saving in expenses (AFAB)	Variable (too broad)
		Increase the number of round trips (AFAC)	Variable
		Reduced air emissions from ships (AFAD)	Variable

b. Filter all the sub-sub-criteria based on the parameter basis and proposed simulation

There are many sub-sub-criteria as listed in Table 5.1. However, not all of them can be used as evaluation criteria. This is because some of the sub-criteria and sub-sub-criteria are linked to the ship characteristics as described in Appendix J. All such sub-criteria are considered as constant or fixed parameters; for instance, capital costs, insurance cost, ship depreciation and manning costs. The sub-criteria 'Training for crew for Arctic operations' is indirectly linked to the ship characteristics that can be set as a fixed parameter. As a result, no further evaluation is required.

According to Ostreng, *et al*. (2013) and AMSA Report (2009), certain areas in the Arctic region that will be at risk from shipping activities include the Bering Strait, Chukotka region (Eastern part of Russia), and Barents Sea. Therefore, all routes within the NSR present the same risk to the Polar bears because all these routes are passing through the straits or regions where the Polar bears live. Furthermore, the whole of the NSR and north of Russia are at risk or exposed to environmental impacts from increasing shipping activities (Ragner, 1999; Ostreng, *et al.* 2013; AMSA, 2009). Hence, the sub-criteria 'Possible extinction of Polar bears' and 'some Arctic fisheries will be affected' are not considered as criteria for this study.

On the other hand, the sub-criteria 'Status of availability of international port along the route' and 'Status of ships repair and maintenance facilities' are variable parameters. However, these sub-criteria are not considered in the study because the simulation for this study would be a transit navigation as mentioned in Step 1 before. There will be no stop-over for ship and ship is simulated for single voyage and no maintenance required.

The sub-criterion 'saving in expenses' is also not considered in this study because it is a broad term that includes fuel costs, NSR fees, ice pilot fees and many other costs. Such costs are going to be selected and evaluated individually in the next step.

Therefore, seven sub-criteria, which are fixed parameters, and three variable sub-criteria are taken out from this study as shown in Table 5.1.

c. List down all the selected criteria and sub-criteria

Table 5.2 shows the selected criteria and sub-criteria of the most effective shipping route within the NSR. According to Saaty (2012), there is no limit to the number of levels in a hierarchy. If one is unable to compare the elements of a level in terms of the elements of the next higher level, one must ask in what terms they can be compared and then seek an intermediate level that should amount to a breakdown of the elements of the next higher level. Thus, a new level has been introduced to facilitate the analysis for comparisons and to increase the precision of the judgements. It should be noted how much more one element contributes than another to satisfying a criterion in the next higher level of the hierarchy. Furthermore, a decision maker can insert or eliminate levels and elements as necessary to clarify the task of setting priorities or to sharpen the focus on one or more parts of the system (Saaty, 2012). Therefore, all sub-criteria in Table 5.2 will be eliminated because of the reasons mentioned. However, the understanding of the issue or problem is not affected if all sub-criteria are taken out from this hierarchical structure.

Table 5.2: The list of screened criteria of route selection

Main Criteria	**Sub-Criteria**	**Sub-sub Criteria**
Economic Factor (EF)	Shipping variable costs (EFB)	Fuel costs (EFBA)
		The NSR fees (EFBB)
		Ice Pilot fees (EFBC)
Environmental Factor (VF)	Disappearing of summer sea ice (VFA)	More navigable days for shipping operations (VFAA)
	Challenges to operation (VFB)	Operational conditions like wind chills, darkness in winter, sea ice & ice bergs, high latitudes etc. (VFBA)
		Shallow seas & straits (Vessel size restriction) (VFBC)
Safety Factor (FF)	Status of shipping and port infrastructure (FFA)	Status of search and rescue facilities (FFAA)

	Status of navigational aids facilities (FFB)	Charting and monitoring (FFBA)
		Radio and satellite communications and emergency response (FFBB)
		Observational networks and forecast for weather, icing, waves and sea ice(FFBC)
Advantages of the NSR in comparison to other alternatives (AF)	Shorter route (AFA)	Saving in time(AFAA)
		Increase the number of round trips (AFAC)
		Reduced emissions from ships (AFAD)

There will be more changes of the criteria in order to make them suitable to the goal of the study. The changes are as follows:

1) The main criterion ‘Advantages of the NSR in comparison to other alternatives’ will be changed into ‘Distance factor’.
2) The sub-sub-criterion ‘more navigable days for shipping operations’ will be changed to ‘the number of navigable days’.
3) The sub-sub-criterion ‘operational conditions like wind chills, darkness in winter, sea ice & iceberg, high latitudes etc. will be changed to ‘operational conditions’.
4) The sub-sub-criterion ‘shallow seas and straits (vessel size restriction)’ will become two sub-criteria ‘depth of seas’ and ‘depth of straits’.
5) The ‘status of search and rescue facilities’ criterion will be changed to ‘search & rescue facilities’.
6) The sub-sub-criterion ‘Observational networks and forecast for weather, icing, waves and sea ice’ will be changed into ‘observational networks & weather forecast’.
7) The sub-sub-criterion ‘saving in time’ will be changed to ‘journey time’.
8) The sub-sub-criterion ‘increase the number of roundtrips’ will be changed to ‘the number of roundtrips’.
9) The sub-sub-criterion ‘reduced emissions from ships’ will be changed to CO_2 emissions from ships. In this chapter, only one type of emission is used, which is CO_2. This is because one type of emission is enough to find out which route is more polluted. Hence, the goal to find the best route can be achieved.
10) Then, all sub-sub-criteria will become sub-criteria.

The final main criteria and sub-criteria for the most effective shipping route within the NSR are shown in Table 5.3.

Table 5.3: The main criteria and sub-criteria for the most effective shipping transit route within the NSR

Main Criteria	**Sub-Criteria**
Economic Factor	Fuel costs
	The NSR fees
	Ice Pilot fees
Distance factor	Journey time
	The number of round trips
	CO_2 emissions from ships
Safety Factor	Charting & monitoring
	Radio & satellite communications & emergency response
	Observational networks & forecast
	Search & Rescue facilities
Environmental Factor	The number of navigable days
	Operational conditions
	Depth of seas
	Depth of straits

***Step 3**: Identification of the shipping routes (alternatives) within the NSR.*

In general, the coastal route or traditional route is the most popular route within the NSR due to better ice condition. However, there are numerous routes and a great variation of the NSR. A major factor determining the choice of a route for navigation along the NSR is the distribution of ice cover and the bathymetry (Baskin *et al*., 1998; Brigham *et al*., 1999). The alternatives (shipping routes within the NSR) will be carefully selected as the sea ice extent and ice cover distribution change every year.

The Russian Arctic seas are very similar in nature. All belong to a group of marginal seas, are almost entirely located within the Arctic shelf, and lie north of the Arctic Circle (Marchenko, 2013). The NSR has many variations of routes but in general, there are four shipping routes across the Arctic sea as mentioned by Mulherin (1996), Honneland (1997), Eide *et al*., (2010), HSVA, (2014), and many other researchers. In fact, these studies showed almost similar routes within the NSR because the key elements in navigating the NSR are the ice conditions and the bathymetry. Therefore, the shipping routes (alternatives) within the NSR can be adapted from one of these studies. Table 5.4 summarises the studies of variation of routes within the NSR and their parameters for choosing the optimal routes.

Table 5.4: The summary of studies with regards to variation of routes within the NSR

Authors	**Number of routes**	**Distance**	**Parameters**
Mulherin, (1996)	Four routes	Not mentioned 1). Coastal route 2). Mid Route 3).Transit route 4). Over the pole route	Common practice, voyage origin and destination, ice conditions, location of ice breaking resources
Honneland, G.B. (1997)	Four routes	Traditional: 3500 nm Central: 3340 nm High-latitudinal: 2890 nm Close-to-the-pole:2700 nm	Ice condition, depth of seas and straits
Baskin, *et al*., (1998)	2 standard routes: 1). 17 routes leg of routes in summer period (June - October) 2). 16 routes leg of routes in winter-spring period (November – May)	Not mentioned	Long-term practice of sea operations, ice conditions, seasonal, bathymetry and voyage purpose
Eide, L.I. (2010)	Four routes	Not mentioned	Transit distance and ice conditions
Stephenson, *et al*., (2014)	Various routes of the NSR	Not mentioned	Ice conditions, bathymetry, vessel size and voyage purpose
HSVA (2014)	Four routes	Route 1: 3048 nm Route 2: 2998 nm Route 3: 2892 nm Route 4: 2729 nm	The routes are subdivided into legs while the number of legs is chosen according to the required spatial resolution with regard to variations in environment conditions (ice conditions, wind speed and etc.) using the routing software called ICEROUTE.
Chang, *et al*., (2015)	Determine one optimal route from the Arctic region,	Not mentioned	Fog, Water depths, Arctic floating ice distributions and sea ice using Google Earth and Higher geometry maze router

In summary, all previous studies used ice conditions as one of the main parameters of choosing the optimal route within the NSR. However, the ice conditions such as sea ice extent have changed so much since the last decades in the Arctic as shown in Figure 5.2. Clearly, the Arctic sea ice extent is very much smaller in the past six years as compared to in the 1990s in which some of the studies were based. Therefore, the recent studies by Eide, Stephenson, HSVA, and Chang will be potential alternatives for this study.

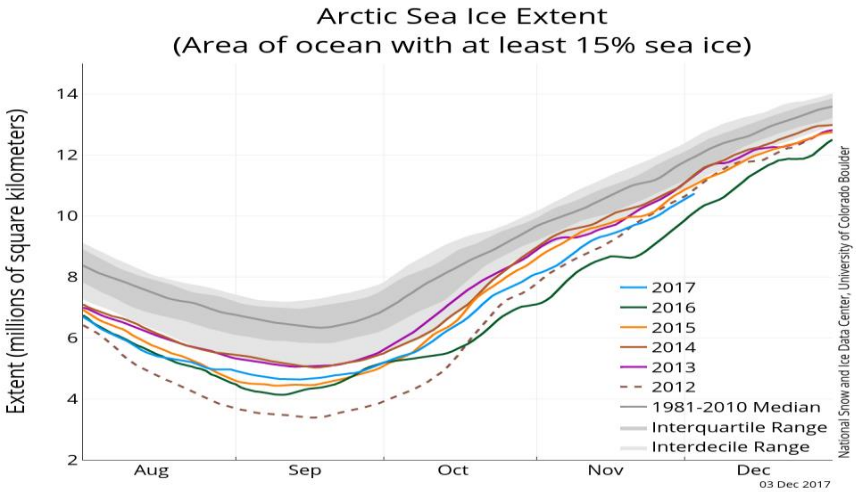


Figure 5.2: Arctic sea ice extent with daily ice extent data from 2012 to 2017 and the median sea ice extent from 1981 to 2010. (Sources: National Snow and Ice Data Center)

Only the study by HSVA gave good details about the routes within the NSR, and thus, will be adapted in this study. The map and details for each route are explained next.

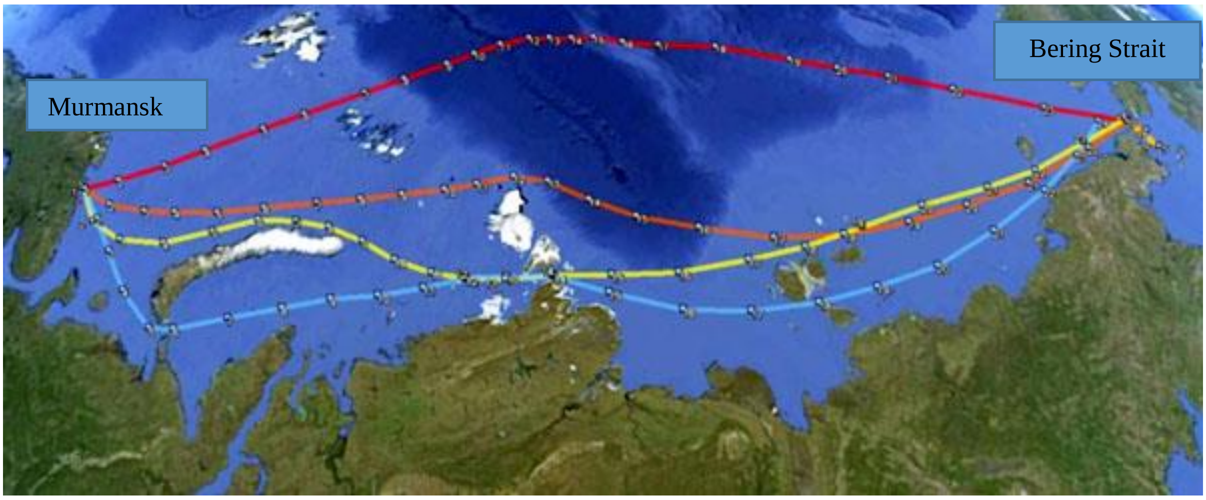


Figure 5.3: The four transit routes along the NSR; 1 (blue), 2 (yellow), 3 (orange) and 4 (red) (Source: HSVA, 2014)

Route 1 (blue, Coastal route) – Murmansk to Bering Strait via Kara gate, south of Severnaya Zemlya and south of New Siberian Islands.

Route 2 (yellow, Middle route) – Murmansk to Bering Strait via north of Novaya Zemlya, south of Severnaya Zemlya and north New Siberian Islands.

Route 3 (orange, Transit route) – Murmansk to Bering Strait via north of Novaya Zemlya, north of Severnaya Zemlya and north of New Siberian Islands.

Route 4 (red, Transpolar route) – Murmansk to Bering Strait via north of Novaya Zemlya, north of Severnaya Zemlya close to the geographical north pole and north of New Siberian Islands.

Step 4: *Development of decision making model*

By combining all the information in Steps 1, 2, and 3, a hierarchical model is developed as shown in Figure 5.4. Consequently, the abbreviation (shown in brackets) for each criterion and sub-criterion has been changed in this chapter to avoid confusion with the previous chapter. This hierarchical structure is not necessarily the final decision-making model because all sub-criteria need to be evaluated afterwards in the next step. In this process of evaluation, some sub-criteria, or even the alternatives, might be ruled out from the study if they are found to be infeasible.

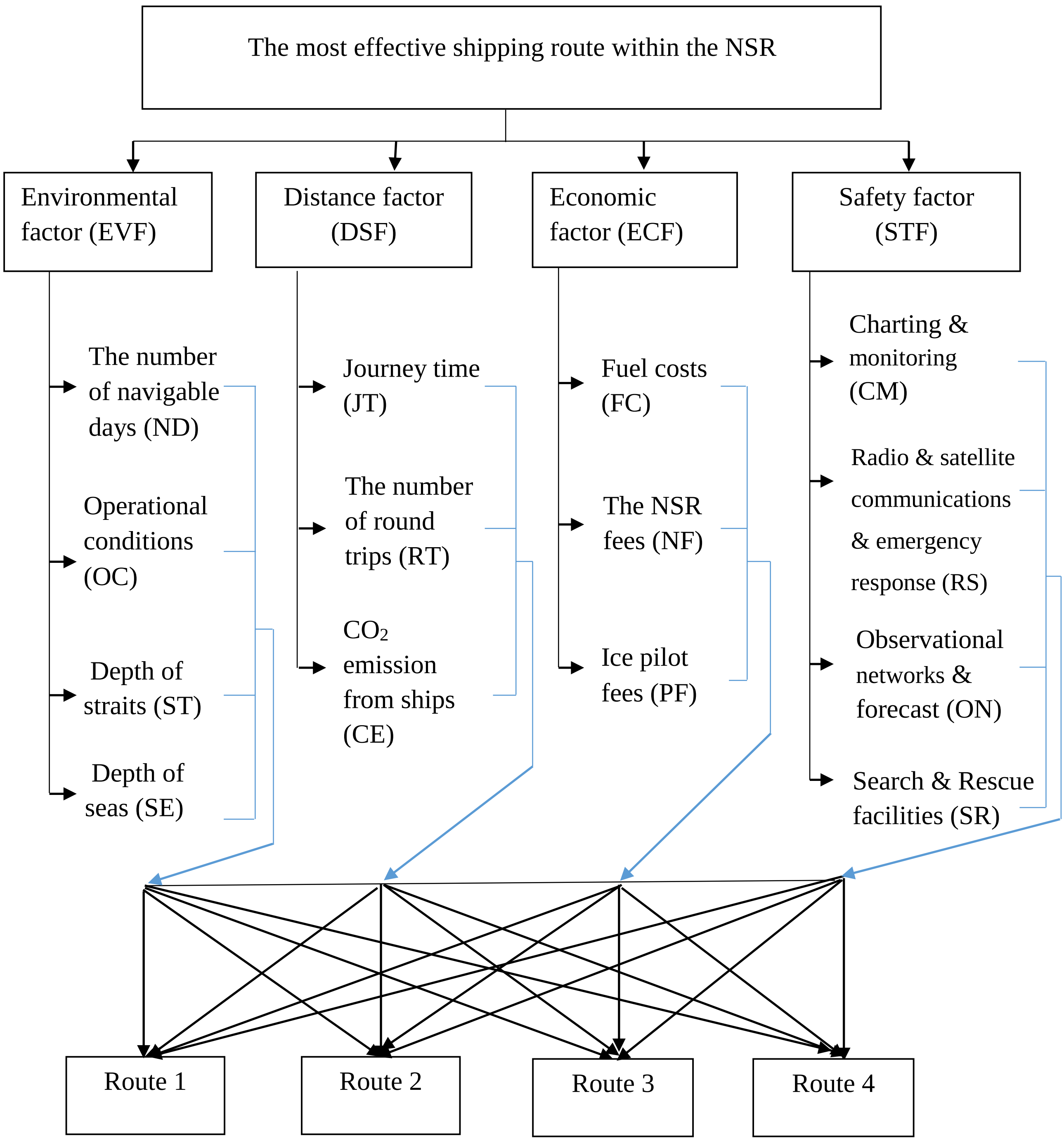


Figure 5.4: The hierarchical model of selection of the most effective route within the NSR

Step 5: Data collection process

A data collection process involves gathering different types of data and then evaluating them accordingly as explained below.

A) Types of data

1. Numerical data for quantitative criteria.

There are nine quantitative criteria in this study, namely the number of navigable days (ND), depth of straits (ST), depth of seas (SE), journey time (JT), number of round trips (RT), CO_2 emissions from ship (CE), fuel costs (FC), NSR fees (NF), and ice pilot fees (PF). These selected quantitative criteria will be calculated or gathered as explained next.

The numerical data for the number of navigable days (ND), depth of seas (SE), and depth of straits (ST) is gathered from work by other researchers.

The numerical data of journey time (JT) can be gathered by manipulating the equation written by Notteboom and Vernimmen (2009) as follows:

$$Journey\ time = \frac{D}{V\ x\ 24} \tag{5.20}$$

where,

D = distance of the route, *V* = actual speed

The total time needed for a vessel to do a complete round voyage as formulated by Notteboom and Vernimmen (2009) is:

$$T_r = \sum_{i=1}^{n} Tpi + \frac{D}{V\,.24} \tag{5.21}$$

T_r is the round voyage time in days; T_{pi} is the total time in port *i* in days; *n* is the number of ports of call on route; *D* is the distance of the round voyage in nautical miles (nm); *V* is the vessel speed in knots. However, in order to find the number of roundtrips (RT) that can be done in one season of the NSR, Equation 5.21 is manipulated as follows;

$$T_r = \frac{Nd}{\sum_{i=1}^{n} Tpi + \frac{D}{V\,.24}} \tag{5.22}$$

Where N_d is a number of navigable days in the NSR.

There are many emissions from ships such as carbon dioxide (CO_2), nitrogen oxides (NO_X), sulphur oxides (SO_X), carbon monoxide (CO), methane (CH_4) and various species of particulate matter (PM) including organic carbon (OC) and black carbon (BC). However, for this research, only CO_2 emission for each route is compared. This is because, the main purpose is to find out which routes has contributed more or less gas emissions. Furthermore, CO_2 also one of the major greenhouse gas which cause the greenhouse effect. The greenhouse effect is the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without this atmosphere (Lallanila, 2018). The equation to find the CO_2 emission from ships (CE) is provided by Abdul Rahman, (2012), as follows:

$$CO_2/\text{kg} = 3.17 \text{ x} \sum i.j.k \left\{\left[MF_k \ x \ \left(\frac{s}{s^*}\right)^3 + AF_k\right] \ x \ \frac{d_{ij}}{24 \ x \ S_{1k}}\right\} \quad (5.23)$$

where,

MF_k = main engine(s) daily fuel consumption

AF_k = auxiliary engine(s) daily fuel consumption

S and S^* = the operational speed and the design at-sea speed of vessel k respectively in units of nautical miles (nm) per hour

dij = the distance between two ports (nm)

To calculate the fuel cost, the fuel consumption of the vessel has to be computed first using the equation written by Stopford (2009), as follows:

$$msME = F^* \left(\frac{s}{s*}\right)^{\alpha} \quad (5.24)$$

where,

$msME$ = actual fuel consumption (tonnes/day)

F^* = design fuel consumption

S = actual speed

S^* = design speed

The exponent α has a value of about three for diesel engines and two for steam turbines.

Then, the fuel cost (FC) calculation can be calculated using the equation written by Magelssen, (2010) as follows:

Bunker Fuel Cost = s x $msME$ x P (5.25)

where,

s = the total journey time,

$msME$ = the fuel consumption in tonne per day

P = the bunker fuel price per tonne

The NSR fees (NF) or ice-breaking tariff does not have a clear calculation formula. Starting from 2009 until now, the ice-breaking fees are negotiable. It is impossible to obtain an accurate and reliable amount of fees for two (2) similar vessels with the same tariff determinants. However, the rough amount of fees can be gathered by using the tariff calculation provided by the NSR Information Office (http://www.arctic-lio.com/nsr_tariffsystem).

The ice pilot fee (PF) is calculated based on the literature surveys from previous studies. This is because the NSR authority does not provide any fee calculation for this matter.

2. Qualitative data. The assessment of the shipping transit route in terms of qualitative attributes is normally expressed using grades. For example, most of the criteria will be assessed by using this set of grades (very good, good, average, poor, very poor). A different set of grades can be used for different attributes if necessary. Qualitative data collection was obtained from expert judgement through a set of belief degree questionnaires (Appendix J). Hence, the linguistic terms or assessment grades are assigned for each qualitative criterion as shown in Table 5.5.

Table 5.5: Assessment grades for main-criteria and sub-criteria

<table>
<tr><th colspan="7">Linguistic terms</th></tr>
<tr><td colspan="2">Goal</td><td>Most Effective</td><td>Reasonably Effective</td><td>Average</td><td>Reasonably Ineffective</td><td>Ineffective</td></tr>
<tr><td rowspan="4">Main criteria</td><td>Environmental factor</td><td>Very good</td><td>Good</td><td>Average</td><td>Poor</td><td>Very poor</td></tr>
<tr><td>Distance factor</td><td>Very good</td><td>Good</td><td>Average</td><td>Low</td><td>Very low</td></tr>
<tr><td>Economic factor</td><td>Low</td><td>Reasonably low</td><td>Average</td><td>Reasonably high</td><td>High</td></tr>
<tr><td>Safety factor</td><td>Very good</td><td>Good</td><td>Average</td><td>Poor</td><td>Very poor</td></tr>
<tr><td rowspan="3">Sub-criteria</td><td>The number of navigable days</td><td colspan="5">Quantitative</td></tr>
<tr><td>Operational conditions</td><td>Very good</td><td>Good</td><td>Average</td><td>Poor</td><td>Very poor</td></tr>
<tr><td>Depth of seas</td><td colspan="5">Quantitative</td></tr>
</table>

	Depth of straits	Quantitative				
	Journey time	Quantitative				
	The number of roundtrips	Quantitative				
	CO_2 emission from ships	Quantitative				
	Fuel Costs	Quantitative				
	The NSR fees	Quantitative				
	The ice pilot fees	Quantitative				
	Charting & monitoring	Very good	Good	Average	Poor	Very poor
	Radio and Satellite communication	Very good	Good	Average	Poor	Very poor
	Observational networks and forecast	Very good	Good	Average	Poor	Very poor
	Search and rescue facilities	Very good	Good	Average	Poor	Very poor

3. The weight values for each of the criteria and sub-criteria are gathered by using the pairwise comparison approach. Expert judgement is needed for this matter and this whole process will be explained in Step 6.

B) Evaluation of the quantitative and qualitative criteria

The comparison between these four routes is based on a voyage transit by one multipurpose ship called Yong Sheng. This particular ship was the first foreign ship that carried containers using the NSR (Pryce, 2015). The details of the ship are shown in Appendix J.

1. Evaluation of qualitative data

The identified criteria are put into two categories: quantitative or qualitative criteria. Sometimes, certain criteria can be quantitative or qualitative criteria depending on the data and the extent of the study. For example, the sub-criterion of operational conditions is considered as a qualitative criterion for this study as shown in Table 5.5. The operational conditions can be broken down into more sub-sub-criteria such as types of ice, wind speed, fog, temperature and so on. These factors can be considered as quantitative criteria. However, at present, such data is more in the general area of the NSR and not distinguished by each route of the study. Furthermore, the NSR is a vast area and has many different characteristics and the comparison for each route must be analysed region by region. Therefore, for simplicity, the operational conditions are considered as qualitative criteria. The assessment of the qualitative data will be explained and calculated in Step 7.

2. Quantitative data

I. The number of navigable days in the NSR

The number of navigable days is different for each route within the NSR. The navigation season is often defined as the number of days per year with navigable conditions, generally meaning days with less than 50% sea ice cover (Liu and Kronbak, 2010; Lei *et al*., 2015).

Referring to Figure 5.5, for icebreaker (IB) cargo ships together with icebreaker escort, the ship navigation in the NSR can start as early as mid-April and stretch through to December. This means that, this particular ice class ship can use the NSR for almost nine months. However, this figure is only for the coastal route of the NSR. According to Stephenson *et al*., (2014), sea ice condition tends to be more severe at higher latitudes. The route at higher latitudes will therefore have fewer navigation days as compared to the lower latitudes.

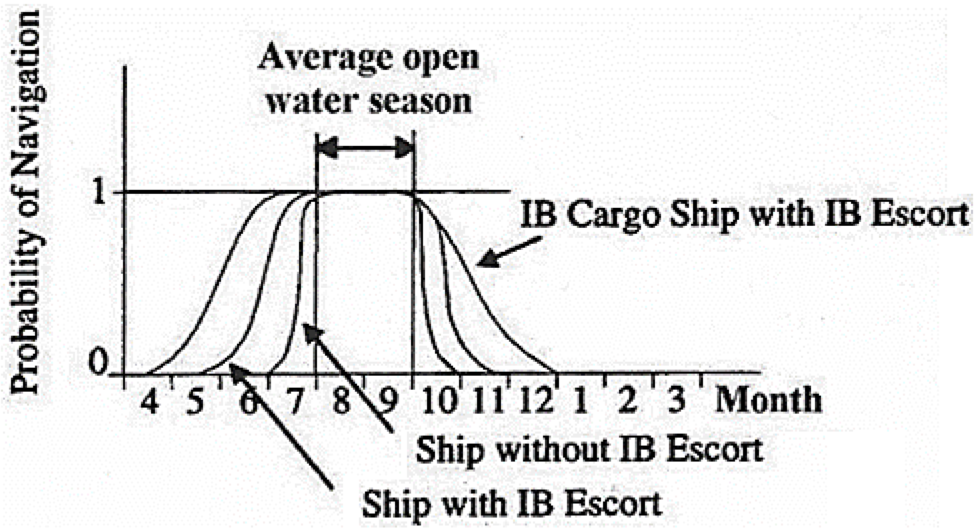


Figure 5.5: Probabilistic shipping seasons and ship capability in the NSR (Source: Lamb, 2004)

The study conducted by Lei *et al*., (2015) used multisource remote sensing data from 1979 to 2012 to analyse seasonal, inter-annual, and spatial changes in sea ice conditions along the NSR. However, this study only provided the number of navigable days for Routes 1 and 3. For Route 2, the number of navigable days is obtained by simply subtracting five from the number of navigable days of Route 1. This is because, according to Stephenson *et al*., (2014), the northern route is usually accessible around five days fewer than the southern route (146 days) of the NSR. The Transpolar route or Route 4 is not accessible for commercial ships but only for highly capable icebreaker ships. With an ice concentration of 50%, the number of open days for all routes within the NSR is as shown in Table 5.6

Table 5.6: The number of navigable days for all routes within the NSR

<table>
<tr><th rowspan="2">Route</th><th colspan="4">Open period (days)</th><th rowspan="2">Source</th></tr>
<tr><th>1980s</th><th>1990s</th><th>2000s</th><th>2012</th></tr>
<tr><td>Route 1</td><td>84</td><td>99</td><td>118</td><td>146</td><td>Lei et al., (2015)</td></tr>
<tr><td>Route 2</td><td>79</td><td>94</td><td>113</td><td>141</td><td>Stephenson et al., (2014)</td></tr>
<tr><td>Route 3</td><td>29</td><td>41</td><td>61</td><td>110</td><td>Lei et al., (2015)</td></tr>
<tr><td>Route 4</td><td>-</td><td></td><td>70 (only for highly capable icebreaker ship)</td><td>70</td><td>Ostreng et al., (2013)</td></tr>
</table>

II. The depth of seas

Table 5.7 shows the average depth of the seas along the NSR. All the information is gathered from Honneland (1997) except for Route 4. Consequently, this particular sub-criterion is a fixed parameter because the seas of the NSR are deep enough for the biggest ships to navigate along each route. Therefore, no comparison or evaluation should be made. This criterion (depth of seas) will be ruled out from this study.

Table 5.7: The depth of seas within the NSR

<table>
<tr><th>Routes</th><th>Barents Sea</th><th>The Kara Sea</th><th>Laptev Sea</th><th>East Siberian Sea</th><th>Chukchi Sea</th></tr>
<tr><td>Route 1</td><td rowspan="4">The average depth is 200 metres</td><td rowspan="3">Average depth is 90 metres and 40% of its total area is less than 50 metres deep</td><td rowspan="3">Average depth is 578 metres, but 53% of the seabed has depths of less than 50 metres</td><td rowspan="3">Average depth is 40 metres</td><td rowspan="4">Average depth is 50 metres</td></tr>
<tr><td>Route 2</td></tr>
<tr><td>Route 3</td></tr>
<tr><td>Route 4</td><td colspan="3">Arctic Ocean- Average is 1500 metres (Waterencyclopedia.com accessed on 4th January 2016)</td></tr>
</table>

III. The depth of straits

Bathymetry represents a second key constraint on navigation in specific areas of the NSR. The continental shelves of the Russian Arctic are unusually broad and shallow, creating draft limitations that restrict the NSR route choice (Sakhuja 2012). Table 5.8 shows the depth of straits for each route of the NSR.

Table 5.8: The depth of straits for each route of the NSR

Routes	**Straits**	**Depth (metres)**	**Source**
Route 1	Kara Gate Strait	40 m	Honneland (1998)
	Vilkitskiy Strait	100-200 m	Stephenson *et al.,* (2014)
	Sannikov Strait	12.5 m	Ragner (2000)
	Long Strait	40-50 m	Honneland (1998)
	Bering Strait	30-50 m	Waterencyclopedia.com
Route 2	Vilkitskiy Strait	100-200 m	Stephenson *et al.,* (2014)
	Long Strait	40-50 m	Honneland (1998)
	Bering Strait	30-50 m	Waterencyclopedia.com
Route 3	Long Strait	40-50 m	Honneland (1998)
	Bering Strait	30-50 m	Waterencyclopedia.com
Route 4	Bering Strait	30-50 m	Waterencyclopedia.com

In summary, the shallowest strait for Route 1 is 12.5m and the shallowest straits for Routes 2, 3 and 4 are 30 m.

IV. Journey time

There are two pieces of information needed before the calculation of journey time can be made. They are the distance between two ports and the speed of the vessel. The distance for each route is shown in Table 5.9 below:

Table 5.9: The distance for each routes

Route	**Distance (nm)**
Route 1	3048
Route 2	2998
Route 3	2892
Route 4	2729

(Source: HSVA, 2014)

The average speed of 14 knots (CHNL Information Office, 2016) by M.V Yong Sheng, will be used for this study. This is because, this particular ship has the minimum ice class requirement for summer navigation in the arctic and recorded the highest average speed compared to other vessels which successfully crossed the NSR in 2016.

By using Equation 5.20 and Route 1 as example, the calculation of journey time is as follows:

Journey time (Route 1) = $\frac{3048}{14\ x\ 24}$

= 9.07 days

The calculation of journey time for Routes 2, 3 and 4 can be found in Appendix K.

Therefore, the total journey times required to complete one single voyage for all routes are shown in Table 5.10 next:

Table 5.10: Total journey time for all routes

Route	Distance (nm)	Journey time (days)
Route 1	3048	9.07
Route 2	2998	8.92
Route 3	2892	8.61
Route 4	2729	13

V. The number of round trips

The navigation season in the NSR is highly spatially heterogeneous, compounding uncertainties for full transits of the NSR (Stephenson, 2014). Moreover, September ice extent may vary extensively year-by-year due to natural variability in cloud cover, atmospheric circulation, local surface winds, and ocean temperature (Kapsch *et al*., 2013; Ogi and Wallace, 2012). Each end of the NSR – the south-western Kara Sea and the south-western Chukchi Sea – has the lightest ice conditions, with the East Siberian Sea having clearly the most difficult ice conditions (Eger, 2011). Therefore, summer shipping navigation in the NSR cannot be thought of as smooth navigation and the speed of the vessels is not always constant throughout the summer season.

Table 5.11 shows the average speed of ice class Arc 4 in 2013 summer season. This data was manipulated from 2013 transit statistics (CHNL Information Office, 2016) of all vessels in the NSR. In summary, the navigation in July and October is two knots slower than in August and September. This also indicates that August and September are favourable for summer navigation when compared to July and October.

Table 5.11: The average speed of vessels using the NSR in 2013 summer season

Month	Average speed (knots)
July	7.8
August	10.2
September	9.47
October	8.2

Thus, in this section, there are a few points that need to be emphasised before the calculation of shipping roundtrips can be made. The navigation season can be divided into two categories. The first category is unfavourable ice conditions, which are in July and October, whereas the second category is favourable ice conditions (August and September). In other words, 50% of the navigation season is in favourable ice conditions and the other 50% is unfavourable. The vessel speed for favourable ice conditions is similar to that used to calculate journey time, which is 14 knots and 12 knots for unfavourable ice conditions for the reason mentioned in a paragraph before.

By using Equation 5.21, and Route 1 as an example, the calculation of a round trip is as follows: Number of navigable days: 146 divide by two periods = 73 days for each period of favourable ice conditions (FIC) and unfavourable ice conditions (UIC).

Tpi = 2 days

n = 2 ports (port of origin and port of destination)

D = 3048 (total distance) where 2523 nm is from Bering Strait to Kara Strait is in 50% sea ice concentration (UIC), whereas another 525 nm (FIC) is from Kara Strait to Murmansk is free from ice all year round (Honneland, 1997; Eger, 2011).

V = 12 knots (UIC) and 14 knots (FIC)

$$\text{Round trips} = \frac{73\ (UIC)}{(2x2)+\left(\frac{2523}{12\ x\ 24}\right)+\left(\frac{525\ (FIC)}{14\ x\ 24}\right)} + \frac{73\ (FIC)}{(2x2)+\left(\frac{3048}{14\ x\ 24}\right)}$$

$$= 5.0967 + 5.5846$$

$$= 10.68 \text{ trips in one season}$$

The calculation for Route 2, 3 and 4 can be found in Appendix L. The number of round trips for the rest of the route are shown in Table 5.12 below:

Table 5.12: The number of round trips for each route

Route	**Round trips**
Route 1	10.68
Route 2	10.48
Route 3	8.40
Route 4	4.12

VI. CO_2 emissions from ship

By using Equation 5.22, the calculation of CO_2 emission for Route 1 is as follows:

$$= 3.17 \text{ x } \left\{\left[30\ x\ \left(\frac{14}{16.6}\right)^3 + 8.4\right]\ x\ \frac{3048}{24\ x\ 14}\right\}$$

= 3.17 x 26.3962 x 9.0714

= 759.0584 kg/voyage

The calculation of CO_2 emissions for the rest of the routes are shows in Appendix N. Table 5.13 below shows the CO_2 emission for each route within the NSR.

Table 5.13: The total CO_2 emissions for each route

Route	**CO_2 emission (kg/voyage)**
Route 1	759.0584
Route 2	746.6071
Route 3	720.2073
Route 4	-

Route 4 is only accessible by highly capable ice-breaking ships which are normally nuclear-powered. Thus, no Co_2 emissions are applicable for Route 4.

VII. Fuel costs

Based on the ship information used for this study (Appendix J), the design speed is 16.6 knots and the engine is diesel. However the design fuel consumption is not known. However, according to Zhao et al. (2016), the daily consumption of fuel oil of MV Yong Sheng is 20 tonnes.

Currently, Route 4 can only be accessed by highly capable icebreaker ships (Ostreng *et al*., 2013) such as nuclear-powered ice-breaking ships. This kind of ship does not use any source of fuel such as diesel. The nuclear-powered icebreakers are usually refuelled once every 5-7 years (Gerrard, 2015). This provides an enormous cost advantage as well as the convenience of not depending on the presence of ports and refuelling locations in remote areas especially in the Arctic region. Nevertheless, the installation and maintenance of the nuclear propulsion system and the fuel itself are quite costly (Gerrard, 2015). Next, the bunker fuel cost can be calculated using Equation 5.24 and is shown in Table 5.14.

Table 5.14: The bunker fuel cost for each route

Route	Journey time (s)	Fuel consumption per day (*msME*)	Bunker fuel price per metric ton (*P*)	Bunker Fuel Cost *S* x *msME* x *P*
Route 1	9.07	28	$301.5* (380 cst)	$ 76 569
Route 2	8.92			$ 75 303
Route 3	8.61			$ 72 686
Route 4	13	0		$ 0

* Rotterdam Bunker Prices as at 27th of August 2019 from http://shipandbunker.com

VIII. The NSR fees

The tariff has changed six times over the period of 1989 to 2014 (Gritsenko and Kiiski, 2015). The newest tariff in 2014 was introduced due to the new navigational rules for the NSR. Based on the 2014 tariff system, the tariff is only applied on the basis of actual rendered services. The tariff will take into account several determinants, such as gross tonnage of vessel, ice class of ship, distance of the escorting, and the period of navigation. The ice-class of a vessel falls into one of ten categories, distances are measured based on a zonal approach (the whole of NSR is subdivided into seven zones, see Figure 5.6) and seasonality is approached by defining the winter-spring sailing season (November to June) and the autumn-summer season (July to October).

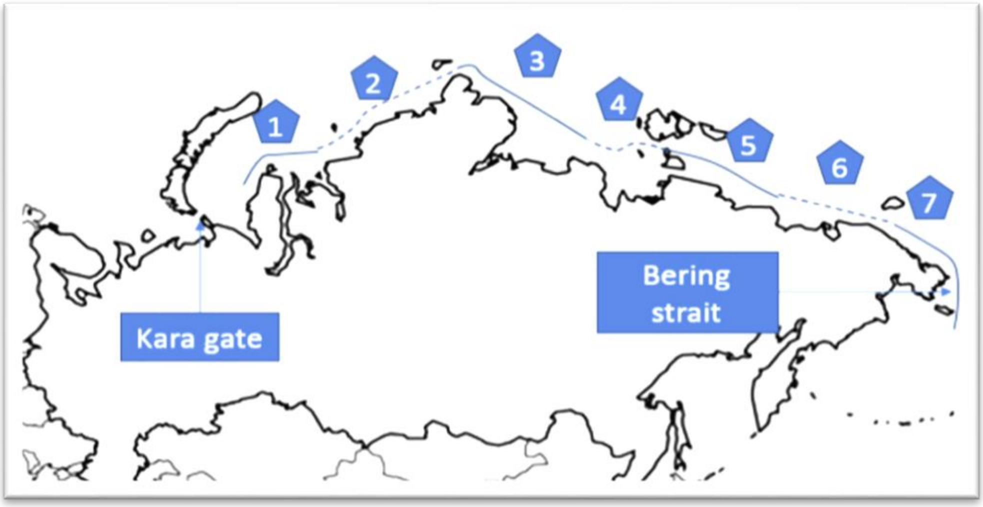


Figure 5.6: The seven Federal Tariff Service of Russia (FTSR) Arctic Zones.
(Source: Pierre and Olivier 2015)

Since 2009, the ice-breaking fees are now negotiable (Eger, 2010). It is impossible to obtain an accurate and reliable amount of fees for two similar vessels with the same tariff determinants. The NSR fees can be calculated based on the literature surveys as follows:

1) Beluga Fraternity ship that crossed the NSR in 2009. The gross tonnage for Beluga Fraternity is 9,611 and she paid fees of €60 000 ($ 67 688), which means $7.04USD per tonnage. Therefore, the NSR fee for the test case is $7.04 × 14357 GT (the Gross Tonnage of the test case ship) = **$101 113 USD**.
2) According to Falck (2012) from the Tschudi Shipping, he reported that the NSR fee should be $5 (USD/GT). The NSR fees for the test case would be $5 USD × 14357 GT = **$71 785 USD**.
3) Zeeshan (2014) mentioned that for the laden voyage the fee is $6.80 USD per tonne cargo loaded. Therefore, for the test case, the NSR fee is $6.80 × 14357 GT = **$97 672 USD**.

If these three rates are considered and used in this test case, the NSR fees for Routes 1, 2, and 3 would be the same amount (Route 4 is outside of the NSR boundaries, hence, not applicable), which is not a problem, but the reality is, each route is very different in terms of ice conditions. According to Stephenson *et al*., (2014), sea ice conditions tend to be more severe at higher latitudes. However, the coastal route of the NSR has been ice-free in summer in recent years. Therefore, the ice-breaking services are needed more in Routes 2 and 3 as compared to Route 1. For that reason, the NSR fees will be calculated by using the tariff table provided by the Russian government, which is:

4) Based on Order 45-t/1 of March 4, 2014 of the Federal Service for Tariffs "About The Approval of Tariffs for The Icebreaker Escorting of Ships Rendered by Fsue Rosatomflot in The Water Area of The Northern Sea Route".

This tariff will provide the maximum amount of the NSR fees for each designated route.

The gross tonnage of MV Yong Sheng is 14,357, and the period of navigation is in the summer-autumn season. Based on this information, Table 5.15 (from the Federal Service for Tariffs document) will be used for the test case as shown next:

Table 5.15: The tariff of the NSR for ships of gross tonnage 10 001 to 20 000 during the summer-autumn navigations

Tariffs during the summer-autumn period of navigation							
Ice class of ship	Tariff in Roubles for a unit of gross tonnage of ship						
	Escorting within 1 zone	Escorting within 2 zones	Escorting within 3 zones	Escorting within 4 zones	Escorting within 5 zones	Escorting within 6 zones	Escorting within 7 zones
None	71,495	85,794	100,093	114,392	128,691	142,990	142,990
Ice 1	50,046	60,056	70,065	80,074	90,083	100,093	100,093
Ice 2	46,472	55,766	65,060	74,355	83,649	92,943	92,943
Ice 3	42,897	51,476	60,056	68,635	77,214	85,794	85,794
Arc 4	35,747	42,897	50,046	57,196	64,345	71,495	71,495
Arc 5	35,390	42,468	49,546	56,624	63,702	70,780	70,780
Arc 6 – Arc 9	35,032	42,039	49,045	56,052	63,058	70,065	70,065

Before using this table, there is some information that needs to be gathered first. The ice class of ship used in this study is Arc 4 and by referring to Figure 5.6, it is assumed that Route 1 only needs two zones (Zones 2 and 4) for icebreaker escorting and Routes 2 and 3 will need escorting within three zones (Zones 2, 3, and 4). Thus, the NSR fees for each route are shown below. This assumption is based on Honneland (1997) and Brigham *et al*., (1999).

Route 1 – RUR (Russian Rubles) 428,97 × 14357 GT = RUR 6 158 722.29 = **$ 92 932 USD**

Route 2 and 3 – RUR 500,46 × 14357 GT = RUR 7 185 104 = **$ 108 420 USD**

Route 4 – there are no NSR fees, as this route is outside the NSR water boundary.

The exchange rate is 1 RUR = $ 0.016 USD as per 27th of August 2019

This calculation can be validated by using the online ice-breaking tariff provided by CHNL information office that can be accessed through http://www.arctic-lio.com/nsr_tariffsystem .

IX. Ice pilot fees

Ice pilot fees in the NSR water area are determined in accordance with legislation of the Russian Federation by taking into account the Gross Tonnage (GRT), ice class, distance of the escorting, and period of navigation (Balmasov, 2015). Nevertheless, official fees for ice pilotage have not been established yet (Balmasov, 2015). The captain of the vessel to be navigated in the NSR is required to have a certain time period of navigation experience (Furuichi and Otsuka, 2013). If the captain lacks this experience, the vessel must have two ice pilots on board while navigating the NSR area (Liu and Kronbak, 2010).

According to Furuchi and Otsuka (2013), the ice pilot fees were stipulated as 673 (USD/day) for the navigation between Kara and Bering straits (NSR region). Therefore, this rate will be used in this study. The only information needed is the distance of the escorting in the NSR region for all routes within the NSR. This is because the other requirements such as GRT, ice class, and period of navigation are fixed parameters for all routes. Because the fee is only charged in the NSR water boundary, so the distance in the NSR region for each route needs to be identified by subtracting it with the data (the distance outside the NSR region) provided by Mulherin (1996).

Route 1: 3048 nm – 525 nm = 2523 nm
Route 2: 2998 nm – 745 nm = 2253 nm
Route 3: 2892 nm – 830 nm = 2062 nm
Route 4 is outside of the NSR water boundary

Next, because the ice pilot fee is charged based on a daily basis, the journey time (number of days in the NSR) in the NSR water boundary can be calculated by using Equation 5.20. Then, the total NSR ice pilot fees for each route can be calculated by multiplying the journey time with the ice pilot fees per day (USD 673). Table 5.16 summarises the total ice pilot fees for each route.

Table 5.16: The ice pilot fees for each route within the NSR

Route	**Journey time (days) (in NSR water boundary)**	**Ice pilot fees per day**	**Total ice pilot fees (USD)**
Route 1	7.51	$673/day	5055
Route 2	6.71		4516
Route 3	6.14		4133
Route 4	This route is outside the NSR water boundary		

After all qualitative and quantitative criteria have been evaluated, there are a few modifications of sub-criteria and alternatives that need to be highlighted here. They are as follows:

- Depth of seas (SE) is taken out from this case study as it turns out to be a fixed parameter. This means, all seas in the NSR for each route are deep enough for any size of ship to navigate. Therefore, no comparison is needed.
- Route 4 (transpolar route) is not eligible at the moment because of the ice conditions. For now, it can only be accessed by highly qualified icebreaker ships. This means, a comparison cannot be made due to the different ships being used. Thus, it will not be included in this study. However, it is clear that Route 4 has a lot of potential to use for commercial shipping in the future because it is the shortest route and no NSR fee is required.

Therefore, the new hierarchical model of the most effective shipping route within the NSR is shown in Figure 5.7.

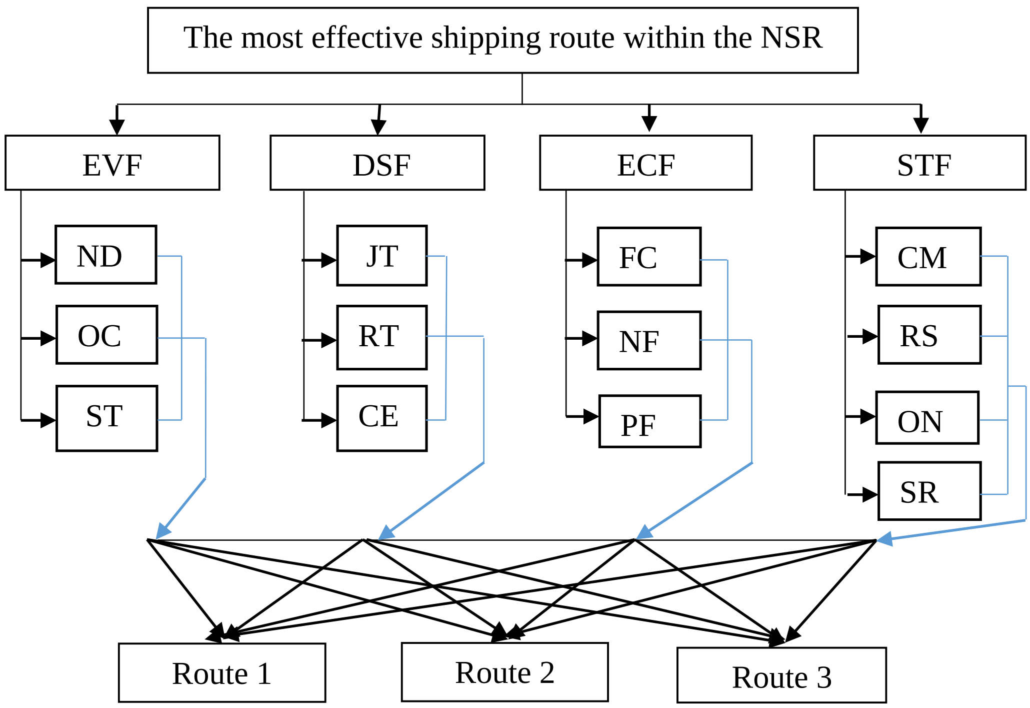


Figure 5.7: The final hierarchical model of selection of the most effective route within the NSR

Step 6*: Establishment of the weights of criteria by using pair-wise comparison approach of AHP*

There are 6 experts involved with the AHP questionnaire (see Appendix O) for expert's background). Referring to the three sub criteria of Distance factor as an example, a 3×3 pair-wise comparison matrix is developed for obtaining the weight of each of them. $A\ (J_T R_T C_E)$ is a matrix expressing the qualified judgement with regard to the relative priority of the Journey time (JT), Round trips (RT) and CO_2 emissions (CE).

Given the importance of the criterion JT to the criterion RT as an example in determining the average rating rate of the pair-wise comparison, the experts' scores are as shown in Table 5.17.

Table 5.17: The expert judgements score on the importance of JT over RT

	Expert A	**Expert B**	**Expert C**	**Expert D**	**Expert E**	**Expert F**
Importance of **JT** compare to **RT**	2	2	3	1	5	1

By using Equation 4.3 (geometric mean), the average rating value of the importance criterion JT to the criterion RT is 1.98 or 2 (Table 5.18). The same calculation technique is applied to all the qualitative data described previously. After obtaining the geometric mean rating values of the criteria, the values will be used for conducting the pair wise comparison matrix.

Table 5.18: The matrix values for criterion Distance factor

	JT	**RT**	**CE**
JT	1	2	1 1/7
RT	1/2	1	2/3
CE	7/8	1 1/2	1
Sum	**2.39**	**4.44**	**2.83**

The implementation of the pair wise comparison techniques involves the expert judgments for analysing the priority of each evaluation parameter to another by incorporating the ratio scale of pair-wise comparison. The same weight and CR calculations described in Step 3 and Step 4 of Section 4.2.1 (Chapter 4) are applied in this study.

The weight values of $A\ (J_T R_T C_E)$ are 0.427 (JT), 0.276 (RT) and 0.297 (CE). The *RI* score (Table 4.2) for three criteria is 0.52 and the CR value for the Distance factor criterion is 0.065. Apparently, the CR value is less than 0.10, therefore the degree of consistency in the pair-wise comparison is acceptable. In a similar way, the weight and consistency ratio values for all sub-criteria are calculated as follows:

i) Main Criteria

$A(E_{CF}E_{VF}S_{TF}D_{SF})$ =

	ECF	EVF	STF	DSF
ECF	1	3	1 1/3	1 3/5
EVF	1/3	1	1 2/9	2/5
STF	3/4	5/6	1	1
DSF	5/8	2 4/7	1	1
Sum	**2.74**	**7.32**	**4.59**	**3.92**

The weight values of $A\ (E_FV_FF_FA_F)$ are 0.3639 (EF), 0.1566 (VF), 0.2123 (FF) and 0.2671 (AF). While the CR value is 0.0572

ii) Environmental factors

$A\ (N_DO_CS_T)$ =

	ND	OC	ST
ND	1	5/6	3/5
OC	1 1/5	1	2 1/4
ST	1 2/3	4/9	1
Sum	**3.89**	**2.28**	**3.83**

The weight values of $A\ (N_DO_CS_T)$ are 0.2957 (ND), 0.4497 (OC) and 0.2544 (ST), while the CR value is 0.0580.

iii) Economic factors

$A\ (F_CN_FP_F)$ =

	FC	NF	PF
FC	1	1 1/2	3
NF	2/3	1	2 1/3
PF	1/3	3/7	1
Sum	**2.0030**	**2.9260**	**6.3131**

The weight values of $A\ (F_CN_FP_F)$ are 0.4948 (FC), 0.3477 (NF) and 0.1575 (PF), while the CR value is 0.0020.

iv) Safety factors

$A\ (C_MR_SO_NS_R)$ =

	CM	RS	ON	SR
CM	1	1 4/5	1 1/2	1 3/8
RS	5/9	1	2	1 2/3
ON	2/3	1/2	1	5/7
SR	5/7	3/5	1 2/5	1
Sum	**2.93**	**3.91**	**5.98**	**4.75**

The weight values of $A\ (C_MR_SO_NS_R)$ are 0.3415 (CM), 0.2827 (RS), 0.1654 (ON) and 0.2104 (SR), while the CR value is 0.0340.

***Step 7**: Construction of the ER calculation*

They are eight quantitative criteria and five qualitative criteria used in this study The eight quantitative criteria are; 1) The number of navigable days (ND), 2) Depth of straits (ST), 3) Journey time (JT), 4) The number of round trips, 5) CO2 emissions from ships (CE), 6) Fuel costs (FC), 7) The NSR fees (NF), and 8) Ice pilot fees (PF). The five qualitative criteria are 1) Operational conditions (OC), 2) Charting and monitoring (CM), 3) Radio and satellite communications and emergency response (RS), 4) Observational networks and weather forecast (ON) and Search and rescue facilities (SR). Before the basic ER algorithm can be applied, these quantitative criteria and qualitative criteria will be assessed accordingly as shown in the following section.

A. The transformation of the quantitative criteria

To aggregate all the initial information using the basic ER algorithm, the assessments on quantitative attributes need to be transformed into assessments using a common set of grades in the format of belief structures. Firstly, a region or a pair of best and worst values for each of the quantitative criteria needs to be specified initially. The worst and best values should be selected in such a way that the values of this attribute for all considered alternatives are in the specific range. Next, the best values is normally regarded to be equivalent to the most preferred grade and the worst corresponds to the least preferred. For instance, “Very Good” and “Very Poor”, respectively. Based on the quantitative criteria calculation shown in Step 5, the Very Poor and Very Good values for the eight numeric sub-criteria are set as shown in Table 5.19

Table 5.19: The best and worst values of criteria

Quantitative criteria	**Best value**	**Worst value**	**Measurement unit**
Journey time	8.61	9.07	days
The number of round trips	10.68	8.4	Round trips
CO_2 emission from ships	720.2073	759.0584	Kg/voyage
Fuel costs	72 686	76 569	$ USD
The NSR fees	92 932	108 420	$ USD
Ice Pilot fees	4132.22	5054.23	$ USD
Number of navigable days	146	110	days
Depth of straits	30	12.5	metres

For each of the other grades between *Very Poor* and *Very Good*, an equivalent values also needs to be identified by decision makers according to their judgement. The grades between the two extreme values are assumed to be evenly distributed. For instance, the value of the number of navigable days (*ND*) equivalent to *Very Poor* is 110 and to *Very Good* is 146; the values equivalent to Poor, Average and Good are calculated as follows:

$$Poor = h_{2,2} = Very\ Poor + \frac{Very\ Good - Very\ Poor}{4}$$

$$= 110 + \frac{146-110}{4} = 119$$

$$Average = h3,2 = \text{Very Poor} + \frac{2 \times (Very\ Good - Very\ Poor)}{4}$$

$$= 110 + \frac{2 \times (146-110)}{4} = 128$$

$$Good = h4,2 = \text{Very Poor} + \frac{3 \times (Very\ Good - Very\ poor)}{4}$$

$$= 110 + \frac{3 \times (146-110)}{4} = 137$$

The assessment grades for the other seven quantitative criteria are determined in a similar way. Decision makers may use other appropriate values to represent the grades if they prefer. Hence, the utilities of evaluation grades for *ND* are shown as:

$h_{1,1} = 110$, $h_{2,1} = 119$, $h_{3,1} = 128$, $h_{4,1} = 137$, $h_{5,1} = 146$

After the relationships between grades and numeric values are established, Equations 5.16-5.18 can directly be used to transform the numerical assessments into the assessments represented by a set of grades and associated belief degrees. For example, using the same sub-criteria, the value of *ND* for Route 2 is $h_1 = 141$ days. Since $h_{5,1} > h_1 > h_{4,1}$, then,

$S^1(141) = \{(h_{4,1}, \gamma_{4,1}), (h_{5,1}, \gamma_{5,1})\}$,

Where,

$$\gamma_{4,1} = \frac{h5,1 - h1}{h5,1 - h4,1} = \frac{146-141}{146-137} = 0.5555, \quad \gamma_{5,1} = 1 - \gamma_{4,1} = 0.4444$$

This assessment is transformed to the format of a belief structure as shown below and can be directly used in the ER aggregation algorithm.

(*Very Poor*, 0.0000), (*Poor*, 0.0000), (*Average*, 0.0000), (*Good*, 0.5555), (*Very Good*, 0.4444)

B. Assessment of qualitative criteria

The assessment can be conducted by comparing available knowledge about the performances of each route with the standards of each assessment grade. For example, for Route 1 on Operational Conditions, there is evidence showing that it has some Good conditions and some Average conditions. Therefore, the performance of Route 1 in terms of Operational Conditions is judged to be Good to a degree of 0.5 and Average to a degree of 0.5. Note that the total degree is equal to 1 (100%), which implies that the degree of completeness is 1 - 1 = 0. The assessment is represented by the set of belief degrees (0.0, 0.0, 0.5, 0.5, 0.0) as shown in Table 5.20 (Expert 4). The order of the belief degrees in the set is arranged to correspond to the other order of grades in the set (Very Poor, Poor, Average, Good, Very Good).

In addition, to accommodate the variations in information about the performance of an option, the variations in expert opinions can also be modelled and taken into account by using the belief degree set. For example, the five expert judgements are set as shown in Table 4.20 on Operational Conditions (OC) for Route 1. This means, every expert counts for 20% from the total of five expert judgements. Then, the assessment may be represented by the set of belief degrees (0.0, 0.14, 0.3, 0.34, 0.22). The assessment of the three routes for each of the qualitative sub-criteria are given in Appendix P.

Table 5.20: The expert judgements of Operational Condition (OC) for Route 1

	Very Poor	Poor	Average	Good	Very Good	**Total**
Expert 1	0	0.2	0.5	0.2	0.1	**1**
Expert 2	0	0.2	0.5	0.3	0	**1**
Expert 3	0	0	0	0	1	**1**
Expert 4	0	0	0.5	0.5	0	**1**
Expert 5	0	0.3	0	0.7	0	**1**
Belief degrees	**0**	**0.14**	**0.3**	**0.34**	**0.22**	**1**

The ER approach can also aggregate information with uncertainties. This means that all available information, whether known or partially known, can be used to support the decision making process, for example, by referring to the set of belief degrees for sub-criteria Search and rescue facilities (SR) in Appendix P, which is (0.0, 0.14, 0.2, 0.42, 0.2). Note that the total degree is less than 1, which implies that the degree of incompleteness in the assessment is 1 – 0.96 = 0.04.

C. **Aggregation of criteria**

In this study, the calculation and aggregation process is conducted using the Intelligent Decision System software (IDS) (Yang and Xu, 2005). However, for demonstration purposes, manual calculation of the ER algorithm will be shown next. Using Environmental factor (*EVF*) as an example, the detailed calculation for generating the assessment for *EVF* (*y*) by aggregating three sub-criteria, the number of navigable days (*ND*), Operational conditions (*OC*) and Depth of straits (*ST*) for Route 1, is shown in Table 5.21 and denoted by *e*1, *e*2 and *e*3 respectively.

Table 5.21: The degree of belief of Environmental Factor and its three sub-criteria

Degree of belief (*β*)		**Evaluation grade**				
		Very Poor	Poor	Average	Good	Very Good
Environmental factor (EVF)	The number of navigable days (ND)	0	0	0	0	1
	Operational conditions (OC)	0	0.14	0.3	0.34	0.22
	Depth of straits (ST)	1	0	0	0	0

Let $y = e_1 \oplus e_2 \oplus e_3$ where $\oplus$ denotes the aggregation of two criteria.

From Table 4.21 the values are:

$\beta_{1,1} = 0$, $\beta_{2,1} = 0$, $\beta_{3,1} = 0$, $\beta_{4,1} = 0$, $\beta_{5,1} = 1$

$\beta_{1,2} = 0$, $\beta_{2,2} = 0.14$, $\beta_{3,2} = 0.3$, $\beta_{4,2} = 0.34$, $\beta_{5,2} = 0.22$

$\beta_{1,3} = 1$, $\beta_{2,3} = 0$, $\beta_{3,3} = 0$, $\beta_{4,3} = 0$, $\beta_{5,3} = 0$.

$\beta_{5,1}$ indicates the number of navigable days (ND) with evaluation grade of 'Very Good', which has grade of '1' belief degree.

By using Equation 5.1, the belief degree values of ND, OC and ST are formed as follows:

S(*ND*) = {(*Very Poor*, 0.00), (*Poor*, 0.00), (*Average*, 0.00), (*Good*, 0.00), (*Very Good*, 1.00)}.

S(*OC*) = {(*Very Poor*, 0.00), (*Poor*, 0.14), (*Average*, 0.30), (*Good*, 0.34), (*Very Good*, 0.22)}.

S(*ST*) = {(*Very Poor*, 1.00), (*Poor*, 0.00), (*Average*, 0.00), (*Good*, 0.00), (*Very Good*, 0.00)}.

The weight values of *ND*, *OC* and *ST* as described in Section 5.6, Step 6 are as follows:

L = 3 and $\omega_{1(ND)}$ = 0.296, $\omega_{2(OC)}$ = 0.45 and $\omega_{3(ST)}$ = 0.254. From Equation 5.2, the basic probability masses $m_{n,i}$ are calculated as follows:

The $m_{n,i}$ of *ND* =

$m_{1,1}$ = 0.296 x 0 = 0.0, $m_{2,1}$ = 0.296 x 0 = 0.0, $m_{3,1}$ = 0.296 x 0 = 0.0, $m_{4,1}$ = 0.296 x 0 = 0.0, $m_{5,1}$ = 0.296 x 1 = 0.296

The $m_{n,i}$ of *OC* =

$m_{1,2}$ = 0.45 x 0 = 0.0, $m_{2,2}$ = 0.45 x 0.14 = 0.063, $m_{3,2}$ = 0.45 x 0.3 = 0.135, $m_{4,2}$ = 0.45 x 0.34 = 0.153, $m_{5,2}$ = 0.45 x 0.22 = 0.099

The $m_{n,i}$ of *ST* =

$m_{1,3}$ = 0.254 x 1 = 0.254, $m_{2,3}$ = 0.254 x 0 = 0.0, $m_{3,3}$ = 0.254 x 0 = 0.0, $m_{4,3}$ = 0.254 x 0 = 0.0, $m_{5,3}$ = 0.254 x 0 = 0.0

The $m_{H,i}$, $\bar{m}_{H,i}$ and $\tilde{m}_{H,i}$ values for each criteria are calculated by using Equations 5.3, 5.4 and 5.5 respectively. These calculations are shown as follows:

$m_{H,1}$ = 1 – 0.296 = 0.704

$\bar{m}_{H,1}$ = 0.296 [1 – (0+0+0+0+1)] = 0.0

$\tilde{m}_{H,1}$ = 1 – (0+0+0+0+0.296) = 0.704

$m_{H,2}$ = 1 – 0.45 = 0.55

$\bar{m}_{H,2}$ = 0.45 [1 – (0+0.14+0.3+0.34+0.22)] = 0.0

$\tilde{m}_{H,2}$ = 1 – (0+0.063+0.135+0.153+0.099) = 0.55

$m_{H,3}$ = 1 – 0.254 = 0.746

$\bar{m}_{H,3}$ = 0.254 [1 – (1+0+0+0+0)] = 0.0

$\tilde{m}_{H,3}$ = 1 – (0.254+0+0+0+0) = 0.746

Equation 5.8 is now applied to calculate the normalised factor (K). Let K = $K_{I(2)}$ Let $m_{n,I(1)}$ = $m_{n,1}$ for n = 1, …, 5. First, the aggregation is between the ND and OC expressed as follows:

$$K_{I(2)} = \left\{1 - \begin{pmatrix} m_{1,1}m_{2,2} + m_{1,1}m_{3,2} + m_{1,1}m_{4,2} + m_{1,1}m_{5,2} + \\ m_{2,1}m_{1,2} + m_{2,1}m_{3,2} + m_{2,1}m_{4,2} + m_{2,1}m_{5,2} + \\ m_{3,1}m_{1,2} + m_{3,1}m_{2,2} + m_{3,1}m_{4,2} + m_{3,1}m_{5,2} + \\ m_{4,1}m_{1,2} + m_{4,1}m_{2,2} + m_{4,1}m_{3,2} + m_{4,1}m_{5,2} + \\ m_{5,1}m_{1,2} + m_{5,1}m_{2,2} + m_{5,1}m_{3,2} + m_{5,1}m_{4,2} \end{pmatrix}\right\}^{-1}$$

$$K_{I(2)} = \left\{1 - \begin{pmatrix} 0 + 0 + 0 + 0 + \\ 0 + 0 + 0 + 0 + \\ 0 + 0 + 0 + 0 + \\ 0 + 0 + 0 + 0 + \\ 0 + 0.0186 + 0.0399 + 0.0453 \end{pmatrix}\right\}^{-1}$$

$K_{I(2)} = \{1 - (0.1039)\}^{-1}$

$K_{I(2)} = 1.1159$

Next, the normalised factor $K_{I(2)}$ can be calculated using Equation 5.9 and shown as follows:

$m_{1,I(2)} = K_{I(2)}(m_{1,1}m_{1,2} + m_{1,1}m_{H,2} + m_{H,1}m_{1,2})$ = 1.1159 (0+0+0) = 0.0

$m_{2,I(2)} = K_{I(2)}(m_{2,1}m_{2,2} + m_{2,1}m_{H,2} + m_{H,1}m_{2,2})$ = 1.1159 (0+0+0.0443) = 0.0495

$m_{3,I(2)} = K_{I(2)}(m_{3,1}m_{3,2} + m_{3,1}m_{H,2} + m_{H,1}m_{3,2})$ = 1.1159 (0+0+0.0950) = 0.1061

$m_{4,I(2)} = K_{I(2)}(m_{4,1}m_{4,2} + m_{4,1}m_{H,2} + m_{H,1}m_{4,2})$ = 1.1159 (0+0+0.1077) = 0.1202

$m_{5,I(2)} = K_{I(2)}(m_{5,1}m_{5,2} + m_{5,1}m_{H,2} + m_{H,1}m_{5,2})$ = 1.1159 (0.0293+0.1628+00697) = 0.2921

Let $\tilde{m}_{H,I(2)} = \tilde{m}_{H,i}$ and the normalisation of the probability $\tilde{m}_{H,I(2)}$ is calculated by using Equation 5.10 as follows:

$\tilde{m}_{H,I(2)} = K_{I(2)}(\tilde{m}_{H,1}\tilde{m}_{H,2} + \bar{m}_{H,1}\tilde{m}_{H,2} + \tilde{m}_{H,1}\bar{m}_{H,2})$ = 1.1159 (0+0+0) = 0.0

Let $\bar{m}_{H,I(2)} = \bar{m}_{H,i}$ and the normalisation of the probability $\bar{m}_{H,I(2)}$ is calculated by using Equations 5.11 and 5.12 as follows:

$\bar{m}_{H,I(2)} = K_{I(2)}\bar{m}_{H,1}\bar{m}_{H,2}$ = 1.1159 x 0.704 x 0.55 = 0.4321

$m_{H,I(2)} = \bar{m}_{H,I(2)} + \tilde{m}_{H,I(2)} = 0.4321 + 0$ = 0.4321

By using the similar calculation techniques, now the results for *ND* and *OC* are combined with *ST* to complete the aggregation for all three sub-criteria.

$$K_{I(3)} = \left\{ 1 - \begin{pmatrix} m_{1,I(2)}m_{2,3} + m_{1,I(2)}m_{3,3} + m_{1,I(2)}m_{4,3} + m_{1,I(2)}m_{5,3} + \\ m_{2,I(2)}m_{1,3} + m_{2,I(2)}m_{3,3} + m_{2,I(2)}m_{4,3} + m_{2,I(2)}m_{53} + \\ m_{3,I(2)}m_{1,3} + m_{3,I(2)}m_{2,3} + m_{3,I(2)}m_{4,3} + m_{3,I(2)}m_{5,3} + \\ m_{4,I(2)}m_{1,3} + m_{4,I(2)}m_{2,3} + m_{4,I(2)}m_{3,3} + m_{4,I(2)}m_{5,3} + \\ m_{5,I(2)}m_{1,3} + m_{5,I(2)}m_{2,3} + m_{5,I(2)}m_{3,3} + m_{5,I(2)}m_{4,3} \end{pmatrix} \right\}^{-1}$$

$$K_{I(3)} = \left\{ 1 - \begin{pmatrix} 0 + 0 + 0 + 0 + \\ 0.0126 + 0 + 0 + 0 + \\ 0.0269 + 0 + 0 + 0 + \\ 0.0305 + 0 + 0 + 0 + \\ 0.0742 + 0 + 0 + 0 \end{pmatrix} \right\}^{-1}$$

$K_{I(3)}$ = $\{1 - (0.1442)\}^{-1}$

$K_{I(3)}$ = 1.1685

$m_{1,I(3)}$ = $K_{I(3)}(m_{1,I(2)}m_{1,3} + m_{1,I(2)}m_{H,3} + m_{H,I(2)}m_{1,3})$ = 1.1685 (0+0+0.1098) = 0.1283

$m_{2,I(3)}$ = $K_{I(3)}(m_{2,I(2)}m_{2,3} + m_{2,I(2)}m_{H,3} + m_{H,I(2)}m_{2,3})$ = 1.1685 (0+0.0369+0) = 0.0431

$m_{3,I(3)}$ = $K_{I(3)}(m_{3,I(2)}m_{3,3} + m_{3,I(2)}m_{H,3} + m_{H,I(2)}m_{3,3})$ = 1.1685 (0+0.0792+0) = 0.0925

$m_{4,I(3)}$ = $K_{I(3)}(m_{4,I(2)}m_{4,3} + m_{4,I(2)}m_{H,3} + m_{H,I(2)}m_{4,3})$ = 1.1685 (0+0.0897+0) = 0.1048

$m_{5,I(3)}$ = $K_{I(3)}(m_{5,I(2)}m_{5,3} + m_{5,I(2)}m_{H,3} + m_{H,I(2)}m_{5,3})$ = 1.1685 (0+0.2179+0) = 0.2546

$\tilde{m}_{H,I(3)}$= $K_{I(3)}(\tilde{m}_{H,I(2)}\tilde{m}_{H,3} + \bar{m}_{H,I(2)}\tilde{m}_{H,3} + \tilde{m}_{H,I(2)}\bar{m}_{H,3})$ = 1.1685 (0+0+0.0580) = 0.0678

$\bar{m}_{H,I(3)}$ = $K_{I(3)}\bar{m}_{H,I(2)}\bar{m}_{H,3}$ = 1.1685 x 0.4321 x 0.746 = 0.3767

From Equations 5.13 and 5.14, the combined degrees of belief are calculated by:

$\beta_n = \frac{m_{n,I(3)}}{1 - \bar{m}_{H,I(3)}}$ = 0,   n = 1,2

$\beta_1 = \frac{m_{1,I(3)}}{1 - \bar{m}_{H,I(3)}} = \frac{0.1283}{0.6233}$ = 0.2058

$\beta_2 = \frac{m_{2,I(3)}}{1 - \bar{m}_{H,I(3)}} = \frac{0.0431}{0.6233}$ = 0.0692

$\beta_3 = \frac{m_{3,I(3)}}{1 - \bar{m}_{H,I(3)}} = \frac{0.0925}{0.6233} = 0.1484$

$\beta_4 = \frac{m_{4,I(3)}}{1 - \bar{m}_{H,I(3)}} = \frac{0.1048}{0.6233}$ = 0.1681

$\beta_5 = \frac{m_{5,I(3)}}{1 - \bar{m}_{H,I(3)}} = \frac{0.2546}{0.6233}$ = 0.4085

The assessment for Environmental Factor (*EVF*) by aggregating sub-criteria, the Number of Navigable Days (*ND*), Operational Conditions (*OC*) and the Depths of straits (*ST*), is therefore given by following distribution:

$S(EVF) = S\,(ND \oplus OC \oplus ST)$

= {(*very poor*, 0.2058), (*poor*, 0.0692), (*average*, 0.1484), (*good*, 0.1681), (*very good*, 0.4085)}.

The calculation and aggregation process can also be computed using the Intelligent Decision System Software (IDS). Figure 5.8 shows the aggregating values for Route 1 on Environmental Factor which tallies with the manual calculation demonstration. For the rest of the criteria, the IDS will be used to aggregate the criteria.

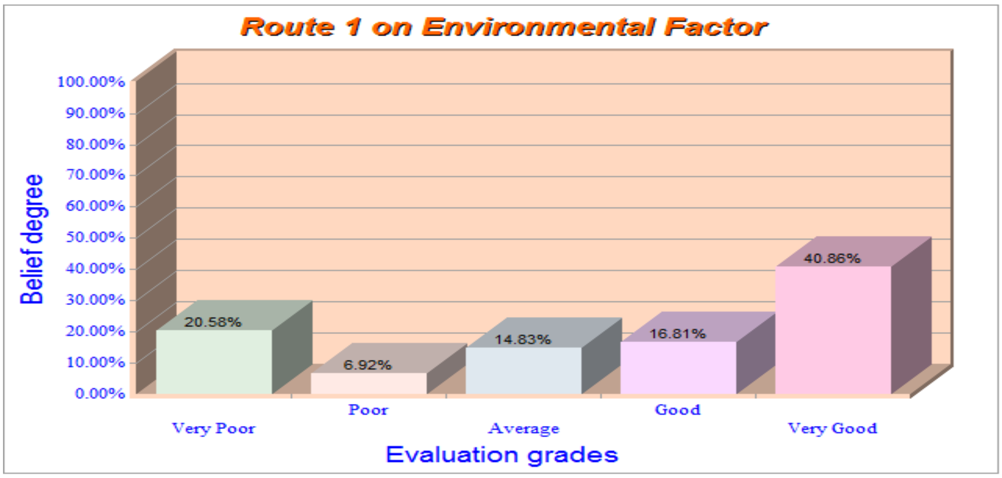


Figure 5.8: The evaluation grades for Route 1 on Environmental Factor

Figure 5.8 shows the evaluation grades for Route 1 on Environmental factor (EVF) in regards to three evaluation sub-criteria namely the number of navigable days (ND), operational conditions (OC) and the depth of straits (ST). It shows that Route 1 has 40.86% of "Very Good" grade which is the highest compared to other grades.

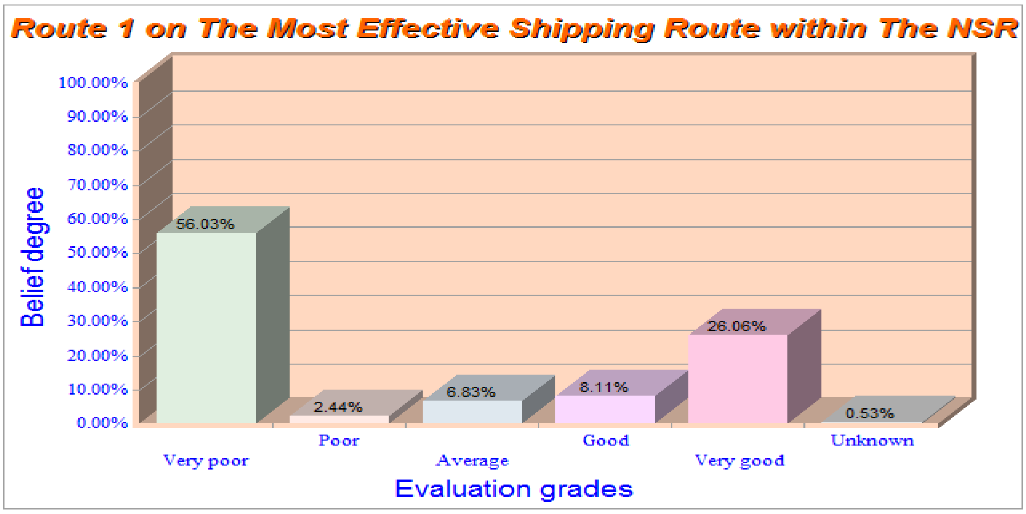


Figure 5.9: The total of belief degree values of Route 1

Figure 5.9 shows the total belief degree values of Route 1. The values are obtained by combining all belief degree values of main criteria (Environmental factor (EVF), Distance factor (DSF), Economic factor (ECF) and Safety factor (STF) using IDS software. The evaluation grade "Very Poor" has the highest belief degree value with 56.03%. It is followed by the evaluation grades "Very Good", "Good", "Average" and "Poor".

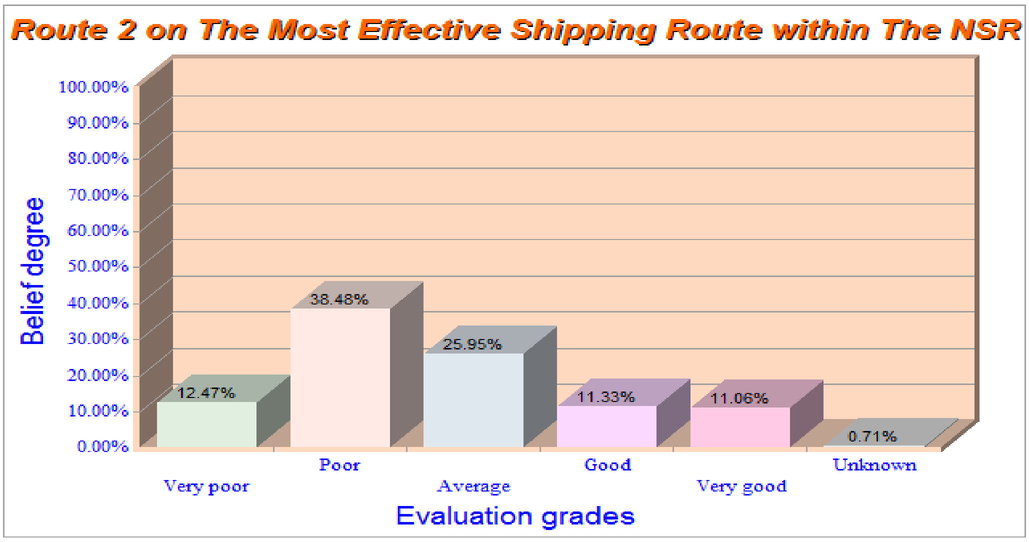


Figure 5.10: The total of belief degree values of Route 2

The alternative "Route 2" is given 38.48% of the belief degree value of the evaluation grade "Poor" which is the highest compared to the others (Figure 4.10) and the lowest belief degree value is 11.06% with evaluation grade "Very Good". The unknown information is given at 0.71%.

For Route 3 (Figure 5.11), the highest belief degree value is 56.47% associated with the evaluation grade "Very Good". The unknown belief degree value is at 0.67%.

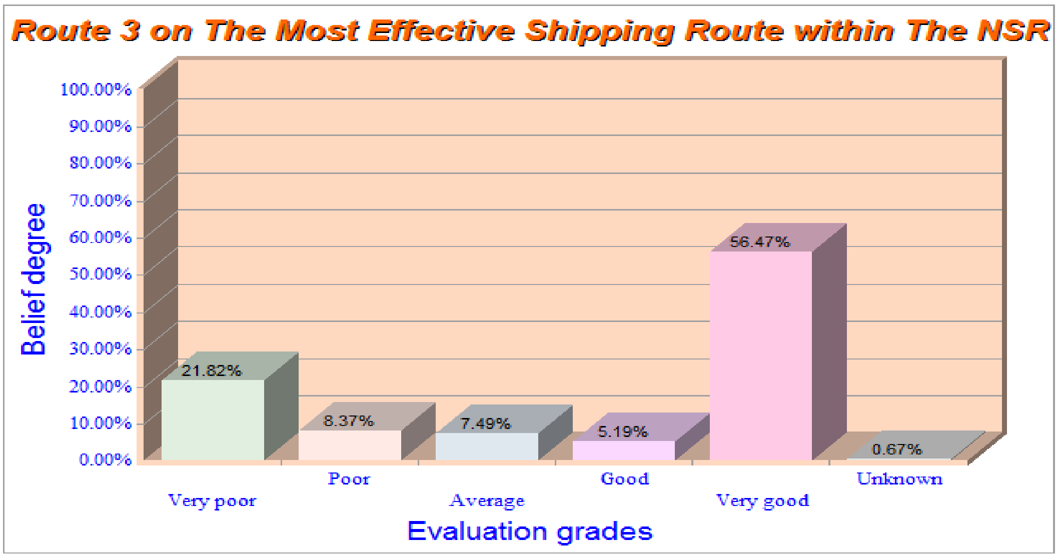


Figure 5.11: The total of belief degree values of Route 3

Finally, the three alternatives are ranked in determining the most effective shipping transit route within the NSR. To construct such a rank, a utility concept is used in this study and a set of utility values is given to the evaluation grades of the parent (the most effective shipping transit route within the NSR) as follows: {(Most Effective, 1.00), (Reasonably Effective, 0.75), (Average, 0.5), (Reasonably Ineffective, 0.25) and (Ineffective, 0.0). by using the belief degree values as described in Figure 4.9. For the alternative "Route 1", the assessment value of this alternative is computed as follows:

Very poor	:	56.03% x 0.0	= 0.0000
Poor	:	2.44% x 0.25	= 0.0061
Average	:	6.83% x 0.5	= 0.0342
Good	:	8.11% x 0.75	= 0.0608
Very good	:	26.06% x 1.0	= 0.2606
Total	:		**0. 3617**

The assessment value of the alternative "Route 1" is known to be 36.17%. A similar calculation technique is applied for determining the assessment values of the alternative "Route 2" and "Route 3". Figure 5.12 summarises the assessment values associated with the ranking of all alternatives in selecting the most effective shipping transit route within the NSR. The alternative "Route 3" is ranked in first place (0.6620) followed by the alternative "Route 2" in the second place (0.4215) and the alternative "Route 1" in last place with 0.3617 assessment score.

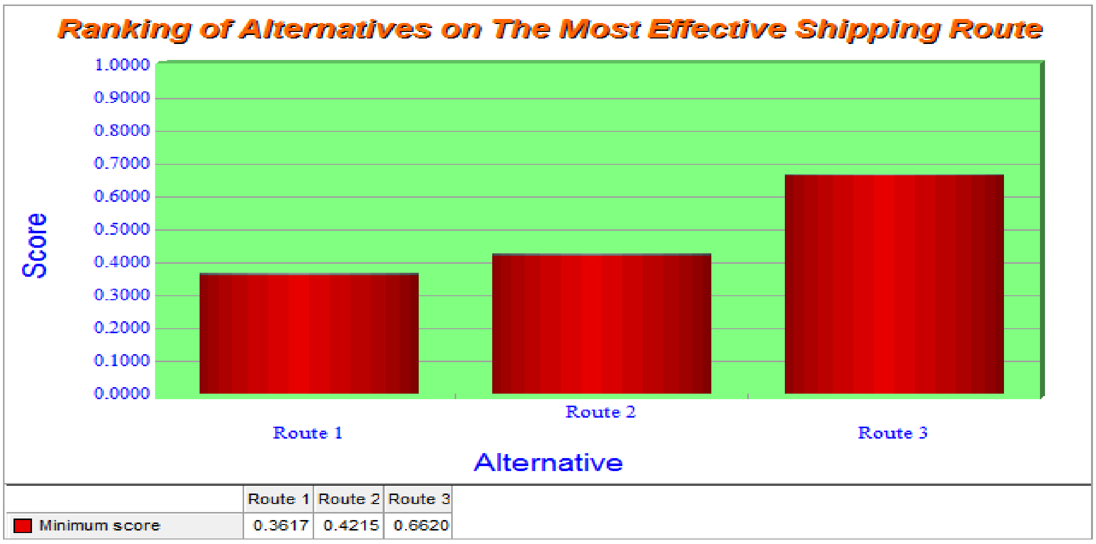


Figure 5.12: The ranking of alternatives on the most effective shipping route within the NSR

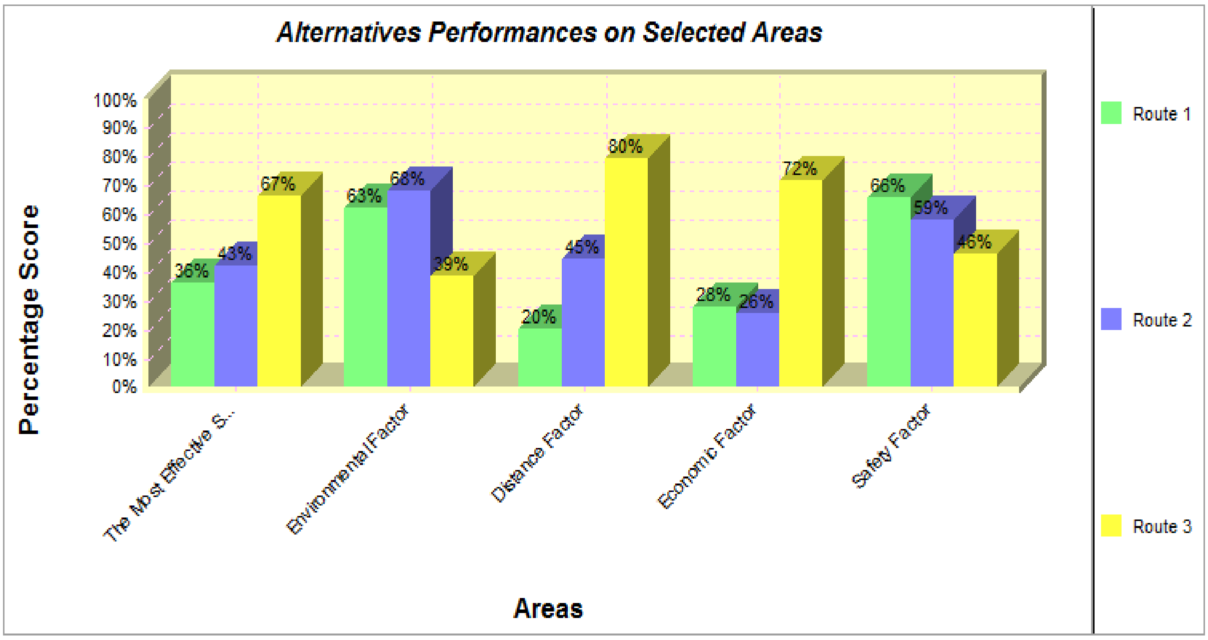


Figure 5.13: The alternatives' performances on each criteria

It is also important for decision makers to have more information regarding the performance for each alternative on each criteria used in this study. Figure 5.13 shows the alternatives' (Routes 1, 2 and 3) performances on each criteria (*EVF*, *DSF*, *ECF* and *STF*). Route 1 is shown in green, Route 2 is in blue and Route 3 is in yellow.

In terms of Environmental factor, Route 2 is ranked as first place with 68% of total score, followed by Route 1 which is only slightly lower with 63%. Route 3 has scored the lowest percentage with 39%. However, Route 3 has shown an outstanding performance and ranked as first on the criteria of Distance factor and Economic factor with 80% and 72% score respectively. Route 2 has scored 45% on Distance factor and Route 1 has scored the lowest with 20% of belief degree. In terms of Economic factor, Route 1 is ranked as second with 28% of score, followed closely by 26% of score for alternative Route 2.

For Safety factor, Route 1 is the safest with 66% of percentage score, followed by Route 2 (59%) and Route 3 (46%).

Step 8: Sensitivity analysis

The sensitive analysis was used to test the logicality of the analysis result delivery. Table 5.22 shows a sensitivity analysis for 30% increase in weight values. As previously mentioned, the calculation was done one at a time, for example, when weight value of EVF increased by 30% (the difference between new and original weight value was divided equally to other criteria, so that the total weight values of all criteria equalled to 1), the scores of the alternatives (recalculated by using IDS) were R1= 0.3771, R2 = 0.4364 and R3 = 0.6457. This means that the ranking of the alternatives remained the same. The observation was the same for other criteria, in which there was no change in ranking between the alternatives. However, the objective of a sensitivity analysis was to ascertain if the model output responds appropriately to changes in the model input, which is certainly shown in Table 5.22.

Table 5.22. Sensitivity analysis of main criteria increased by 30% of weight values

Main Criteria	**Original weight**	**EVF 30%**	**DSF 30%**	**ECF 30%**	**STF 30%**
EVF	15.7	20.41	13.03	12.06	13.58
DSF	26.7	25.13	34.71	23.06	24.58
ECF	36.4	34.83	33.73	47.31	34.28
STF	21.2	19.63	18.53	17.56	27.56
	Score of the alternatives				
	R1	**R1**	**R1**	**R1**	**R1**
	0.3617	0.3771	0.3279	0.3306	0.3891
	R2	**R2**	**R2**	**R2**	**R2**
	0.4215	0.4364	0.4200	0.3744	0.4323
	R3	**R3**	**R3**	**R3**	**R3**
	0.6620	0.6457	0.6917	0.6872	0.6424

One important point to mention was that the changes of ranking could occur, especially between Route 1 and Route 2 only when the weight values of safety criteria (STF) was increasing by not less than 100%. With 100% weight increase of STF (the criteria that performed the best by Route 1 as compared to the other alternatives) the final scored were 0.4633 (Route 1), 0.4621 (Route 2) and 0.5585 (Route 3).

Appendix Q shows the sensitivity analysis with 10% and 20% increase in weightage values for the main criteria.

5.6 Conclusions

A set of four structural performance criteria has been conceptualised and mentioned in this study for developing a comprehensive structural assessment framework. These criteria were hierarchically aggregated, through the use of an ER approach. Such an approach has been used to aggregate the assessment criteria and rank the three alternatives respectively. Besides, this study has demonstrated the application of powerful decision analysis methods, namely AHP and Utility theory techniques. The qualitative data of this study was fully obtained from expert judgements and the quantitative data were obtained from the past literature and through calculations.

The result shows that Route 3 as the best route within the NSR. However, through ER approach, the performance for each alternatives can be analysed as well. For example, Route 1 as the lowest ranking between three routes has scored better in terms of safety compared to other alternatives. On the other hand, Route 2 has proven the best in environmental factor. Route 3 as the best alternatives has outperform the other routes in distance and economic factor. Meaning that, the decision maker does not necessarily have to choose Route 3 as their final option. They can choose Route 1 which is the safest route. Having said that, ER approach has ranked the Route 3 as the best alternatives which taking into account all evaluated criteria. The results produced by the decision-making technique in this chapter are capable of assisting shipping companies in making rational decisions in choosing the most effective shipping transit route within the NSR.

CHAPTER 6:

SELECTION OF THE BEST SHIPPING TRANSIT ROUTE BETWEEN THE FAR EAST AND NORTHWEST EUROPE BY USING A TOPSIS METHOD

Summary

The NSR has for long attracted interest from observers and shipping companies because of its shorter distances, especially between the Far East and Northwest Europe. Thus, many studies have analysed the economic potential of the NSR, as well as the comparison of transport cost components between the NSR and the Suez Canal Route (SCR). This project also includes qualitative factors such as safety and service factor which were not used by previous studies. In dealing with a multiple-criteria decision making problem, the TOPSIS method was employed. The AHP technique was used again to find the weight for each criterion. Two case studies were conducted which are for liner services and tramp services. The results of TOPSIS analysis will demonstrate the best shipping transit route between the Far East and Northwest Europe.

6.1 Introduction

Shipping lanes or maritime transport routes are a substantial strategic part of the maritime transport system. A maritime route is a passage over the sea that connects the two different geographical points, where the land transport is incompetent to provide an efficient and effective means of transportation. Maritime routes follow a defined way of voyage and are subject to certain geographical, natural and political limitations (Rodrigue *et al*., 2009). Nevertheless, the international shipping industry is responsible for the carriage of around 80% of world trade (UNCTAD, 2017).

Shipping is the life blood of the global economy. Without shipping, intercontinental trade, the bulk transport of raw materials, and the import/export of affordable food and manufactured goods would simply not be possible. Currently, the seaborne trade between Europe and Far East is carried through the traditional route of Suez Canal and Cape of Good Hope; thus, an emerging alternative that can connect these two markets is the Northern Sea Route (NSR).

This chapter aims to analyse the best shipping transit route from the Far East to Northwest Europe. The previous chapter (Chapter 5) has identified the best route of the NSR.

This route (Route 3 of the NSR) will be used to compare with the SCR and other conventional routes. A multi-criteria decision making (MCDM) approach will be used to achieve this objective. There are several types of MCDM methods such as 1) analytic hierarchy process (AHP), 2) analytical network process (ANP), 3) elimination and choice expressing reality (ELECTRE) and 4) multi-attribute utility theory (MAUT) (Rolander *et al.,* 2003: Gade and Osuri, 2014). The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was chosen in this study, and the reason for choosing this method will be further explained in Section 6.3.

6.2 Literature review

Several research projects that tried to evaluate the technical and economic feasibility of developing international commercial shipping in the NSR even before climate change effects were widely discussed (Lassere, 2014). This is because, Russia, for the first time have allowed their Arctic route to be open for foreign shipping. In addition, especially after the 1930s, the USSR had developed a series of active commercial ports and a busy seaway along the NSR that rested on the escort of many powerful nuclear and diesel icebreakers (Ragner, 2008). Besides Wergeland's (1991, 1992) and Mulherin (1996) which assessed the business potential of the NSR, some research programmes have been carried out since the early 1990s as listed by Lassere (2014). These research programmes are INSROP (1993–1999, mainly funded by Japan, Norway and Russia which study the Northern Sea Route); Ice Routes - The Application of Advanced Technologies to the Routing of Ships through Sea Ice (1997–1998, European Union); ARCDEV – Arctic Demonstration and Exploratory Voyages (1997–1999, European Union, studying the western Russian Arctic seas); ARCOP – Arctic Operational Platform (2002–2006, European Union, studying the NSR); Northern Maritime Corridor (2002–2005, European Union, Norway and Russia, studying the North, Barents and Kara Seas); JANSROP (2002–2005, Japan, studying the NSR); and AMSA – Arctic Marine Shipping Assessment (2006–2008, initiated by the Arctic Council, considering the whole Arctic). Therefore, these research emphasised the NSR as a potential transit route and gateway to Russian resources

Lasserre (2014) conducted a full literature survey on Arctic route (NWP, TPP and NSR) by accumulating twenty-six simulations from 1991 until 2013. He tried to find the parameters used to calculate the profitability of the routes compared (NSR, NWP, and SCR) for the container sector. Therefore, this research builds on the work from Lasserre, but focuses on the NSR. Therefore, only seventeen surveys adopted from Lasserre's surveys and thirteen more surveys are added for review in this study. The thirteen added literature surveys (see Appendix R for summary of the research) are from Ramsland (1999), Kamesaki *et al*. (1999) Omre (2012), Ueta and Goda (2012), Otsuka and Furuichi (2013), Furuichi and Otsuka (2013), Raza and Schoyen (2014), HSVA (2014), Lassere (2014), Chang *et al*., (2015), Moon *et al*., (2015), Zhang *et al.* (2016) and Faury and Cariou (2016). Thus, in this section, Lasserre's work will be reviewed and compared with the added surveys to see the similarities and differences between all models.

Thirty simulations were identified and analysed: ten articles from journals; eight technical reports; three book chapters; six conference communications and three Master's Degree theses. They were published between 1991 and 2015, but twenty were published in or after 2009 (first international ship using the NSR), attesting to the renewed interest in Arctic shipping in the climate changing context. Only two theses tackle destination traffic (i.e., shipping going to/from the Arctic for the exploitation of natural resources (Juurma, 2006; Falck, 2012), while the twenty-five others are interested in transit shipping. The majority display the study of container traffic (10); seven address bulk shipping (LNG, tanker, dry bulk), three are interested in general cargo, seven studies address the mixture of container and general cargo and bulk shipping. Three studies did not consider ice-class vessels; seven simulated an ice-class vessel without specifying which class. Conversely, this study only focuses on the NSR and does not include other Arctic routes such as the NWP or the Transpolar Passage (TPP).

Basically, almost all studies looked at the profitability of shipping in the NSR except for one (HSVA, 2014), which only aimed to calculate travelling time, fuel consumption and gas emission for various ship types and ice conditions in the NSR. For all studies, when they established comparisons, the articles compared the NSR with the Suez Canal Route (SCR) (22 articles), Panama (3), the Trans-Siberian rail link (2), pipeline (1) and one article (Moon, *et al*., 2015) which came out with combinations of sea route and rail link with six (6) routes in total. Three articles did not compare the NSR with any other routes. A study by HSVA (2014) has a different objective, which is to understand the impact of shipping in the Arctic area by focusing on the fuel consumption of different ship types and exhaust emissions in relation to fuel consumption data. The analysis of this particular study can be found in Section 5.2 of Chapter 5. Therefore, no further analysis will be conducted on this study by HSVA. However, it is important to mention that from the study by HSVA, the parameters found are that different types of ships have different fuel consumption rates, speed and ice breaking capability. Thus it will also influence the amount of gas emitted from the ship.

Lasserre (2014) reported that fuel costs are the largest single cost factor according to all simulations in his study. The trend is also the same for the added literature surveys. For instance, the fuel costs vary: 55% (Furuichi and Otsuka, 2013), 63% (Chang, 2015) and 49% (Lasserre, 2014). However, Raza and Schoyen (2014) showed that the fuel cost makes the second largest cost component after the chartering cost. It also should be noted that Raza and Schoyen, (2014) considered using chartering cost in contrast to other studies that focus on capital cost.

The average cruise speed of a commercial ship differs widely depending on the model. Lasserre (2014) reported that, for year-round navigation, 3 models suggest an average speed between 7 and 11 knots (kts); 6 consider the average speed will be between 11 and 13 kts; two opt for an average speed between 13 and 15 kts, and one bets on an average speed of 17 kts (Verny and Grigentin, 2009). For summer shipping, two studies use an average speed slower than 10 kts; two consider the speed between 11 and 12.9 kts; three between 13 and 15 kts, and 4 above 15 kts (up to 25,8 kts with Hua *et al*., 2011 and 26 kts with Cho 2012). The updated literature also shows the same situation, for year-round navigation a study by Ramsland (1999) suggests between 6-14 kts. For summer transit, Omre (2012) suggested 10 kts, Ueta and Goda (2012) -15 kts, Otsuka and Furuichi (2013) - 13.1 kts, Furuichi and Otsuka (2013) -14.1 kts, Raza and Schoyen (2014), consider between 12 kts for ice water and 19.5 kts for open water. A study by HSVA (2014) used various types of ships and considered 6 to16 kts (they considered these 4 months in their study; April, July, September, and November). Lasserre (2014) consider an average of 14 knots on summer shipping, Chang *et al.*, (2015) suggest an average between 8 and 14 kts (depending on the region within the NSR) and Moon *et al.*, (2015) surprisingly suggested 20 knots. The similarity between these models is that the year-round transit tends to have a lower average speed as compared with the summer shipping. Nevertheless, it is debatable whether commercial ships can achieve an average speed greater than 15 knots because of drifting ice, fog and other environmental obstacles that still exist in current conditions in the NSR (Lassere, 2014).

The estimates for the increased capital cost for the construction of an ice-class ship vary widely too. Table 6.1 displays the range of values for capital cost premium for an ice-class commercial ship, with a similar capacity as the benchmark vessel, set forth among the models.

Table 6.1 Estimates of capital cost premium for a commercial ice-class ship depending on the class, from the selected simulations. (Adopted and edited from Lasserre (2014))

Authors	**Ice class category considered**	**Capital cost premium (%)**
Griffiths (2005), Mejlaender-Larsen (2009), Wergeland (2013)	Ice class’’	+10–35
Liu and Kronbak (2010)	1B	+20
Mulherin *et al*., (1996), Kamesaki (1999), Kitagawa (2001)	PC7	+20–36
Otsuka and Furuichi (2013)	PC7	+10
Mulherin *et al*., (1996), Schøyen and Bråthen (2011)	PC7 to PC4	+20
Mulherin *et al*., (1996); Dvorak (2009)	PC6	+1–20
DNV (2010)	PC4	+30
DNV (2010)	PC4 and DAS	+120
Dvorak (2009)	PC3	+6
Somanathan *et al*., (2007, 2009)	PC2	+30
Srinath (2010)	PC2	+40
Chernova and Volkov (2010)	DAS/ high ice class	+30–40

Most studies include the canal fees or icebreaker tariffs in their study except two which are reported by Lasserre (2014). One study (Hua *et al*., 2011) considers that there will be no NSR fees, which is a daring assumption given that Russia intends to use the NSR toll precisely to finance the maintenance of its Arctic icebreaker fleet and Cho (2012) does not compute NSR fees into the calculations. It is also noticeable that all models do not use the tariff table provided by the Russian authority as their references. Most models use a tariff rate provided from the real ships that have sailed across the NSR before (Falck, 2012).

Lasserre (2014) also pointed out that, eight models rest on the same cost structure for the crew, assuming wages and advantages are similar as crews operating along classic routes, whereas 7 mention that there definitely is a need for a well-trained crew for Arctic shipping. This means that they either imply, or explicitly mention crew costs are higher: experienced crew command a higher salary if the employer wants to make sure the firm will retain their services. Other models do not mention crew cost structure issues. For the case of 10 updated studies, only Chang (2015) did not include crew costs in his study.

Insurance premiums are also the object of a wide range of estimates for all models. Lassere (2014) made a comprehensive analysis on the insurance premium subject for his selected simulations, which is similar to the additional simulations. Three models rely on no insurance premiums. One (Raza and Schoyen, 2014) mentioned that no extra charge for Protection and Indemnity (P&I) insurance premium but only added hull and machinery (H&M) insurance and insurance for increased value (IV) for the NSR shipping. Otsuka and Furuichi (2013) quote 120 thousand USD/year including both P&I and H&M insurance. Lasserre (2014) opted for 800 thousand USD/year and a 50% premium, while Omre (2012) at 1%/year of capital cost. Interestingly, Furuichi and Otsuka (2013) assumed 0.343%/year of the ship building cost and an additional 10 USD/GT/year for P&I and H&M insurance premium. Apart from that, they also include Aden Emergency Charge at 40 USD/TEU for the SCR which is the only study that considers that. Noticeably, such a wide range of cost estimates underline the degree of uncertainty these models have to cope with.

Given all the parameters involved, 18 models conclude that Arctic routes can be profitable for commercial shipping in the short term, and 8 conclude conditions are difficult for a profitable exploitation of these routes (see Tables 6.2 and 6.3). One study (Lasserre, 2014) concludes that the NSR can be profitable if the distance of the port is much shorter (in this case, between Rotterdam and Yokohama) and not profitable if the distance is further south of Yokohama (Rotterdam – Shanghai).

Table 6.2: List of the simulations that conclude the NSR is profitable

Year	**Authors**	**Results**
1991	Wergeland, T. (Ed.)	Scenario 1: NSR: \$10,980, Panama: \$27,560 Scenario 2: NSR: \$22,200, Suez: \$34,160
1992	Wergeland, T.	Same as Wergeland 1991
1999	Ramsland, T. R.	More positive cash flow each month (July to February) for the NSR compared to SCR
2006	Juurma, K.	Transport of oil by seaway: 12 Euros/tonne. By pipeline: 20 Euros/tonne
2010	Srinath, B.N.	Polar routes (NWP, NSR & Polar) show better profit margin for all three scenarios because of more round trips.
2010	Liu, M. & Kronbak, J.	With a 50% of NSR fees reduction, the NSR is profitable when it opens for 3 and 6 months with a lower bunker price, but it is not economically competitive, no matter how many days it is

		navigable. With an 85% reduction of NSR fees, the NSR is always more profitable than Suez for a 9 month shipping season with low bunker cost. If bunker cost increases the NSR is still profitable but the SCR incurs a loss.
2011	Hua, X. *et al*.	The NSR saves between 3 and 5% of fuel cost compared to SCR
2011	Schoyen, H. & Brathen, S.	The NSR is cheaper compared to the SCR and via Cape of Good Hope.
2012	Falck, H.	The NSR route saves: $839,000 for bulk ship and $8,264 000 for LNG ship compared to SCR.
2012	Omre, A.	The NSR-SCR combined shipping by ice class 4000 TEU-ship is competitive against the same size (4000 TEU) and the larger container ship (6000-8000 TEU) except for 15000 TEU-ship.
2012	Ueta, H., & Goda, H.	Bulk carrier: total cost for NSR = $266 000, SCR = $284 000
2013	Wergeland, T.	At bunker cost of $500/t, cost is cheaper with Arctic routes (NSR, NWP, TPP) compared to SCR.
2013	Furuichi, M. & Otsuka, N.	Same as Omre, A. (2012)
2013	Otsuka, N. & Furuichi, M.	Iron ore shipping cost: NSR = $1259, Panama = $1725 LNG shipping cost: NSR = $1580, SCR = $1927 Frozen fish shipping cost: NSR = $250, SCR = $350
2014	Lassere, F.	Cost per TEU (Rotterdam to Yokohama), NSR=$761, SCR=$940
2014	Raza, Z. and Schoyen, H.	Total cost per round voyage, SCR = $11 160 297, NSR = $6 480 585
2015	Chang, K.Y. *et al.*	The NSR is around 30-45% more cost saving than the SCR
2016	Faury, O. & Cariou, P.	The NSR provides a competitive advantage in the months from August to November when conservative assumptions on ice conditions (higher bound) are considered for the level of ice thickness encountered along the route and from July to November when a lower bound is assumed.

Note: The values stated were taken directly from the studies (not converted into current values)

It also should be noted that the study by Omre (2012) did not directly compare the NSR with the SCR, but she has proven that the saving can be made if the ships use the NSR for summer transit (the rest of the year using the SCR) instead of using the SCR for the whole year. The same conclusion can be made for Furuichi and Otsuka (2013).

Table 6.3: List of the simulations that conclude the NSR is not profitable

Year	**Authors**	**Results**
1996	Mulherin, N. *et al.*	The ships in current use (1996) on the NSR have approximately 25% of the carrying capacity of cargo vessels using the traditional warm-water trade routes. It requires at least four trips along the NSR to deliver the same amount of cargo that can be delivered in one trip through the SCR
1999	Kamesaki, K. *et al*.	Capital costs have the most significant impact on the NSR operational costs. In terms of year-round operation, even if the NSR is used only seasonally, the cost would be about 10% higher than in the Suez Canal route with conventional handy-size bulk carriers.
2001	Kitagawa. H	Same as Kamesaki *et al*., 1999
2009	Verny, J. & Grigentin, C.	NSR cost more per TEU ($2500-2800) than SCR ($1400-1800) and Trans-Siberian Railway ($1800-2200).
2010	Chernova, S. & Volkov, A.	Cost per TEU, NSR: $1416 (eastbound) and $1133 (westbound) per TEU, SCR = $979 per TEU
2010	Eide, L. *et al*., (DNV)	Year 2030, S1: Not competitive for any of the hubs, S2: competitive for Northern Asian hubs (Tokyo) Year 2050, S1: Not competitive unless bunker price above $900/tonne. S2: Tokyo hub will be competitive, Hong Kong hub will be competitive if large values of bunker price and longer summer season but still low probability
2012	Ueta, H., & Goda, H.	Cost per TEU: NSR = $722, SCR = $448
2012	Carmel, S.	Cost per container is higher along the NSR because large ships cannot use the NSR for now; the reliability of the route is too low
2014	Lassere, F.	Cost per TEU (Rotterdam to Shanghai), NSR=$879.46, SCR=$806.74
2015	Moon, D. *et al.*	TKR – TSR has competitiveness in all factors. SCR is competitive in qualitative factors such as reliability, flexibility and freight safety. The NSR has strength in transport distance and transport time but weak in cost and all qualitative factors. The best for marine transport.

		Overall ranking: 1) Route 1, 2) Route 6 (the NSR), 3)Route 4, 4) Route 2, 5) Route 3, 6) Route 5 (SCR)
2016	Zhang, Y. et al	The distance reduction and time saving of the NSR have neither translated to unit profit increase in container shipping, nor unit cost saving in oil shipping
2016	Zhao, H. et al.	The NSR–SCR is not profitable if the navigable period is as short as 4 or 6 months. However, the profit of the combined route will become close to or exceed that of the SCR given enough navigable time (e.g., more than 8 months) and a relatively low ice-breaking charge

6.2.1: A mixture of models and conclusions

The models are of diverse quality and purpose. Falck (2012) displayed simplified simulations in the frame of more general presentations. Eide *et al.*, (DNV) (2010), Carmel (2012) or Cho (2012), Ueta and Goda (2012) do not disclose many details. However, simulations from authors like Kitagawa (2001), Verny and Grigentin (2009), Furuichi and Otsuka (2013), Srinath (2010), Liu and Kronbak (2010), Wergeland (2013) and Lasserre (2014) offer detailed and accounted for hypotheses with several parameters.

Carmel (2012) underlines the fact that, beyond the transit time and the cost issues, a major issue for container shipping along the NSR lies in the route's reliability. According to Lasserre (2014), Maersk container shipping company, has achieved a 99% reliability on its schedule, despite congestion and political risks like piracy. Maersk Company doubts very much that such a high level can be achieved with Arctic routes, given the variability of ice coverage, especially during transition seasons.

The general conclusion that seems to emerge from these models is direct costs are low for transit shipping using Arctic routes. However, the models are by definition simplifications of the reality and do not take into account all variables, and sometimes oversimplify them. They rest on simplifications of the cost structure (structural limitation) and, for most, on the choice to focus on cost issues. Many of the issues from the past researchers have been figured out by Lasserre (2014), For instance, the twice-yearly redesigning of schedules on a seasonal use of Arctic routes implies for container shipping; marketing issues like the load factor, and never the risk-aversion that characterises liner shipping regarding the risk of delays due to unpredictable drifting ice, especially at the beginning and the end of potential. Thus, this study will use the cost simulation constructed by Lasserre (2014) added with other researchers as well. Although this study by Lasserre has proven to be the best cost simulation for the container shipping in the NSR, he still failed to include some qualitative factors such as reliability and safety factor in his study.

Based on the review, no studies incorporated the qualitative factors into their study except for one. Moon *et al*., (2015) came out with 3 quantitative factors (distance, time and cost) and 3 qualitative factors (service, safety and awareness) in their study. They also used TOPSIS methodology to find the best transport route between Korea and Europe. However, they failed to consider some parameters such as load factor and emissions. Furthermore, the calculated transport cost also did not consider many things such as maintenance cost, capital or chartering cost and ships delay because their study was based on a single voyage/trip. With the single trip, given the shorter distance of the NSR, it is quite possible that the cost is lower for the NSR compared to the SCR. Speed of the vessel navigating along the NSR was also found unrealistic with 20 knots. Therefore, they concluded that the NSR is better than the SCR in their results. This study by Moon *et al*., (2015) was using the TOPSIS method to compare the 6 routes considered. They used a classic or original TOPSIS equation to find the relative closeness of each alternative. This was found to be a problem because this particular original equation is only for a model with two alternatives. More than that, in this case, 6 alternatives, are surely causing a consistency problem and leading to wrong decision making. This issue will be explained in the next section in Step 6.

As shown in Table A6.1 (Appendix R), many of the studies have compared routes by transportation costs without taking into account the qualitative aspect of the route. Even though some studies mentioned about the risks and safety factors of the routes, for instance, the piracy problem and the ice conditions of the route, but they cannot integrate the qualitative factor together with the quantitative factor. Hence, the Multi-Criteria Decision Making (MCDM) is an efficient decision-making technique that considers multiple criteria regardless whether qualitative or quantitative. Finally, MCDM can choose the optimal alternative.

6.3 Background of TOPSIS Method

The TOPSIS method is a well-known MCDM technique, and was first proposed by Hwang and Yoon (Kuo, T. 2017; Zhang and Yu, 2012; Jahanshahloo *et al*., 2006) It is a practical and useful technique for ranking and selecting a number of externally determined alternatives through distance measures. The basic principle is that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the furthest distance from the negative ideal solution (NIS) (Kandakoglu, *et al.*, 2009; Shih *et al*,, 2007, Chen *et al*., 2011; Doukas *et al.*, 2014). The TOPSIS simultaneously considers the distances to both PIS and NIS. The ranking of alternatives in the TOPSIS is based on 'the relative similarity to the ideal solution', and a combination of these two distance measures (Young *et al*., 1994; Raju *et al*., 2010; Shih *et al.*, 2007). Further detailed information of the TOPSIS steps and algorithms can be referred to in Section 4.2.

Shih *et al*., (2007) pointed out that TOPSIS is a straightforward technique and suitable for cases with a large number of attributes and alternatives, and especially appropriate for use with objective or quantitative data. Moreover, according to Huang and Li, (2012), TOPSIS has many advantages, and these are listed below:

- It is a compromise that can be obtained efficiently;
- it uses logical thinking that represents the rationale of human choice;
- it has a scalar value that expresses both the best and worst alternatives simultaneously;
- it uses a comprehensible computation process that can be easily programmed into a spreadsheet;
- the performance measures of all alternatives on attributes can be visualised on a polyhedron, at least for any two dimensions; and
- the results are easily explained to and accepted by decision makers (Shih *et al*., 2007; Abo-Sinna and Amer 2005).

6.4 TOPSIS Algorithm

In TOPSIS method, there are seven main steps described as follows:

Step 1: Determine the weight of each criterion and sub-criterion.

Step 2: Construct the decision matrix and the normalised decision matrix.

Step 3: Construct the weighted normalised decision matrix.

Step 4: Determine the positive ideal solution (PIS) and negative ideal solution (NIS).

Step 5: Calculate the distance separation measure of each alternative from the PIS and NIS.

Step 6: Calculate the relative closeness of each alternative.

Step 7: Rank the preference order of all the alternatives.

According to Jahanshahloo *et al*., (2006), the TOPSIS method can be concisely expressed in a matrix format as shown in Table 6.4.

Table 6.4: A decision matrix form in TOPSIS method

	C_1	C_2	…	C_n
A_1	X_{11}	X_{12}	…	X_{1n}
A_2	X_{21}	X_{22}	…	X_{2n}
A_m	X_{m1}	X_{m2}	…	X_{mn}

where $A1, A2, \ldots, Am$ are the possible alternatives that shipping companies can choose; $C1, C2, \ldots, Cn$ are the possible evaluation criteria or attributes against which an alternative performance is measured; xij is a crisp value indicating the performance rating of each alternative Ai with respect to each criterion $C\ j$ (Mahmoodzadeh *et al*., 2007). The main TOPSIS method process with seven steps is described in detail as follows:

Step 1: Calculation of the weight of the evaluation criteria using an AHP approach

Please refer section 4.5 in Chapter 4.

Step 2: Construct the normalised decision matrix, R_{ij}

The purpose of this step is to convert the various attributes' dimensions into non-dimensional attributes. This process can be conducted by using the following transformation calculation.

$$R_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} X^2 ij}},\ i = 1, 2, \ldots \ldots, n \tag{6.1}$$

Step 3: Calculate the weighted normalised decision matrix, V_{ij}

The weighted normalised decision matrix is obtained by multiplying the normalised decision matrix in Step 2 with the weight of all the criteria. This particular heuristic helps a decision maker analyse the problem by having them broken down into a number of criteria. Once all the weights of criteria have been determined, this process of step 3 will help to sort them in their relative priority. The V_{ij} is calculated as follows:

$$V_{ij} = w_j \times R_{ij}\ ,\ \ i = 1,2, \ldots \ldots, m; \quad j = 1,2, \ldots \ldots, n \tag{6.2}$$

where w_j represents the weight of the j^{th} attribute or criterion (Yoon and Hwang, 1995; Mahmoodzadeh *et al*., 2007).

Step 4: Determine the positive ideal solution (PIS), $V+$ and negative ideal solution (NIS), V^-

According to Yoon and Hwang (1995), an ideal solution is defined as a collection of ideal levels (or ratings) in all criteria considered. It is to be as close as possible to such an ideal solution based on the rationale of human choice. PIS and NIS are determined respectively as follows:

$$V^+ = \{V^+_1, V^+_2, V^+_3, \dots \dots, V^+_n\} = \{(max_j V_{ij} \mid j \in J)\}, \{min_j V_{ij} \mid j \in J')\} \quad (6.3)$$

$$V^- = \{V^-_1, V^-_2, V^-_3, \dots \dots, V^-_n\} = \{(min_j V_{ij} \mid j \in J)\}, \{max_j V_{ij} \mid j \in J')\} \quad (6.4)$$

where J is associated with the benefit criteria and J' is associated with the cost criteria (Mahmoodzadeh *et al*., 2007).

Step 5: Calculate the distance separation measure for PIS, D^+_i and NIS, D^-_i

Distance separation is considered as a degree of separation between two points of the study. The purpose of this step is to measure all the alternatives with their PIS and NIS. The D^+_i and D^-_i values can be computed using Equations 6.5 and 6.6.

$$D^+_i = \sqrt{\textstyle\sum_{j=1}^{n}\left(V_{ij} - V^+j\right)^2}, \quad I = 1,2, \dots \dots, m \quad (6.5)$$

$$D^-_i = \sqrt{\textstyle\sum_{j=1}^{n}\left(V_{ij} - V^-j\right)^2}, \quad I = 1,2, \dots \dots, m \quad (6.6)$$

Step 6: Calculate the relative closeness to the ideal solution, RC_i^+

This calculation can be conducted using Equation 6.7 together with the information obtained from Step 5. The purpose of this step is to select the best alternative according to the shortest distance from the PIS and the farthest distance from the NIS. The relative closeness of the alternative A_i with respect to RC_i^+ is defined as follows:

$$RC_i^+ = \frac{D^-i}{D^+i + D^-i}, \quad i = 1,2, \dots \dots, m \quad (6.7)$$

where the index value is $0 \leq RC_i^+ \leq 1$. An alternative A_i is closer to V^+ as RC_i^+ approaches 1.

However, Equation 6.7 has been debated by some researchers due to inconsistent explanation of the relative closeness (Li, 2007; Abdul Rahman, 2012; Kuo, 2017). An alternative way to determine the shortest distance from PIS and the farthest distance from the NIS is using the model proposed by Zimmermann and Zysno (1985). This model is defined as a function of the distance (D^+_i) between a given alternative i and the PIS.

$$\mu^+ = \frac{1}{1+D_i^+} \qquad (6.8)$$

where D^+_i is the distance separation measures for PIS. An alternative measurement of NIS can be defined as Equation 6.9 which elaborates the distance (D^-_i) between given alternative i and the NIS.

$$\mu^- = 1- \frac{1}{1+D_i^-} = \frac{D_i^-}{1+D_i^+} \qquad (6.9)$$

Therefore, a class of intersection connectives is suggested. According to the intersection connectives proposed by Yager (1980), the relative closeness to the ideal solution can be obtained using Equation 6.10.

$$RC_i^+ = \mu^{+\cap-} = 1 - \min\,[1, (1 - \mu^+)^P + (1 - \mu^-)^P\,]^{\frac{1}{P}} \text{ for } P \geq 1 \qquad (5.10)$$

where μ^+ and μ^- are defined by Equations 6.8 and 6.9 respectively. Different values of P are connected with different behavioural patterns of decision makers' uncertainty. The P values should be from 1 until infinity (∞).

Nevertheless, Kuo (2017), who proposed a new equation to overcome the consistency problem, has confirmed that if the model has only two alternatives involved, the original TOPSIS equation (Equation 6.7) can be used. This is because, according to him, with an increasing number of alternatives, the consistency rate tended to decline.

Step 7: Rank the preference order of alternatives

Based on the relative closeness to the ideal solution in Step 6, the large the RC_i^+ value is, the better the performance of the alternative A_i (Devi *et al*., 2009; Mahmoodzadeh *et al*., 2007).

6.5 A Generic Methodology

A flow chart of the test case is illustrated in Figure 6.1. Basically, the flow chart begins with identifying the issue faced by shipping companies and setting up a goal that needs to be achieved. The determination processes of the evaluation criteria, alternatives, model development and data collection of the selected criteria are the main body of this flow chart. Besides, the construction of the selection criteria and the implementation of the TOPSIS method are also highlighted. Finally, this diagram concludes with the result of the TOPSIS method which is the ranking preference order of all alternatives.

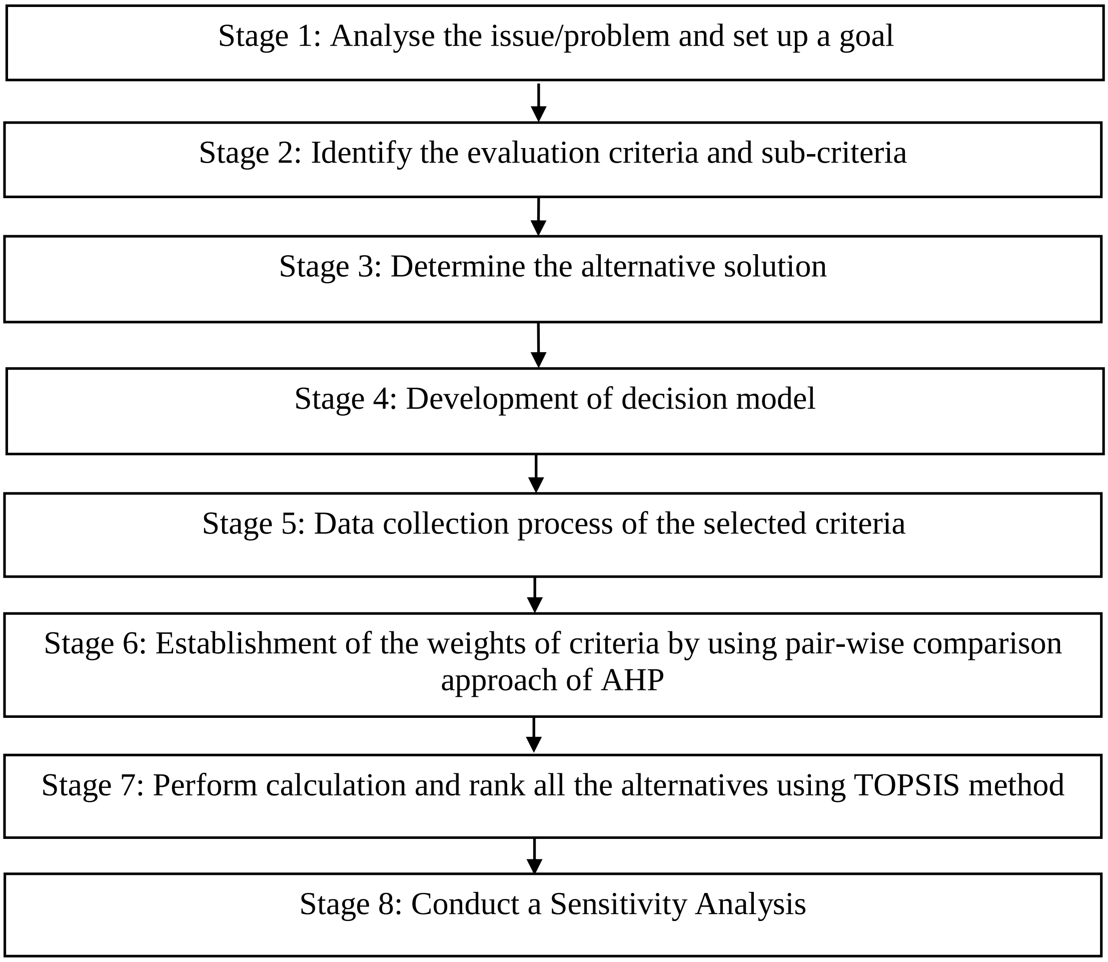


Figure 6.1: Flowchart of the methodology of selecting the best shipping transit route between the Far East and Northwest Europe

Stage 1: Set up a goal

The goal of this study is set up based on the shipping companies' requirements incorporating the current situations in the shipping routes selected. Different shipping companies, for example liner or tramp shipping, have different operations, parameters and other concerns, but the goal is always the same, to find the route that will give them the highest profit as possible. Shipping companies have to identify the best shipping route for them, incorporating with a number of significant parameters.

Stage 2: Identify the evaluation criteria and sub-criteria

The same five principles as mentioned in *Step 2* of Section 5.4 (Chapter 5) will be considered when criteria are being formulated. The process of identifying the criteria also will be the same as the previous chapter, which are through literature surveys, discussion with experts and brainstorming technique. Again, only the significant criteria will be chosen for use in this study.

Stage 3: Determine the alternative solution

The alternative will be identified through the literature surveys. The past researchers have conducted many work published through journals, books, conference papers etc. and will be a good source to find the significant alternatives that can be used in this study.

Stage 4: Model development

A model or hierarchical structure of the problem containing the goal, evaluation criteria and sub-criteria which are identified from Stage 1 to Stage 3 will be developed. By using the proposed model, it is possible to assist shipping companies in achieving the goal(s) that has been set in Stage 1.

Stage 5: Data collection process

The data collection process will be conducted using a set of questionnaires and interview sessions for obtaining the qualitative dataset. Such questionnaires will be sent to the selected experts for expressing their judgments on the issues discussed. This set of data will be used to perform a calculation for the TOPSIS method.

Stage 6: Establishment of the weights of criteria and sub-criteria

The weight measurement of all the criteria and sub-criteria determined in Stage 2 will be conducted using a Pair-wise comparison technique in association with the analytic hierarchy process (AHP) approach as described in *Step 3* of Section 4.4 (Chapter 4). To construct the measurement, a set of questionnaires will be sent to a number of experts for analysing the priority of each evaluation parameter to another by incorporating the ratio scale of the Pair-wise comparison.

Stage 7: Perform calculation and rank all the alternatives using a TOPSIS method

A TOPSIS method will be used in this study to perform the calculation process of PIS and NIS. After obtaining both values (qualitative and quantitative) for all alternatives, the preference ranking order of such alternatives can be constructed using the relative closeness to the ideal solution, $RCi+$ algorithm. The best alternative will be chosen by shipping companies based on the $RCi+$ value closest to one which has the shortest distance from the positive ideal solution point and the farthest distance from the negative ideal solution point. All seven steps of TOPSIS calculation mentioned in Section 6.3 will be performed at this stage.

Stage 8: Conduct a Sensitivity Analysis

A sensitivity analysis process will be conducted using OAT method which was mentioned in section 3.5 of Chapter 3.

6.6 Case Study of selection of the best shipping route between the Far East Asia and Northwest Europe

The purpose of this test case is to assist shipping companies to select the best shipping route between the Far East Asia and Northwest Europe.

Stage 1: Identify the problem matter and set up a goal

The discussion technique with the selected experts has been used to set up an appropriate goal that needs to be achieved. Every time the Arctic sea ice extent reaches a new record low, many new reports and studies predict a rapid increase in shipping activities in the Arctic. Expectations are high that the NSR will rival traditional routes and complement the Suez Canal route as a key waterway for trade between the Far East and Northwest Europe. At the same time, the unpredictability of international trade, economic recession and the sharp increase in bunker fuel price will result in economic loss to the shipping companies. If the short distance offered by the NSR can overcome this problem, it is very sensible for shipping companies to start to venture in this route. However, there are many risks associated with the NSR compared to the other traditional routes. Is it worthwhile for shipping companies to take all the risks? Thus, the goal of this study is to select the best shipping transit route between the Far East and Northwest Europe. All models in the previous literature only focus on either container or bulk shipping. In this study, both types of shipping are considered because there are differences especially in their operations. Thus, this study would like to see the outcome for both type of shipping services.

Besides all models from literature, this research is also prone to simplifications and work with estimates. This research will be conducted for both types of shipping which are Liner shipping (containership) and Tramp shipping (bulk and tanker ships). These two shipping simulations will be further explained next.

A) Design of Scenario 1 – Liner shipping
   A scenario modelling of a 4500 TEU containership based in Rotterdam and servicing Shanghai through the NSR is competing with a similar ship going through the SCR and stopping over at three intermediate ports, Malta, Dubai and Singapore. The goal of this simulation is to get an approximate cost of operation per transported twenty-foot equivalent unit (TEU). The first scenario considers summer shipping for a 4-month shipping season (realistic and similar to modelling in Chapter 4). A regular ship (for the SCR) compared with ice strengthened PC6 ice–class ship which is plying the NSR.
B) Design of Scenario 2 – Tramp shipping
   In this study model, panama bulker of 75,000 DWT (40,537GT), which is loading 90% of its capacity as 67,500 tonne of iron ore, is used for both the NSR and the SCR. Again, a regular ship is used for the SCR and ice-classed PC7 for the NSR. This tramp shipping is simulated from Narvik (Norway) to Qingdao (China). This scenario considers a 4-month summer shipping season, same as the first scenario. In contrast with the first scenario, this scenario is based on the calculation of a single leg due to the nature of tramp shipping.

More details about these two scenarios will be demonstrated in Stage 5.

Stage 2: Identify the evaluation criteria and sub-criteria

In this stage, the process is broken down into two more steps.

a) List down all the selected criteria and sub-criteria

By using the brainstorming technique, a discussion technique with the selected experts and literature surveys, the main evaluation criteria can be grouped into six categories which are 1) Distance (DE), 2) Transport Time (TT), 3) Total Cost (TC), 4) Transport Services (TS), 5) Safety (SY) and 6) Emissions (EM). Some criteria have numerous sub-criteria as listed in Table 5.6. All the criteria and sub-criteria will assist the TOPSIS method to work efficiently in order to achieve the goal described in Stage 1. These selected criteria will be used both for the Liner shipping and Tramp shipping.

Most of these criteria are the same as in the previous chapter (Chapter 5), such as distance, time, cost and emissions. This is because, the previous chapter shared the same goal with this chapter. Hence, these factors can be used straight away in this chapter. Furthermore, comprehensive references for most of the criteria such as Distance, Transport time, Total Cost, and Emissions can be found almost in all previous literature mentioned earlier in this chapter. Some studies such as Lassiere (2014) and Schoyen and Brathen (2010) mentioned about the reliability and flexibility issues but never integrated these factors in their study because they cannot apply it with their quantitative/numerical method. Sub-criteria, Load Factor, Frequency and Capacity Supply were adopted with most studies that used containership as their test case model. Safety criterion is also generally mentioned in all studies listed in Table A6.1, such as ice, fogs, waves that increase the risks of using the NSR, but again they have failed to integrate it in their models. The only thing they have used with the environmental data (distribution of ice, fogs and waves) was to calculate the vessels' speed within the NSR. For example, Mulherin (1996) use the Monte Carlo method to calculate vessels' speed in the NSR associating with many years of environmental data.

Table 6.5: The list of criteria and sub-criteria associated with the TOPSIS goal

Criteria	**Sub-criteria**	**Goal**
Distance (DE)	-	Cost
Transport Time (TT)	-	Cost
Total Cost (TC)	-	Cost
Transport Services (TS)	Reliability (RY)	Benefit
	Flexibility (FY)	Benefit
	Frequency (QY)	Benefit
	Load Factor (LF)	Benefit
	Capacity Supply (CS)	Benefit
Safety (SY)	Transport Safety (TF)	Benefit
	Freight Safety (FS)	Benefit
Emissions (EM)	CO_2 (CO)	Cost
	NO_x (NO)	Cost
	SO_x (SO)	Cost

The final list of criteria in Table 6.5 is sufficient to describe the selection of the best shipping route between the Far East and Northwest Europe. Such a list can be updated from time to time based on the scope of study, size of ship and other factors as well.

b) Determine the goal of sub-criteria

The function of the goal of each sub-criterion is to determine the PIS and NIS. There are two possible levels of goal, for each variable parameter which are either “Benefit” or “Cost” goal (Table 6.5). The goal “Benefit” is related to a positive solution, while the goal “Cost” is associated with a negative solution in determining the PIS and NIS. This process can be referred to in Equations 6.3 and 6.4 in Step 4 of Sections 6.3.

Stage 3: Identify the possible alternatives solution

There are two alternatives considered in this study which are the NSR and the SCR. Twenty-two out of twenty-four studies in the literature used these two routes for cost comparison. The remainder of the studies also include the Tran-Siberian Railway (TSR), air route, Trans-polar Passage (TPP) and Panama Canal route. Most of the routes are proven ineffective for example, studies by Verny and Grigentin (2012) and Moon, *et al*., (2015) proved that TSR is ineffective for freight transport between the Far East and Europe. Other than that, the Panama Canal route is irrelevant to this study because this route is not a popular choice for transit between the Far East and Europe because of the longer distance. Meanwhile, TPP has been proven as unfeasible in Chapter 5 and cannot be an alternative for this study. Cape of Good Hope route also has been proven unprofitable by Verny and Grigentin (2012) due to the longer distance for ships to navigate.

Stage 4: Model development

According to the final list of the criteria and sub-criteria in Table 6.5 and the list of alternatives in Stage 3, a model of this study was developed as shown in Figure 6.2. Basically, there are three tiers of information, namely 1) goal (on the top), 2) criteria (in the middle) and 3) sub-criteria (a tier after the criteria), while all the alternatives are shown at the bottom of the model. To achieve the goal, four criteria have been identified. Each criterion has a number of evaluation sub-criteria attached. For example, under the criterion “TS”, there are four sub-criteria namely “RY”, “FY”, “QY”, “LF” and “CS”, in which each sub-criterion is linked with all the alternatives.

For criterion "Total Cost", the cost items involved were taken from past models and can be used for both Liner and Tramp shipping cost calculation. The details about the total cost for both types of shipping are discussed in Stage 5

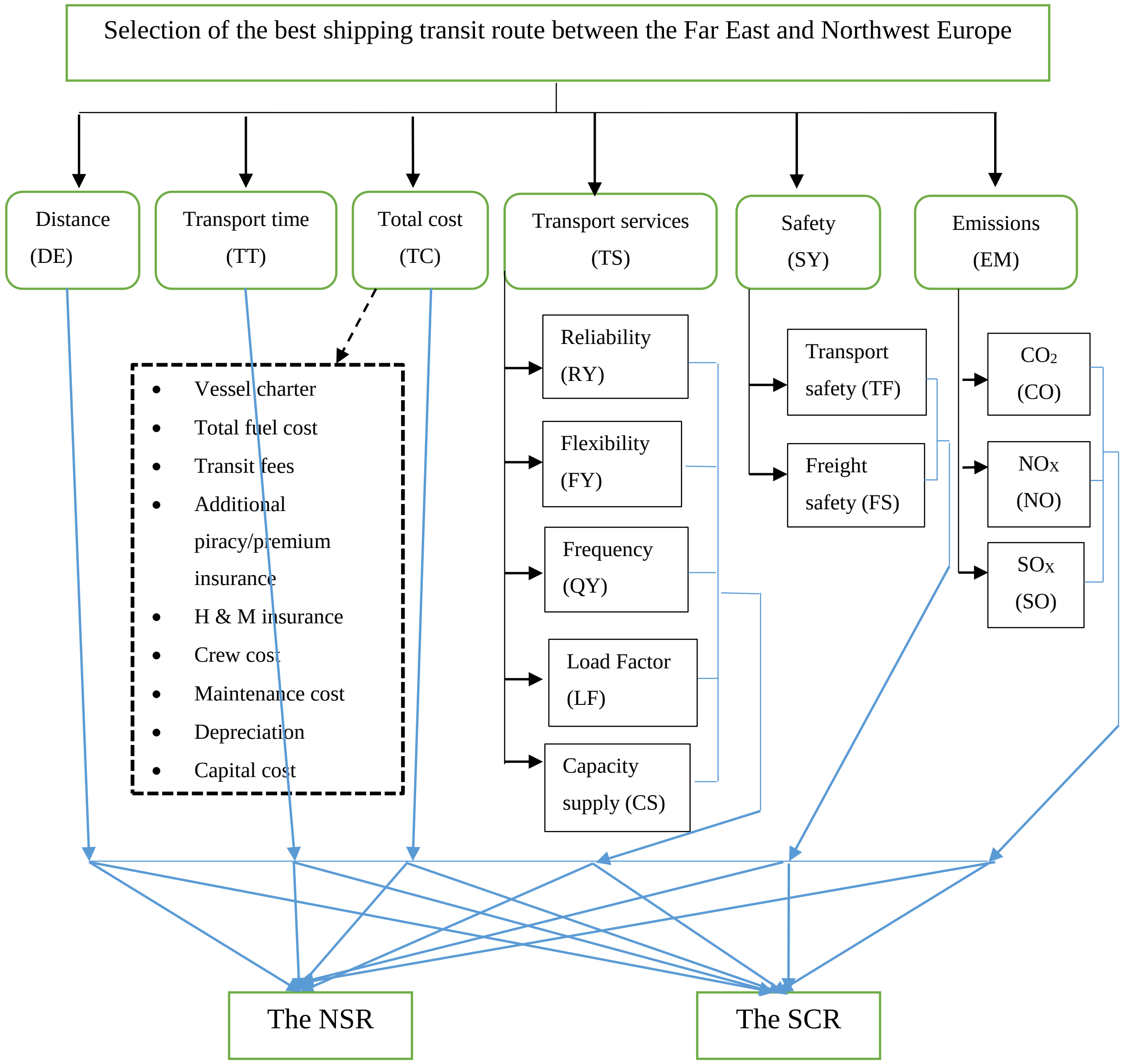


Figure 6.2: The hierarchical model of selection of the best shipping transit route between the Far East and Northwest Europe market.

Stage 5: Data collection process

All the necessary data need to be collected from various sources and are then aggregated into a specific table. Such a process collects both quantitative and qualitative data. The developed model can have a mixture of both quantitative and qualitative datasets. The idea of using qualitative datasets in some parameters is to improve the prediction of the outputs when dealing with uncertainty situations. The outputs may be different if different outputs are used. In the real practice, shipping companies can use their own dataset in order to get the real output without affecting the model.

i) Quantitative data

In this study, there are seven quantitative datasets and five of them have been obtained using mathematical algorithms, namely 1) transport time, 2) total cost, 3) carbon dioxide, 4) frequency, 5) capacity supply. The other two datasets which are 'Distance' and 'Load Factor' have been obtained from literature surveys. Most of the equations and calculations for these quantitative data are shown in Chapter 5. Table 6.6 shows the calculation of quantitative data for the Liner shipping. The data are gathered mostly from previous literature and own estimation. This calculation shown in Table 6.6 and Table 6.7 are for illustrative purposes only.

Table 6.6: First scenario, summer transit (120 days) for 4500 TEUs containership, Shanghai-Rotterdam

	NSR	**SCR**	**Notes**
Distance	7085	11447	In nautical miles (nm). Calculation based on Lassere (2014) and own calculation. Distance within the NSR = 2892nm (Route 3, took from Chapter 4), outside the NSR = 4193nm
Load factor (westbound)	70%	87%	Based on Lassere (2014). For TOPSIS data: average for each bound: NSR: 57.5%, SCR: 73.5%
Load factor (eastbound)	45%	60%	
TEU transported per trip (westbound)	3150	3915	For example, NSR, 70% x 4500 TEU size of containership = 3150 TEU
TEU transported per trip (eastbound)	2025	2700	
Maintenance, days per 4 months	3	1	Based on Somanathan (2009)
Suez Canal delay (days)		2	Based on Lassere (2014)
Ports called at	1	4	Days in Port = 2, For SCR, three intermediate ports are Singapore, Dubai and Malta
Stop days at port (per leg)	2	8	SCR = 4 (ports) x 2 (days) = 8
Total of stop days	2	10	SCR (delay + Stop days at port) = 2+8=10 days
Average sailing speed (knots)	17	20	Average speed inside the NSR = 14 kts; outside 20 kts (Refer number IV, Step 5, Section 5.5 of Chapter 5)

Journey time (days)	17.35	23.85	Refer Equation 5.20 from Chapter 5 for Journey time formula
Total time (days)	19.35	33.85	Sailing time + stop days
Total round trip during summer	6.04 rounded at 6	3.5 rounded at 4	Refer Equation 5.21 from Chapter 5 for Round trip formula Total summer days for the NSR is 117 days (120 days minus 3 maintenance days)
Total TEUs transported	15525	13230	NSR, westbound (wb) = 3150 TEU/trip x 3 trip = 9450 TEUs wb, Eastbound (eb) = 2025 TEUs/trip x 3 trip = 6075 TEUs eb.
Cost analysis			
Crew cost (thousand USD)	572	520	$130000 monthly for 23 crew (Lassere 2014), add 10% for the NSR
Insurance (thousand USD)	1 200	800	For a standard ship: Wergeland (2012): $339,450/yr, Srinanth (2010): $1,400,000/yr For the NSR, Verny & Grigentin (2009): $1,204,000/yr, Srinanth (2010): 2,400,000/yr. In this study the insurance cost is based on Lassere (2014): $800 000/yr. the NSR add 50% premium (Srinath, 2010 and Eide *et al*., 2010)
Aden Emergency charge (thousand USD)		529.2	Charge at 40USD/TEU based on Furuichi and Otsuka (2013)
Capital cost (thousand USD)	3 764	3 011	Based on Lassere (2014), Suez: conventional 4500 TEU ship, at $90 M with over 20 years, straight line depreciation method: $752 800/month. NSR: 1AS 4500 TEU ship, with 20% construction premium ($108M), same depreciation; $940 995/month
Maintenance (thousand USD)	240	200	Schoyen (2011): +20%, Wergeland: +23%. In this study the cost is based on Lassere (2014): $600 000/yr and plus 20% for the NSR
Transit fees (thousand USD)	1 733	960	For the NSR $7.44/Tonne (Lassere, 2014), Average loaded TEU weight: 15t/TEU Suez= $240 000/transit (Suez Canal Authority)
Average Transit fee per trip, (thousand USD)	288,8	240	
Fuel consumption rate, tons/day	40t/day and 108t/day	100t/day	Lassere (2014)
Fuel consumed, tons	1288	2385	NSR

			Inside of the NSR: 8.61 days x 40t/day = 344.4t Outside of the NSR: 8.74 days x 108t/day = 943.92t
Bunker price, IFO 380, USD/t	615	615	Average price in September 2019 (shipandbunker.com)
Fuel cost (single trip) (thousand USD)	792	1 467	
Fuel cost, total (whole season) (thousand USD)	4 752	5 866	NSR = 6 trips, SCR = 4 trips
TOTAL COST (thousand USD)	12 206.5	11 886.8	For 4 months
Cost per TEU, (USD)	**789.72**	**898.47**	Total cost divide by total TEU transported

The calculation of total cost for criterion ‘TC’ (Cost per TEU) is shown in Table 6.6. Subsequently, the other five quantitative datasets are also gathered from the table, namely; 1), distance 2) transport time, 3) load factor, 4) frequency, and 5) capacity supply. The quantitative data for carbon dioxide emission (CO) (for both liner and tramp) are calculated using Equation 5.22 in Step 5 of Section 5.5 (Chapter 5).

Table 6.7 shows the calculation of total cost for the second scenario of bulk shipping. Hence, five quantitative data sets are gathered from the table namely, 1) distance, 2) total time, 3) frequency, 4) capacity supply and 5) total cost. Criterion ‘Load factor’ is gathered through expert judgements because there is no literature found on the subject matter. As mentioned previously, the bulk shipping scenario is for single voyage and the data for ‘round trip’ and ‘capacity supply’ are gathered with the assumption that the bulk shipping operates in the whole summer of the NSR. This information is important to know how many trips can be done (as well as total cargo transported) by the bulk ships when operating in the summer months of the NSR. This information is useful, for example, the ships (bulker) are chartered to use for a specific amount of cargo within a specific time of the year. This could be a potential in the future as the Arctic holds a massive amount of energy resources (oil, gas and etc.) so the bulk ships can be used regularly.

Table 6.7: Second scenario: summer transit (120 days) for 75000 DWT bulk carrier, Narvik-Qingdao

	NSR	**SCR**	**Notes**
Distance (NM)	6800	11800	Otsuka & Furuichi (2013)
Cargo capacity (tonnes)	67 500	67 500	90% of loading capacity
Sailing speed (knots)	13.1 (within NSR) 15 (open water)	15	Otsuka & Furuichi (2013)
Total loading/unloading time (days)	6	6	Depends on the port facilities. It is assumed 6 days in this study
Journey time (days)	20.05	32.78	Refer Equation 5.20 (Chapter 5) for Journey time formula
Total time (days)	26.05	38.78	
Round trip during summer	5	3	Refer Equation 5.21 (Chapter 5)
Total cargo transported	337500	202500	NSR: 67500 tonnes times 5 roundtrip
Engine power (kw)	12 000	10 000	Ice class ship has more engine power
Fuel consumption (t/day)	47	43	Otsuka & Furuichi (2013), which is fuel consumption ratio is 185gr/KW/h
Bunker price, IFO 380, USD/t	615	615	Average price in September 2019 (shipandbunker.com)
Total fuel cost, (USD)	**579 545**	**866 867**	
Transit fees, (USD)	343 548	219 217	NSR –$5 (USD/t), Ice pilot = $672/day (9 days) Suez – Suez canal calculator
Port due (USD)	35 000	35 000	0.428 (USD/GT) Otsuka & Furuichi (2013)
Overhead expense (USD/voyage)	**378 548**	**254 217**	
Insurance (USD)	10 133.45	13 728.12	Otsuka & Furuichi (2013), NSR: $389/day, SCR: $354/day
Crew cost (USD)	78 514.7	106 257.2	NSR: $3014/day, SCR: $2740/day – Otsuka & Furuichi (2013), NSR + 10% of Suez (Lassere, 2014)
Maintenance cost (USD)	32 354.1	43 356.04	NSR: $1242/day, SCR: 1118/day – Otsuka & Furuichi (2013),
Operational cost (USD/voyage)	**121 000**	**163 341**	
Depreciation cost (USD/voyage)	**296 553.2**	**372 815.4**	Ice class IA, +10% , Straight line method, 10 years lifetime, yearly depreciation is 10% of the capital NSR: $11384/d, SCR: 9613.6/d – Otsuka & Furuichi (2013),
Total cost (USD/voyage)	**1 375 548.45**	**1 657 240.76**	

ii) Qualitative data

The data of RY, FY, SP, TY, FS, CO (for bulk scenario), NO and SO were obtained from the selected experts who are originally from the shipping background (see Appendix S) by using a rating scale ranging from 0 to 10 as shown in Table 6.8.

Table 6.8: The rating scale of the qualitative data

0 low	1	2	3	4	5 medium	6	7	8	9	10 high

Table 6.8 illustrates the range of the rating scale that would give an idea to all three experts for evaluating the criteria mentioned previously with respect to all the alternatives. Subsequently, all feedback received from them will be calculated using arithmetic mean for determining the average rating value. For example, regarding the criterion ‘RY’ with respect to the alternative ‘NSR’, the three experts ticked number one, two and two respectively. Then, the average rating value for such a criterion is 1.67 (5 ÷ 3). A similar calculation process is applied to all other qualitative criteria. Therefore, Table 6.9 and 6.10 summarise all the quantitative and qualitative data for Liner and Tramp shipping. These data will be used next for TOPSIS calculation.

Table 6.9: The data of all the evaluation criteria for Liner Shipping

	DE	TT	TC	TS					SY		EM		
				RY	FY	QY	LF	CS	TF	FS	CO	NO	SO
NSR	7085	19.35	789.72	1.67	2	6	57.5	15525	1	1.67	3174	3	3
SCR	11447	31.85	898.47	8.67	8	4	73.5	13230	9	8.33	6643	5	5

Table 6.10: The data of all the evaluation criteria for Tramp Shipping

	DE	TT	TC	TS					SY		EM		
				RY	FY	QY	LF	CS	TF	FS	CO	NO	SO
NSR	6800	26.05	1375548.5	2.67	2.33	5	4	337500	2.33	2.33	2688	3	3
SCR	11800	38.78	1657240.8	8.33	8.67	3	8.33	202500	8	8	4586	5	5

Stages 6 and 7: Construct the calculation process by using the TOPSIS method

Step 1: Estimate the weight of each criterion

The weight estimation process of the evaluation criteria in Figure 6.2 can be conducted using a Pair-wise comparison technique. The implementation of this technique is associated with a number of selected expert judgments for analysing the priority of each criterion to another by incorporating the ratio scale of pair-wise comparison. The step-by-step process for such a technique can be referred in *Step 3* of Section 4.4 (Chapter 4). This particular section is the generic methodology of this Pair-wise comparison technique.

A set of questionnaires (Pair-wise comparison technique) has been sent to the 15 selected experts and only three has responded (the same three experts for qualitative data questionnaire). The feedback received from them is investigated according to their judgements on the criteria under discussion. Consequently, after the calculation has been made, the weight values for the evaluation criteria are shown in Table 6.11 for the Liner shipping scenario and Table 6.12 for the Tramp shipping scenario.

Table 6.11: The weighting vector values of all criteria for Liner Shipping

Level 1	**Weight values**	**Level 2**	**Weight values**
DE	0.0612	-	-
TT	0.1311	-	-
TC	0.2252	-	-
TS	0.2576	RY	0.37
		FY	0.21
		QY	0.13
		LF	0.18
		CS	0.12
SY	0.2347	TF	0.5
		FS	0.5
EM	0.0902	CO	0.3974
		NO	0.2417
		SO	0.3608

Table 6.12: The weighting vector values of all criteria for Tramp Shipping

Level 1	**Weight values**	**Level 2**	**Weight values**
DE	0.1484	-	-
TT	0.1015	-	-
TC	0.2083	-	-
TS	0.1308	RY	0.3315
		FY	0.2347
		QY	0.1377
		LF	0.1385
		CS	0.1776
SY	0.3156	TF	0.5
		FS	0.5
EM	0.0954	CO	0.3987
		NO	0.2547
		SO	0.3466

The new weights (normalised weighting vectors) of all the sub-criteria are calculated after obtaining the weighting vector values of all the main criteria and sub-criteria. The purpose of this calculation is to obtain the normalised weighting vector values of the evaluation criteria, by multiplying the weighting vector value of each sub-criterion in the specific group with the weighting vector value of the main criteria of the group. The step-by-step process of the TOPSIS method will be shown by using the liner shipping scenario. Refer to Appendix T for the TOPSIS calculation for the tramp shipping scenario. Referring to the TS's group of liner shipping scenario as an example, the normalised weighting vector ($R_Y F_Y Q_Y L_F C_S$) values of all the sub-criteria in this group are obtained as follows:

$$w\,(R_Y F_Y Q_Y L_F C_S) = \begin{matrix} RY \\ FY \\ QY \\ LF \\ CS \end{matrix} \begin{bmatrix} 0.37 \\ 0.21 \\ 0.13 \\ 0.18 \\ 0.12 \end{bmatrix}$$

$$(w(NR_Y F_Y Q_Y L_F C_S)) = \mathrm{w}\ (R_Y F_Y Q_Y L_F C_S) \begin{bmatrix} 0.37 \\ 0.21 \\ 0.13 \\ 0.18 \\ 0.12 \end{bmatrix} \times 0.2576 = \begin{matrix} RY \\ FY \\ QF \\ LF \\ CS \end{matrix} \begin{bmatrix} 0.0953 \\ 0.0541 \\ 0.0335 \\ 0.0464 \\ 0.0309 \end{bmatrix}$$

As a consequence, the normalised weighting vector values of all the sub-criteria in the TS's group of the liner shipping scenario will be used in this test case. In a similar way, the normalised weighting vector values of all the other sub-criteria are obtained as shown in Table 6.13. This table summarises the final weighting values of all the sub-criteria by incorporating the weighting vector values of all the main criteria.

Table 6.13: The normalised weighting vector values of all criteria for liner shipping

	DE	**TT**	**TC**	**TS**					**SY**		**EM**		
Weight (wj)				**RY**	**FY**	**QY**	**LF**	**CS**	**TF**	**FS**	**CO**	**NO**	**SO**
	0.0612	0.1311	0.2252	0.0953	0.0541	0.0335	0.0464	0.0309	0.1174	0.117	0.0358	0.0218	0.0325

Step 2: Construct the normalised decision matrix, R_{ij}

The normalised decision matrix of the test case is computed using Equation 6.1 in association with a set of data in Table 6.9. By using the alternative 'NSR' with respect to the criterion 'DE' as an example, the value of R_{ij} is calculated as follows:

$R_{ij} = \frac{7085}{\sqrt{7085^2 + 11447^2}} = 0.5263$

In a similar way, the calculation technique is applied to all the alternatives with respect to all the attributes for calculating the R_{ij} values. Table 6.14 summarised the normalised decision matrix value.

Table 6.14: The normalised decision matrix value for liner shipping

	DE	TT	TC	TS					SY		EM		
				RY	FY	QY	LF	CS	TF	FS	CO	NO	SO
NSR	0.5263	0.5192	0.6602	0.1891	0.2425	0.8321	0.6162	0.7611	0.1104	0.1966	0.4311	0.5145	0.5145
SCR	0.8503	0.8546	0.7511	0.9819	0.9701	0.5547	0.7876	0.6486	0.9939	0.9805	0.9023	0.8575	0.8575

Step 3: Calculate the weighted normalised decision matrix, V_{ij}

Referring to the normalised weighting vector values of each criterion in Table 6.13 and the normalised decision matrix value in Table 6.14, the weighted normalised decision matrix of this test case is calculated by using Equation 6.2. For instance, the V_{ij} value of the alternative 'NSR' with respect to the criterion 'DE' is computed as follows:

$V_{ij} = 0.0612 \times 0.5263 = 0.0322$

The output of the calculation is obtained as shown in Table 6.15.

Table 6.15: The weighted normalised decision matrix for liner shipping

	DE	TT	TC	TS					SY		EM		
				RY	FY	QY	LF	CS	TF	FS	CO	NO	SO
NSR	0.0322	0.0681	0.1487	0.0180	0.0131	0.0279	0.0286	0.0235	0.0130	0.0231	0.0154	0.0112	0.0167
SCR	0.0521	0.1120	0.1691	0.0936	0.0525	0.0186	0.0365	0.0200	0.1167	0.1151	0.0323	0.0187	0.0279

Step 4: Determine the positive (PIS), V^+ and negative ideal solutions (NIS), V^-

Based on the output values in Table 6.15 in association with the goal of each sub-criterion described in Table 6.5, the positive and negative ideal solutions are determined respectively. In this test case, the values of $\{(max_j V_{ij} \mid j \in J)\}$ and $\{min_j V_{ij} \mid j \in J')\}$ belong to the positive ideal solution (Table 6.16) and Equations 6.3 is referred.

Table 6.16: The positive ideal solution (PIS), V^+ liner shipping

	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Cost	Cost	Cost
	DE	TT	TC	TS					SY		EM		
				RY	FY	QY	LF	CS	TF	FS	CO	NO	SO
NSR	0.0322	0.0681	0.1487	0.0180	0.01312	0.0279	0.0286	0.0235	0.0130	0.0231	0.0154	0.0112	0.0167
SCR	0.0521	0.1120	0.1691	0.0936	0.05248	0.0186	0.0365	0.0200	0.1167	0.1151	0.0323	0.0187	0.0279

The goal of each criterion in the NIS will be changed to the opposite of the PIS. For instance, from 'Benefit' to 'Cost' and the other way around. The values of $\{min_j V_{ij} \mid j \in J')\}$

and $\{(max_j V_{ij} \mid j \in J)\}$ belong to the negative ideal solution (Table 6.17) and Equation 6.4 is refers.

Table 6.17: The negative ideal solution (NIS), V^- for liner shipping

	Benefit	Benefit	Benefit	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Benefit	Benefit	Benefit
	DE	**TT**	**TC**	**TS**					**SY**		**EM**		
				RY	**FY**	**QY**	**LF**	**CS**	**TF**	**FS**	**CO**	**NO**	**SO**
NSR	0.0322	0.0681	0.1487	0.0180	0.0131	0.0279	0.0286	0.0235	0.0130	0.0231	0.0154	0.0112	0.0167
SCR	0.0521	0.1120	0.1691	0.0936	0.0525	0.0186	0.0365	0.0200	0.1167	0.1151	0.0323	0.0187	0.0279

Step 5: Calculate the distance separation measures for PIS, D^+_i and NIS, D^-_i

The distance separation is divided into two parts which are related to the PIS and NIS. The D^+_i is computed using Equation 6.5, while the D^-_i is calculated using Equation 6.6. By using the distance separation values of D^+_i and D^-_i, μ^+ and μ^- are calculated using Equations 6.8 and 6.9. Referring to the alternative 'NSR' as an example, the values of D^+, D^-, μ^+ and μ^- are obtained as follows:

$$D^+ = \sqrt{\begin{array}{c}(0.0322 - 0.0322)^2 + (0.0681- 0.0681)^2 + (0.1487 - 0.1487)^2 + (0.0180 - 0.0936)^2 \\ + (0.0131 - 0.0525)^2 + (0.0279 - 0.0279)^2 + (0.0286 - 0.0365)^2 + (0.0235 - 0.0235)^2 \\ + (0.0130 - 0.1167)^2 + (0.0231 - 0.1151)^2 + (0.0154 - 0.0154)^2 + (0.0112 - 0.0112)^2 \\ + (0.0167 - 0.0167)^2\end{array}}$$

$$= \sqrt{0.0265} = 0.1629$$

$$D^- = \sqrt{\begin{array}{c}(0.0322 - 0.0521)^2 + (0.0681- 0.1120)^2 + (0.1487 - 0.1691)^2 + (0.0180 - 0.0180)^2 \\ + (0.0131 - 0.0131)^2 + (0.0279 - 0.0186)^2 + (0.0286 - 0.0286)^2 + (0.0235 - 0.0200)^2 \\ + (0.0130 - 0.0130)^2 + (0.0231 - 0.231)^2 + (0.0154 - 0.0323)^2 + (0.0112 - 0.0187)^2 \\ + (0.0167 - 0.0279)^2\end{array}}$$

$$= \sqrt{0.0033} = 0.0575$$

In a similar way, the calculation technique is applied to the other alternative with respect to all criteria for obtaining values of D^+ and D^-. Table 6.18 summarises the values of the distance separation and closeness of each alternative

Table 6.18: The distance separation and closeness values of each alternative for liner shipping

	D^+	D^-
NSR	0.1629	0.0575
SCR	0.0575	0.1629

Step 6: Calculate the relative closeness to the ideal solution (RC_i^+)

Since this study has only two alternatives, therefore Equation 6.7 can be used to find the relative closeness to the ideal solution. The best shipping route will be chosen by shipping companies based on the RC_i^+value closest to the one which has the shortest distance from the positive ideal solution point and the farthest distance from the negative ideal solution point. Referring to the alternative 'NSR' as example and the D^+ and D^- value from Table 6.18 the value of RC_i^+ is computed as follows:

$$RC_i^+{}_{NSR} = \frac{0.0575}{0.1629 + 0.0575} = 0.2609$$

$$RC_i^+{}_{SCR} = \frac{0.1629}{0.0575 + 0.1629} = 0.7391$$

Table 6.19: The value of RC_i^+ for all alternatives and shipping types

RC_i^+	**Liner shipping**	**Tramp shipping**
NSR	0.2609	0.3105
SCR	0.7391	0.6895

Step 7: Rank the preference alternatives

Based on Table 6.19, it is obvious that the value of RC_i^+ for the SCR is closer to one or larger than the NSR. This indicates that, for both types of shipping (liner and tramp) the SCR has been proven to be the best route for transit shipping compared to the NSR.

Stage 8: Sensitivity Analysis

The sensitivity analysis was conducted to validate the model presented in this chapter. The method used was also the same as previous chapters. For 10%, 20% and 30% in weightage increase, there were no changes of ranking between the NSR and the SCR, which means that the model was robust. Table 6.20 shows a sensitivity analysis of 30% increase in weightage value for the main criteria (Liner shipping).

Table 6.20: A sensitivity analysis of 30% increases of weight value for main criteria (LINER shipping)

Criteria	Original weight	30% weight increase	TOPSIS result
Distance (DE)	0.0612	0.0796	NSR = 0.2676 SCR = 0.7324
Transport Time (TT)	0.13110	0.1704	NSR = 0.2974 SCR = 0.7026
Total Cost (TC)	0.2252	0.2928	NSR = 0.2603 SCR = 0.7398
Transport Services (TS)	0.2576	0.3349	NSR = 0.2291 SCR = 0.7709
Safety (SY)	0.2347	0.3051	NSR = 0.2039 SCR =0.7961
Emissions (EM)	0.0902	0.1173	NSR = 0.2670 SCR = 0.7330

From Table 6.20, with 30% increase in weight value of main criteria, TOPSIS result showed that the SCR was still the best option. This means that there is nochange in ranking between the two routes. Obviously, the situation was the same for 10% and 20% increase of weight value. The ranking of the weightage value has changed but TOPSIS result was still the same. For example, Table 6.21 shows the new ranking of the main criteria when criterion TC increased by 30%.

Table 6.21. The weight scores and ranking of all criteria when criterion TC increased by 30%.

Criteria	Original weight values	Ranking	New weight values	Ranking
DE	0.0612	6	0.0477	6
TT	0.1311	4	0.1176	4
TC	0.2252	3	0.2928	1
TS	0.2576	1	0.2441	2
SY	0.2347	2	0.2212	3
EM	0.0902	5	0.0767	5

This indicated that for 30% increase of weight values for criterion TC, the value of RC_i^+ only increased by 0.01542. There was no change in position between the alternatives. This was because the score for the NSR was very low, especially for sub-criteria RY, FY, TF and FS. Referring to Table 6.9, the NSR scored better than the SCR with eight out of 13 criteria for Liner Shipping. However, the final results (TOPSIS calculation) showed that the SCR was the best shipping route. This was easy to find out because the sub-criteria RY, FY, TF and FS scored very low as compared to the SCR. Therefore, the next sensitivity analysis would be focused on these four sub-criteria.

For 30% increase in value for RY, FY, TF and FS (2.17, 2.6, 1.3 and 2.17, respectively) the TOPSIS calculation showed that the NSR scored 0.275 and the SCR scored 0.725. However, the SCR was still the best option. This indicated that the score for the NSR should be more than 30%.

For 300% increase in value for RY (5), FY (6), TF (3) and FS (5) (new values in bracket), the new RC_i^+ for the NSR was 0.384 and the SCR was 0.616. This analysis also showed that the SCR was still the better option.

After a few more trials to find the minimum score for the NSR to beat the SCR, the scores were as follows; RY (5), FY (6), TF (6), and FS (6) (Table 6.22, in brackets showed the percentages of increase from the original scores). The TOPSIS calculation showed that the NSR was finally the better option with 0.5050 RC_i^+ value and 0.4950 for SCR.

Table 6.22: A sensitivity analysis of new data of selected evaluation criteria for liner shipping

	DE	TT	TC	TS					SY		EM		
				RY	FY	QY	LF	CS	TF	FS	CO	NO	SO
NSR	7085	19.35	789.72	5 (300%)	6 (300%)	6	57.5	15525	6 (600%)	6 (400%)	3174	3	3
Suez	11447	31.85	898.47	8.67	8	4	73.5	13230	9	8.33	6643	5	5

For Tramp shipping, the analysis was almost of the same indication as Liner shipping. However, because of the different weight values and weight ranking between these two types of shipping the sensitivity analysis for Tramps shipping must be conducted.

For Tramp shipping the NSR also scored better in eight out of 13 criteria. It also scored quite low in the same criteria as Liner shipping. However, the weight values for safety factor (comprised of TF and FS) scored much higher as compared to the other criteria (Table 6.12). In that case, the sensitivity analysis will be conducted only for TF and FS sub-criteria.

By referring to Table 6.12, for 200% increase (there was no need to conduct for 10%, 20% and 30% increase value because of the same reason mentioned before) of value for TF and FS, and the new values were 4.66 for both criteria. Then, the TOPSIS calculation was conducted again and the results showed that the NSR scored 0.4431 and the SCR scored 0.5569, which means that the SCR was still the best option.

For 300%, the new values for TF and FS were 6.99 for both criteria. The final results with the new values were: the NSR with 0.625 and the SCR with 0.375. The NSR has now to be the best option.

As a conclusion, the conducted sensitivity analysis showed that the model output responded appropriately to changes in the model input. Besides, the NSR needs to perform very well in terms of safety and transport services for both types of shipping to be the best shipping transit form the Far East to Europe. From the sensitivity analysis conducted, the NSR should be performed from 200% to 300% and up to 600% higher than the current score. It is worth to mention that with 300% up to 600% increase, the new value is still lower than the SCR but it is enough to be the best option because the NSR has performed very well in other areas (Table 6.22).

6.7 Conclusion

Despite the better quantitative data for the NSR which derive from a shorter distance, shorter total time, low total cost, more round trips, more capacity supply, and low emissions, the NSR is still an unviable option compared to the SCR. This is because the qualitative data for the NSR such as reliability, flexibility, load factor and safety of the route have scored quite low compared to the SCR. This also shows that the past literature that concluded that the NSR is profitable based only on cost structure does not help the shipping companies to decide whether to use the NSR for shipping transit or not. The model proposed in this study, together with the TOPSIS method calculation, is capable of assisting shipping companies in making informed decisions and preventing any loss of revenue. Having said that, the NSR has much potential as a shipping transit route because of the reasons mentioned above. This will not, however, occur soon, due to the challenging ice conditions, and the existing infrastructures are still not adequate to accommodate shipping operations**.**

CHAPTER 7:

DECISION STRATEGIES TO ENHANCE THE USE OF THE NSR USING SOFT SYSTEMS METHODOLOGY (SSM)

Summary

The Northern Sea Route (NSR) as the new shipping route has raised some issues as discovered and briefly explained in Chapter 2. These issues are believed to restrict the use of the passage for shipping transit despite the benefits it offers such as the shorter distance. However, in this chapter, only several issues or problems will be discussed as identified from Chapter 6. These issues will be further broken down to find the root of the problems and systematically analysed by using Soft System Methodology (SSM).

7.1 Introduction

The shipping industry has been highly unprofitable for many years (Glave *et al*., 2014). Making things worse, earnings have been exceptionally volatile. Several factors are responsible, notably the trade industry's spotty recovery from the global financial crisis, redoubled efforts by corporate customers to control costs, increased inward-looking policies and the rise of trade protectionism (UNCTAD, 2018).

These problems are real and significant, and largely beyond the power of any one company to address. However, shipping companies cannot afford to throw up their hands and accept their fate. Hidden beneath these issues (and driving them to a degree) is another set of challenges that shipping lines can readily take on.

The calculation of total cost for both Liner and Tramp services to use the NSR has been proven profitable (see Chapter 6). Therefore, shipping companies need to find the opportunity to overcome all the risks that are involved in using the NSR. From a project point of view, risk taking is vital to companies seeking market success. Risks are, however, often thought of only as a negative, despite the fact that they can present significant opportunities and possibilities for organisational innovation and new competitive advantage leading to short- and long-term profitability. In fact, risk and opportunity are a duality—like two sides of the same coin (Bekefi *et al*., 2008).

Managing hazardous risks has been recognised as a critical business issue prompted by events as diverse as the financial debacles and hurricanes disaster (Bekefi *et al*., 2008). That is why it is important to address the issues or problems that restrict the use of the NSR and to find the solutions to the problems. By doing that, the risks of using the NSR can be reduced, potentially increasing the profit of shipping companies and the traffic flow of the route.

In network design, more than a few shipping companies use outmoded approaches to design their routes; new and more powerful systems use algorithms to make better, more effective decisions about networks (Agarwal and Ergun, 2008; Bekefi *et al*., 2008). However, not all problems can be overcome by using algorithms and numbers. There are several categories of the complexity of problems in the world, as well as methods and methodologies to solve them. Problems vary between two extremes (Diaz-Parra *et al*., 2014) as follows:

1) Hard Problems. These are situations where the "what?" (this is the problem) and the "how?" (as they solve the problem) are clearly defined. Some examples of hard problems include maximising corporate profits, minimising the cost of production of the company, changing the tyre on the car, preparing a chocolate cake, and constructing a building, among others. Some methodologies related to hard problems are systems theory, operational research, decision theory, and systems analysis.

2) Soft Problems. These are situations where the "what?" is very difficult to define and the "how?" is difficult to solve. Some examples of the soft problems include defining the business mission, solving the problem of poverty in a country, implementing a quality programme in a company to develop an information system for decision making, and implementing a strategic change in the company, among others. A methodology related to soft problem is Soft Systems Methodology (SSM).

7.2 Literature review

SSM was developed as a means for understanding and dealing with the diversity of views and interests (Smith and Shaw, 2018). SSM is a methodology and a learning system that can be used both for general problem solving and in the management of change. To intervene in such situations, SSM uses the notion of a ''system" as an interrogative device that will enable debate amongst concerned parties. According to Jackson (2001) and Mingers (2000b), SSM represents a different approach to traditional systems engineering (SE), in that it is claimed that the system should not be viewed as some part of the world which is to be engineered or optimised, but instead should be seen as a process of enquiry. In other words, the notion of a system is no longer applied to the world but is instead applied to the process of dealing with the world.

SSM remains the most widely used and practical application of systems thinking (Mingers and White, 2010) (see Table 6.1 for range of applications). The methodology has been described in several books and many academic articles. There are now several hundred documented examples of the successful use of SSM in many different fields, ranging from ecology, to public services, information systems, and business applications (Smith and Shaw, 2018). Despite revisions to the methodology (Checkland and Poulter, 2006), it is the classical view of the methodology that is most widely used in practice (White and Mingers, 2010).

Table 7.1: Application of SSM and PSMs (Mingers and White, 2010)

Health	Angelis *et al*., (1998), Brazier *et al*., (2008), Fahey *et al*.,(2004), Gregory and Midgley (2000), Hindle *et al*., (1998), Kotiadis and Mingers (2006), Lehaney and Paul (1996b), Walsh and Hostick (2005), White (2003)
Environment, agriculture	Bunch (2003), Hjortso *et al*., (2005), Kayaga (2008), Marshall and Brown (2003), Pahl-Wostl (2007), Paliwal (2005), Ridley (2005), White and Lee (2009)
Supply chain, production, projects	Bennett and Kerr (1996), Bunch (2003), Costello *et al*.,(2002), Hipkin and De Cock (2000), Horlick-Jones *et al*.,(2000), Ishino and Kijima (2005), Ormerod (1999), Winter and Checkland (2003)
Other applications	Brown *et al*., (2006), Costello *et al*., (2002), den Hengst *et al*., (2007), Horlick-Jones *et al*., (2000), Ormerod (1996; 1999; 2005; 1998)

Recent interest has been focused on using the approach to tackle major problems (Jackson, 2001), where there is a continued recognition that traditional SE and soft systems thinking are important and that together, they may bring significant developments to problem solving (Wierzbicki, 2007; Winter, 2006). Thus, it can be assumed without controversy, that these problems are generally complex, and in order to deal with them, there needs to be some contribution by both approaches. It is also now fairly well understood that tackling complex problems may involve different phases and therefore, different methods may be appropriate at different points in the whole business of dealing with the problem. These conditions provide a backdrop to recent developments in SSM and can be captured by the following themes as analysed by Mingers and White (2010) in their article.

The first theme relates to the fact that SSM has been adopted by many organisations and incorporated into other approaches. In fact, many practitioners have used SSM in parts and/or with other approaches. Researchers have recognised that this development is quite important but theoretically under-researched, and there have been various attempts at providing guidance for combining different methodologies.

The second theme is related to the first one in that the difference between hard and soft systems has come under scrutiny, with some researchers arguing that the difference is artificial. It may depend on how the approach is used and the extent to which it is used in a soft or hard way. Some researchers have explored using SSM with more formal modelling approaches either in terms of an integrated approach or in combination, while others claim more sensible reasoning for combining the hard with the soft. This development can be seen in the growing number of papers that have integrated or combined SSM with approaches such as simulation.

The final theme is connected to a growing interest in understanding and exploring the design of the intervention itself. This builds on the permanent view that if operational research (in particular PSMs) is to have a significant role and influence, it needs to come closer to the actual concerns of practitioners (and stakeholders). It was suggested in a recent paper, that SSM is a methodology used to support and structure thinking about, as well as intervening in, complex organisational problems.

7.3 The background of Soft Systems Methodology (SSM)

Soft systems methodology (SSM) is a general method for system redesign. Participants build ideal-type conceptual models (CMs), one for each relevant world view. They compare them with perceptions of the existing system in order to generate debate about what changes are culturally feasible and systemically desirable (Mingers and Rosenhead, 2004).

The background to SSM as an approach to systems thinking is well established (Mingers, 2000b). It was developed in response to the perceived failure of traditional systems engineering (SE), particularly with regard to management problems (Mingers and White, 2010). On the other hand, traditional SE develops systems by considering the purpose or objective, then works backwards to find ways of achieving that objective, often via a device of a (mathematical) model that pursues an objective from a declared point of view; SSM was developed as a result of the failure of this approach in many management situations. In other words, they attempted to apply a Hard Systems Approaches (HSA) to fix business problems. What they discovered was the approach often stumbled at the first step of problem definition. The pioneers of SSM found that in many situations, the questions ‘what is the objective?’ and ‘what are we trying to achieve’ were part of the problem (Checkland in Rosenhead and Mingers, 2001). This happens quite simply because the different stakeholders have divergent views on what constitutes the system, the purpose of the system, and therefore the problem. Without an agreement on objectives or if the objectives are badly defined, the results of traditional SE would be loss of confidence in the model, and most likely lead to dissatisfaction on the part of those whose view of the objectives is not implemented. Thus, the primary contribution of SSM is in the analysis of complex situations where there are divergent views about the definition of the problem.

Two key players in the development of the SSM are Peter Checkland (1999) and Brian Wilson (2001), who through “action research” were able to put together a practical and pragmatic approach to the identification and solution of “soft” ill-defined problems. Figure 7.1 shows the purpose of SSM.

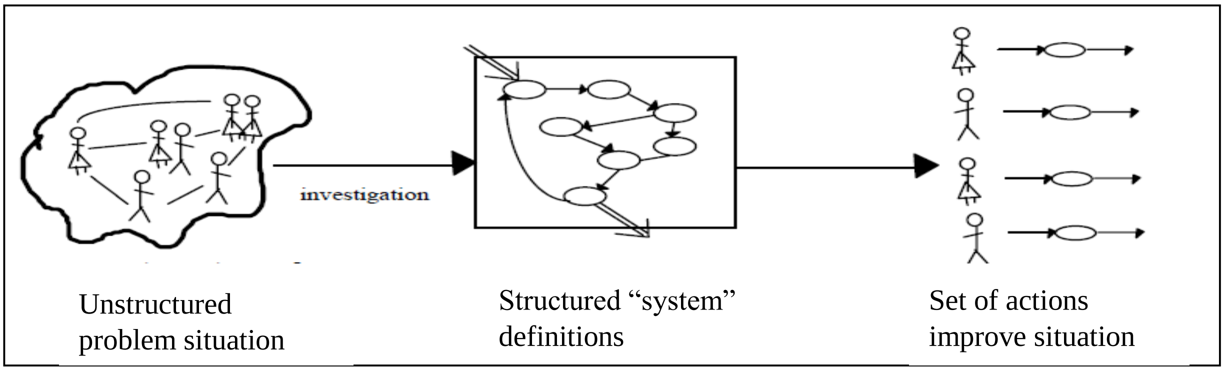


Figure 7.1: The purpose of Soft System Methodology (Gasson, 1994)

SSM was developed to provide a tool for investigating unstructured problem situations. Such unstructured problems are characterised (Rosenhead and Mingers, in Mingers and Rosenhead, 2004) by the existence of:

• Multiple actors,

• Multiple perspectives,

• Incommensurable and/or conflicting interests,

• Important intangibles,

• Key uncertainties.

This methodology was more than just a process; Checkland (1999) and Wilson (2001) also developed a set of tools to help users carry out the steps. These include:

- Rich Picture
- Conceptual Model
- CATWOE

These tools will be further explained in the next section.

7.4 Generic methodology of SSM

There are seven steps of SSM as shown in Figure 7.2.

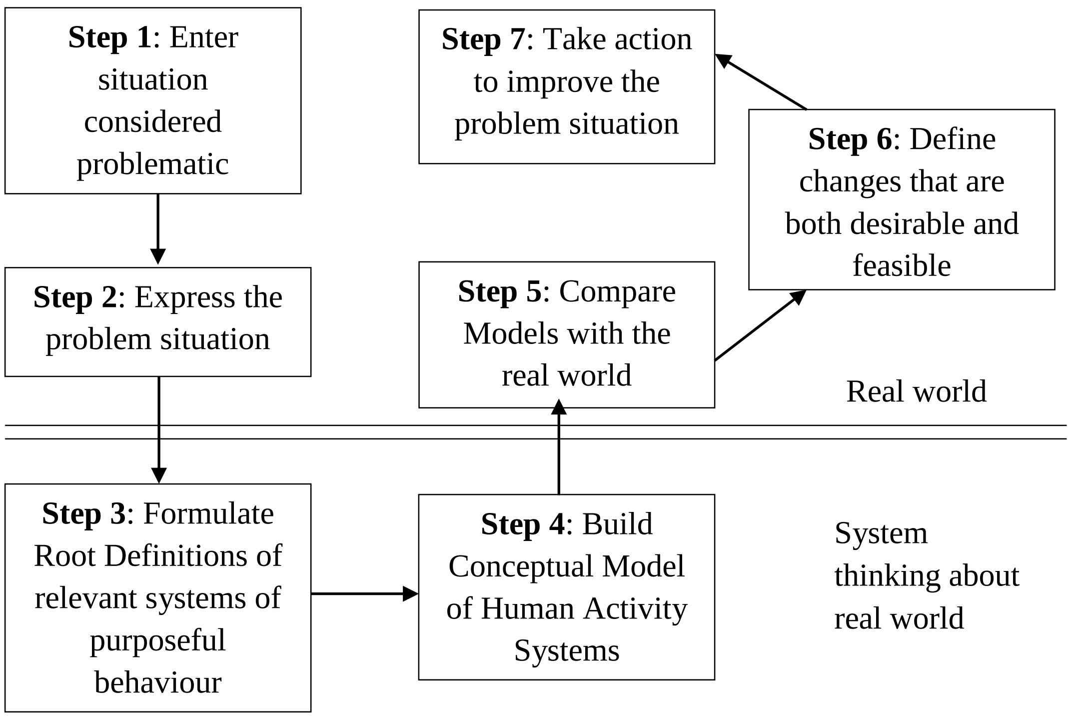


Figure 7.2: Seven steps of SSM (Gasson, 1994)

Step 1: Enter situation considered problematic

This step is concerned with the real world and the gathering of information and views about situations that are considered to be problematic, and therefore, there is some scope for improvement. Typically, once it has been agreed that some change or review is needed. This step also involves some basic research into the situation to gather information on the key stakeholders and current performance and issues.

The investigator(s), referred to by Checkland and Scholes (1990) as "would-be improvers of the problem situation", try to understand, in as wide and holistic a sense as possible, the problem situation context and content. This can be done by the use of interviews, observations, and workshops, where organisational actors describe their work and the problems that they encounter. It is important to see this stage as a prelude to expressing the problem situation; a means of moving to a state of affairs where the situation is understood reasonably well and is capable of being expressed in words and diagrams.

Step 2: Express the problem situation

Recognising that the real world is messy, the second step in concerned with capturing multiple views of the situation. To accomplish this, Checkland *et al*., (2001) developed the notion of a Rich Picture to capture the various perceptions. They understood that complex situations could not be adequately captured by words alone; diagrams and pictures are far more effective and can pack a higher density of information per cm^2. The idea behind the construction of a Rich Picture of a particular situation is that it (Burge, 2015):

- Allows differences of interpretation to be identified
- Permits agreement to be made on the interpretation to be taken
- Is a source of inspiration as to what relevant systems could be modelled through the assimilation of relationships, issues etc. It helps identify themes to take into the systems world.

Because every situation is different and it is necessary to capture this potential variety, there are no formal Rich Picture modelling symbols. In order to make explicit (visible and open to question) the decision on what to include or exclude, it needs to include as much information as possible in order to obtain a "rich" (in the sense of full, complete, wide-ranging) picture of how, and in what environment, the system operates.

Step 3: Formulate Root Definitions of relevant systems of purposeful behaviour

The purpose of this stage, according to Checkland in Gasson (1994), is to name the system. This is seen as important because by naming a thing, for this case a system, means that we define exactly what we mean by our understanding of it. This understanding is defined with sufficient precision to enable other people - the client of the analysis, or people who will be affected by the changes which we are proposing - to understand how we are defining their system of work and to contribute to, or perhaps challenge, our definition of it.

The root definitions of the system are derived in two stages: by deriving input-output diagrams, which reflect different perspectives of the same system, then by using these as the basis for a precise "Root" definition of the system as seen from each perspective.

(a) Input-Output Diagrams

This stage imposes some structures onto the analysis, by producing a set of transformations that achieve the purposes of the proposed "system". While wanting to make the system as inclusive as possible, it is important to limit the number of transformations that will be analysed. A useful set of transformations is between five and seven as suggested by Gasson (1994) and can be decided by explicitly discussing with clients or being given suggestions by clients as to what to include and what to exclude from the system.

Gasson (1994) suggested thinking holistically when selecting input-output transformations for the new system. This is because this process is to define a set of transformations that must achieve the aims of all the people involved in the system. To derive an input-output transformation, the following variables need to be defined:

- input to a work process
- output from that work process
- the transformation: the work process that gets from the input to the output
- how success is measure, in achieving the transformation

Figure 7.3 shows the input-output diagram for the system.

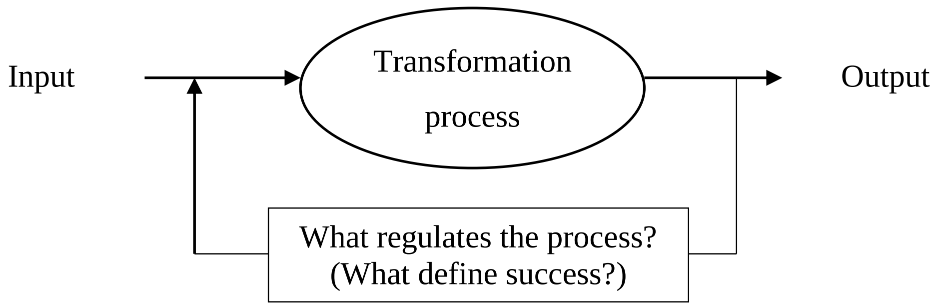


Figure 7.3: The input-output diagram

(b) Root Definitions

The Root Definitions consist of naming the system that supports each transformation. The Root Definitions "names" the system in a structured way, which makes us understand what the system is going to do and how it is going to do it. When deriving a Root Definition, the CATWOE mnemonic (Checkland, 2001) is used, to ask the following questions (Table 7.2):

Table 7.2: The definition and the question of CATWOE mnemonic

Customer:	Who is the system operated for?
Actors:	Which single group of people will perform the activities involved in the transformation process?
Transformation:	What single process will convert the input into the output? Remember that the input and output must be those at the system boundary, which should be the same for all transformations defined.
Weltanschhaung: (this means world-view, in German)	What is the view which makes the transformation worthwhile? (this has a lot to do with how success is defined, but also states why the transformation process is being performed at all)
Owner:	Who has the power to say whether the system will be implemented or not?
Environment:	What are the constraints (restrictions) which may prevent the system from operating?

Step 4: Build Conceptual Model of Human Activity Systems

Deriving a conceptual model is a method of analysing the activities that need to take place in order to clearly define what the actors need to do in order to achieve the transformation. The activities listed must be from the one group of actors named in the root definition. To achieve the objectives of the system, the activities need to be listed and numbered in the order that they are performed.

Deriving a conceptual model involves two steps:

- Listing all activities required to achieve the root definition of the system (each activity should begin with a verb).
- Graphically relating the activities together, with monitoring and feedback activities.

According to Burge (2015), the conceptual models sometimes is not complete because such a model is specifically developed for Human Activity Systems (HAS). The systems achieve their purpose through human activity as opposed to software intensive systems or hardware (product) intensive systems. It is the fact that HAS contains humans that makes the conceptual model incomplete.

Step 5: Compare Models with the real world

Step 5 is returning to the real world and comparing the reality experienced and captured in the models. The purpose of the comparison is to initiate discussion from which changes to improve the situation that can be identified. The approach uses the models to provide a means of perceiving a different view of reality by testing assumptions that may exist but are ill founded. It is the difference between what happened in reality and the logical model that raises the questions that will ultimately lead to change.

The conceptual models derived can be compared with the real world in a number of ways (Burge, 2015):

• The activities can be considered individually, with each activity compared to real life for its effectiveness and its links to other activities.

• Activity diagrams (like conceptual models, but for real-world activities) can be drawn and compared to the conceptual models.

Whichever method is used, the intention is to derive a list of process changes; changes to work processes and activities that are necessary in order to move towards the system modelled in the conceptual model.

Step 6: Define Changes that are both Desirable and Feasible:

The purpose of this stage is to gain some input from the organisational stakeholders: managers, shareholders, customers of the organisation, those people who will be affected by changes to the existing system and those people who will be involved in implementing changes. Of course, it is not usually feasible to interview a representative sample of all of these people; but the minimum that should be done is to speak to those affected by the proposed changes, to elicit their opinion on what their priorities are, and what they consider feasible or infeasible and why.

Step 7 Take action to improve the Problem Situation

Once the changes that are considered 'desirable' and 'feasible' have been identified, the effort is expended to implement these. This implementation will result in new systems that will affect the bigger system leading to more opportunities and problems, and so the process starts again.

7.5 Case study: The application of SSM for solving the problems of the NSR

Step 1: Finding out the problem situation

The NSR has been open since 1991 when the Russian President at that time announced it open for international use. However, the ice conditions still became a major obstacle for vessels to get through the passage and finally in 2009, the Beluga ship was the first foreign vessel that went across the NSR. Since then, many foreign vessels have also been attracted to use the NSR as a transit route. The Arctic sea ice extent also recorded a lower extent (Figure 5.2) especially each summer. With this condition, one expects to see that the traffic will increase each year. However, the statistics show otherwise (Table 7.3). What would be the problem? Why has the NSR failed to attract shipping companies to use it despite the shorter distance it offers for shipping transit, especially between the Far East and Europe? From Table 7.3, it can be seen that, the ships transiting the NSR stopped increasing in 2013 (73 ships). It then started to decline onwards until 2016 (no record found in 2017 and 2018).

Table 7.3: The summer shipping transit traffic of the NSR from 2011 to 2016 (source: www.nsraadministration.com)

Type of cargo	2011	2012	2013	2014	2015	2016	Total
Liquid	15	26	31	27	1	1	**101**
Bulk	3	6	4	1	0	2	**16**
LNG	0	0	1	0	0	0	**1**
General cargo	4	0	13	15	3	4	**39**
Others	19	14	22	10	14	11	**90**
Total	**41**	**46**	**71**	**53**	**18**	**18**	**247**

Step 2: Expressing the problem situation

Some weaknesses of the NSR have been figured out in Chapter 6, which are Reliability, Flexibility, Load factor, and Safety factor. These factors have scored the lowest points in TOPSIS calculation as compared to the Suez Canal Route. Furthermore, these factors have already been mentioned by previous researchers, as listed and explained in Chapter 2. Indeed, the NSR has failed to attract shipping companies to use it for shipping transit because of the named factors. The 'Rich Picture' of the problems is shown in Figure 7.4. This problem diagram shows the issues or problems of the NSR and the related issues derived from it. This diagram also identifies the need to solve the particular problems. Based on the problem diagram of the NSR, eight issues have been identified, with hard and soft problems.

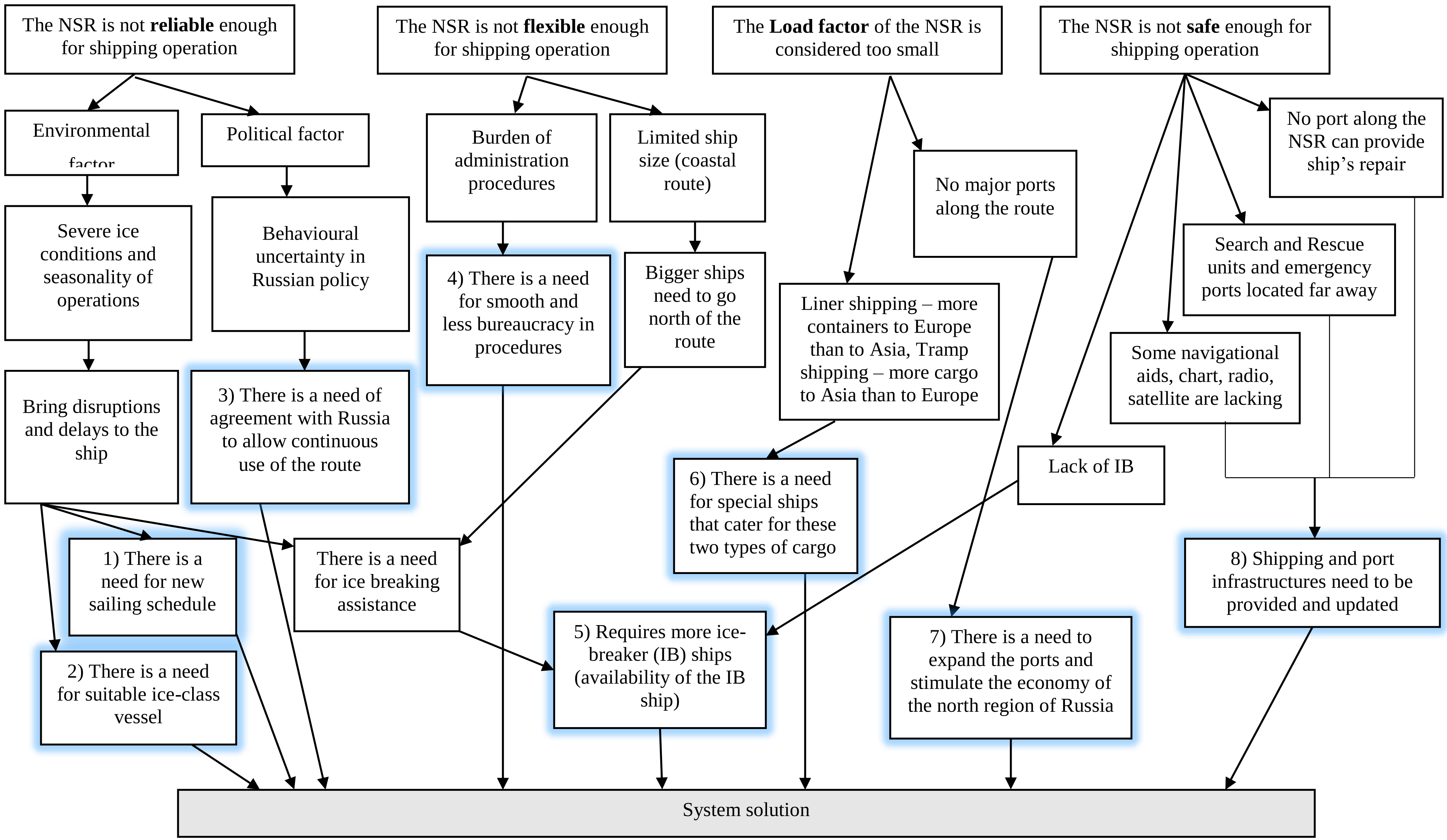


Figure 7.4: The problems diagram of the NSR

Step 3: Formulate Root Definitions of relevant systems

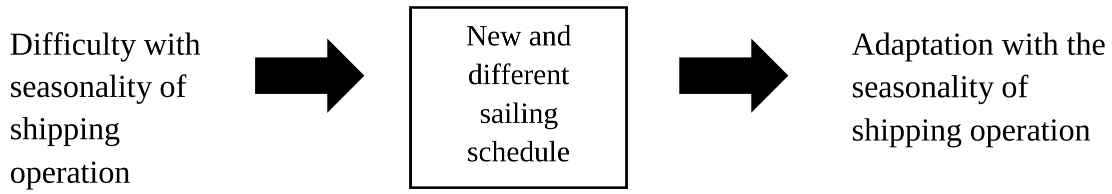
All eight issues from the problem diagram were further analysed and run through into two sub-steps: Input-output diagram and CATWOE process.

Step 3(a) Input-output diagram

In this step, a different approach will be used to formulate the root definitions for each system identified. Instead of using interviews to gather all information from multiple actors, this research uses a literature survey.

1) New sailing schedule for the NSR shipping

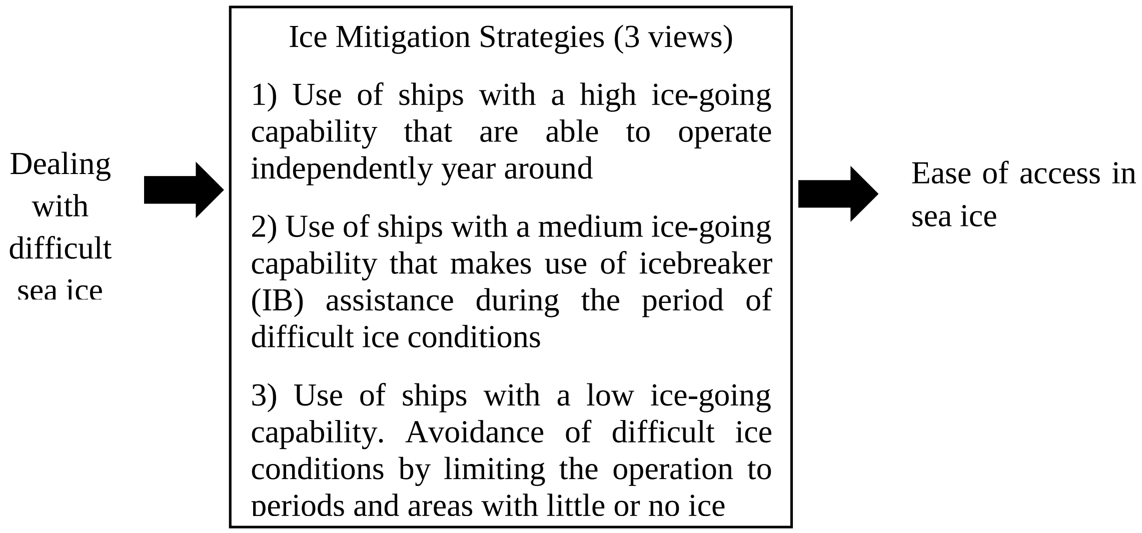
This idea has been identified by many previous researchers such as Omre (2012), Furuichi and Otsuka (2013), and Lasserre (2014). This problem, however, is only for container shipping that operates in a very tight schedule.



Success = Liner shipping services can be implemented

2) Suitable ice-class vessel for NSR shipping

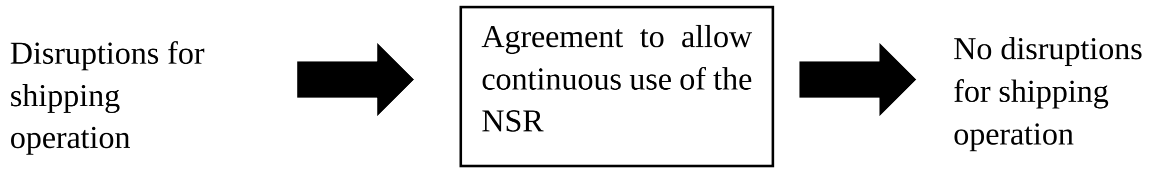
The solution for reliability issue, in particular the ice conditions in the NSR, has been proposed by Bergstrom *et al*., (2014). They suggested three views as shown in the diagram below.



Success = Reduce accidents and increase the reliability of the route

3) Agreement with Russia to allow continuous use of the route

This transformation process, which is to have an agreement with the Russia to allow continuous use of the NSR, was inspired from the Suez Canal Route (SCR) situation. Under the Convention of Constantinople, the SCR may be used "in time of war as in time of peace, by every vessel of commerce or of war, without distinction of flag”.



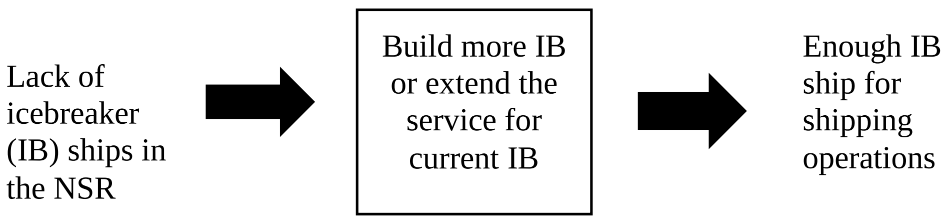
Success = allow continuous use of the NSR regardless of any situation that may

4) Smooth and less bureaucracy in administration procedures

This problem has been identified by Ragner (2000), Verny and Grigentin (2009), Erikstad and Ehlers (2012), and Liu and Kronbak (2010). This proposed transformation process is derived from logical thinking to the problem.

Success = Less bureaucracy and time taken in the procedure

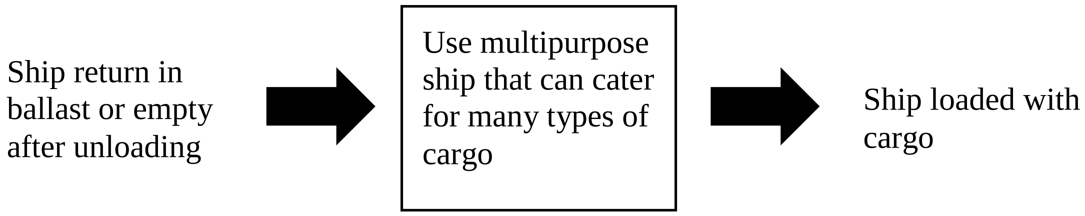
5) Requirement of more icebreaker ships



Success = Improved safety and reliability of the route

Many researchers, particularly, Ragner (2000) and Pastusiak (2016), have identified the problem and suggested such transformation process as shown in the diagram above.

6) Requirement of a special ship that caters for two types of cargo (bulk and container)



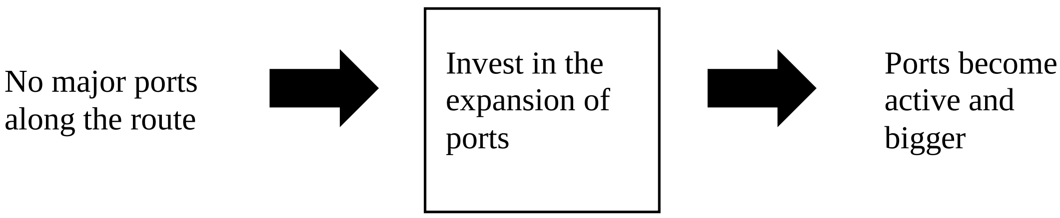
Success = Increase the profitability to shipowner

This problem has been identified by Humpert (2015) and Ragner (2000). The transformation process is suggested through logical thinking and also from the statistical data from a multipurpose ship named Yong Sheng. This Chinese ship is an ice-class multipurpose ship that operates in summer time in the NSR. This ship operates with cargo loaded from the Far East to Europe and vice versa, which is a rare situation occurred in the NSR.

7) No major ports along the route

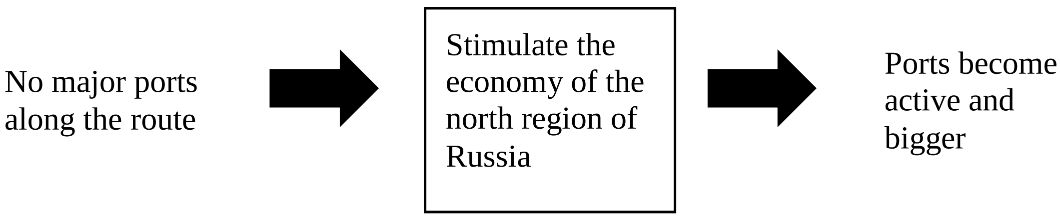
There are two views of the transformation process for this particular problem:

a) Directly invest to expand the ports



Success = increase the load factor of the route

b) Stimulate the economy of the north region of Russia

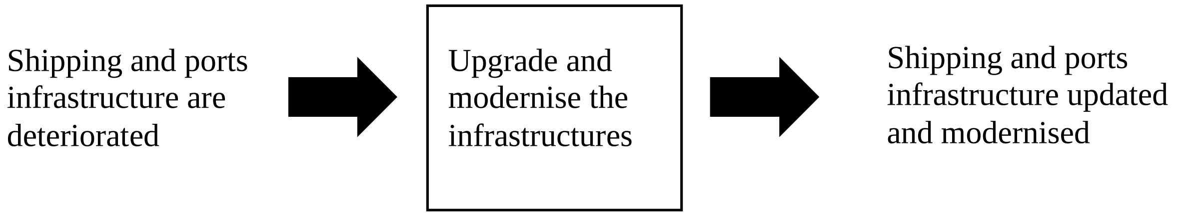


Success = increase the load factor of the route

This problem has been identified by multiple researchers such as Verny and Grigentin (2009) and Lasserre (2014). This situation here is a soft problem and many views can be taken to find the solutions. However, the view to "stimulate the economy of the north region of Russia" will be used for a further step because it is a much broader view. Plus, the view to expand the ports is also one of the ways to stimulate the economy of the north region of Russia.

8) Provide and modernise the shipping and port infrastructures

Almost all the literature has spotted this particular problem. Ragner (2000) and Pastusiak (2016) analysed this issue in great detail. The transformation process proposed here is a logical step to be conducted with the provided input.



Success = Safety and reliability of the route is increased

Step 3(b) – Root definition through CATWOE process

All eight problems will go through the CATWOE process.

1) New sailing schedule

C	Shipowner
A	Shipowner
T	Construct new sailing schedule
W	The profitability can be increased
O	Shipowner
E	High uncertainty as no other model has been used before

This system is owned by the shipowner, as it can construct a new sailing schedule, namely the combined NSR-SCR. The NSR is used in summer time and the SCR for the rest of the year. This work can be referred to Furuichi and Otsuka (2013) and Omre (2012). From the work of past researchers, it was concluded that this kind of strategy will increase the profit to the shipping companies. However, shipowners should have gathered more information to construct a reliable sailing schedule as there is high uncertainty because no such model exists before.

2) Suitable ice class vessels - Ice Mitigation Strategies

C	Shipowner
A	Shipowner/charterer
T	Use various Ice Mitigation Strategies (depends on the shipowner's decision)
W	Safety of the crew/ship/cargo is important
O	Shipowner
E	The cost of the ice-class ship, which is expensive

This system is owned by the charterer or shipowner where the shipowner can use various Ice Mitigation Strategies. There are still risks involved because of the nature of the route but the system proposed should have minimised it to as low as possible. If the shipowner chooses to build the ice-class ship, there will however be a very high cost involved and this affects the profitability of the company.

3) Agreement with Russia to allow continuous use of the route

C	All users of the NSR
A	Foreign countries and Russia
T	An agreement to allow the use of the route in any cases. Increase marketing that promotes international transit without discrimination of flag.
W	This will allow continuous use of the route and decrease uncertainty
O	Foreign countries and Russia
E	High uncertainty as Russia will not easily sign the agreement

This system is owned by all countries who are willing to use the NSR without any disruption due to the uncertain behaviour of the Russian state in terms of its policy. The proposed system will allow continuous use of the NSR and also may increase the shipping traffic, which will benefit the Russian government as well.

4) Smooth and less bureaucracy in administration procedures

C	Users of the NSR
A	Russian government
T	Rebuild the Standard Operating Procedure (SOP) of registration and permit to transit
W	Less administration procedure/less time taken, less cost involved in the registration process
O	Russian government
E	The system is not easy to change. May take a while for all parties involved to understand the system.

This system is owned by the Russian government because they are responsible for ship registration and issuing permits to use the NSR. All users of the NSR should have experience in having fewer administration procedures, which leads to less time and cost incurred if the Russian government revised and rebuilt the Standard Operating Procedure (SOP) of administration and registration process. However, the system in the beginning will take more time for all parties involved to understand it.

5) Requirements of IB ships

C	Users of the NSR
A	Russian government
T	Build more icebreakers or extend the services of the current IBs.
W	To ensure safety and smooth navigation
O	Russian government
E	High cost involved to build an IB

This system is owned by the Russian government, as they are the authority of the NSR. The Russian government can deploy two strategies to make sure the number of icebreaker ships is adequate for shipping operations within the NSR. First, they need to extend the services of the current IB ships by refurbishing the ships. Second, they must build more IBs with different classes and sizes. Although the second strategy will involve high cost, the new ships can stay in the service for 25–30 years as compared to the prolonged IB ships, 5–10 years added time. Nevertheless, both strategies can be applied at the same time.

6) Empty/ballast ship after unloading – use of multipurpose ship

C	Users of the NSR/shipowner
A	shipowner
T	Use a multipurpose ship to cater for the different cargoes
W	Increase profitability and optimise the ship
O	shipowner
E	The ship has a complex design and is difficult to build

Shipowners can invest in building the multipurpose ship to cater for the different cargoes flowing east and westbound of the route. This ship for example, carries containers from China to Europe, then loads with iron ore from Norway to China. This system together with “Ice Mitigation strategy” and “New sailing schedule system” will increase the profitability of the shipowner as well as lower the risk involved and improve safety.

7) No major ports along the route- Stimulate the economy of Northern Russia

C	People in the north region of Russia
A	Russian government/ foreign country
T	Stimulate the economy of the north region
W	Ports are depending on the economic growth of the region. Successful ports are located to optimise access to an active hinterland
O	Russian government/port authority
E	Happen in the long term May affect the fragile Arctic environment

This is a pure soft problem of the NSR that needs more views from other stakeholders and other parties such as the local people, investors, and the government. The expansion of ports is based on the market and the economy of the region. In other words, port choice is determined by a number of factors. Tongzon (2009) listed seven determinants of port choice, namely 1) frequency of ship visits, 2) port efficiency, 3) adequate infrastructure, 4) location, 5) port charges, 6) quick response to port users' needs, and 7) port's reputation for cargo damage. Therefore, the economic potential of the north region of Russia must be identified first. According to Melia *et al*., (2017), the Arctic economic growth is focused on four key sectors – mineral resources, fisheries, logistics, and Arctic tourism – all of which require shipping, and could generate investment reaching $100bn or more over the next decade. The transformation process can be designed around these four key sectors. However, this problem will need more funding and more time to make it successful.

8) Provide and modernise the shipping and port infrastructures

C	Users of the NSR
A	Russian government
T	Serious investment needed to upgrade and provide all the infrastructures along the route
W	Safety is important to all users of the NSR
O	Russian government and other parties
E	Limitations of communication systems in high latitude. Current maritime digital communication systems were not designed to cover Polar waters.

This is a straightforward system that needs a serious investment from the Russian government to update and modernise the current facilities in the NSR. The Russian government also needs to provide all missing infrastructures such as the communication systems because the current maritime digital communication systems were not designed to cover Polar waters.

Step 4: Build Conceptual Model of Human Activity Systems

Most of the problems and the systems identified were hard problems such as to create a new sailing schedule, use ice mitigation strategies, refine the administration procedure, build ice-breaker ships, use a multipurpose ship, and modernise the infrastructures. There are however only two soft problems identified, which are dealing with the uncertain behaviour of the Russian government and stimulating the economy of northern Russia. This means, for the hard problems, the solutions to the problems are almost straightforward. For example, requirement for icebreaker ships and modernise the infrastructures. These are in theory easily solved by building more icebreakers and infrastructures. Nevertheless, the conceptual models for the hard problems which can still be constructed are shown in Step 4 b).

a) General conceptual model for hard problems

In general, all hard problems for the NSR as mentioned before can be solved by using this proposed conceptual model, shown in Figure 6.5.

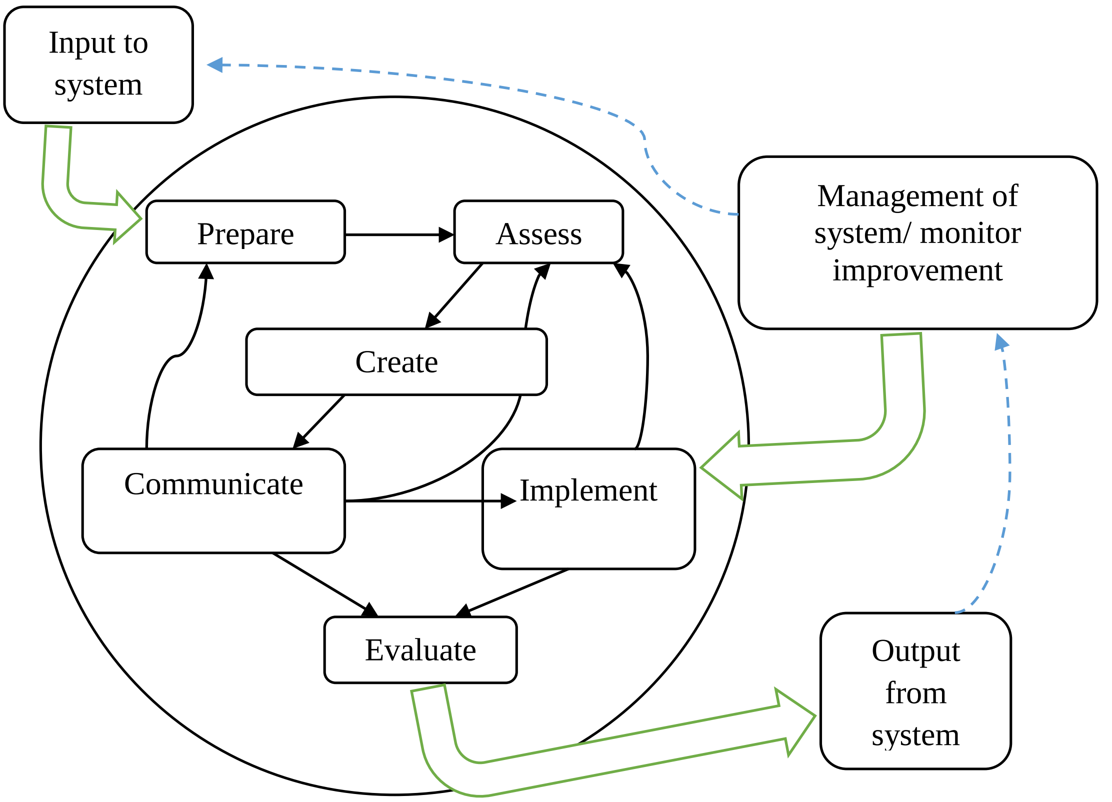


Figure 7.5: General conceptual model for solving hard problems of the NSR (Haines, 2007)

Any organisation embarking on strategic planning must first decide if it is an event, a process, a change in roles or a change in the way day-to-day business is run. While the complete answer is all of these, strategic planning must culminate in a significant change in the way daily business is conducted. This model is taken from a strategic planning process (Haines, 2007) that is used to solve known problems and clear objectives. There are six steps involved in this process, explained below.

STEP 1: PREPARE

This step lays a foundation for the strategic planning process by establishing the purposes of the plan; identifying stakeholders; determining what information, roles, and resources are necessary for the process; and developing the timeline for it. The products of the steps involved are the formation of a strategic planning workgroup and the identification of data needed to inform the strategic planning process.

STEP 2: ASSESS

The Assess step is the process through which the strategic planning workgroup reviews and analyses programme-related data, so the programme can allocate resources and services in the most strategic way. The Assess step, determines where the programme currently is. The product of the Assess step is an analysis programme consisting of Strengths, Weaknesses, Opportunities, and Threats (SWOT) based on the data review.

STEP 3: CREATE

In the Create step, the five-year strategic plan is to be written and developed. The strategic planning workgroup reviews the SWOT analysis and uses the findings to identify and prioritise strategies that the programme intends to implement during the five-year cooperative agreement. Then the program logic model is revised and the annual work plan is aligned with the prioritised strategies and the timeline to implement them. The main product of the Create step is the written strategic plan.

STEP 4: COMMUNICATE

The Communicate step involves sharing information about the strategic plan in ways that make the plan understandable and useful to stakeholders. The products of the Communicate step are the communication messages and products disseminating each year about the strategic plan, including its creation, implementation, and evaluation.

STEP 5: IMPLEMENT

In the Implement step, the strategies in the strategic plan are put into action as outlined in the strategic plan implementation timeline. The product of the Implement step is the completion of activities in annual work plans, as reflected in the achievement of objectives.

STEP 6: EVALUATE

Evaluate step evaluates the implementation of the strategic plan and the programme activities. The programme develops evaluation questions and collects data to inform the annual workplan for the coming year. Evaluation data were used to monitor how the five-year strategic plan is progressing. The products of the Evaluate step are evaluation findings, summaries of how the strategic plan is progressing, and description of changes to programme activities based on evaluation findings.

b) Conceptual models of eight root definitions of problem

This section is a proposed conceptual model for each identified root definition. Even though six out of eight problems are hard problems, they can still be constructed as shown next.

1) New sailing schedule conceptual model

This conceptual model for a new sailing schedule for container shipping within the NSR starts with two options, which are to design a new sailing schedule or to use other established models developed by Furuichi and Otsuka (2013) and Omre (2012) as shown in Figure 7.6. If the company chooses to design a new sailing schedule, some factors need to be considered such as ship size, ice class, fleet size, and other related factors.

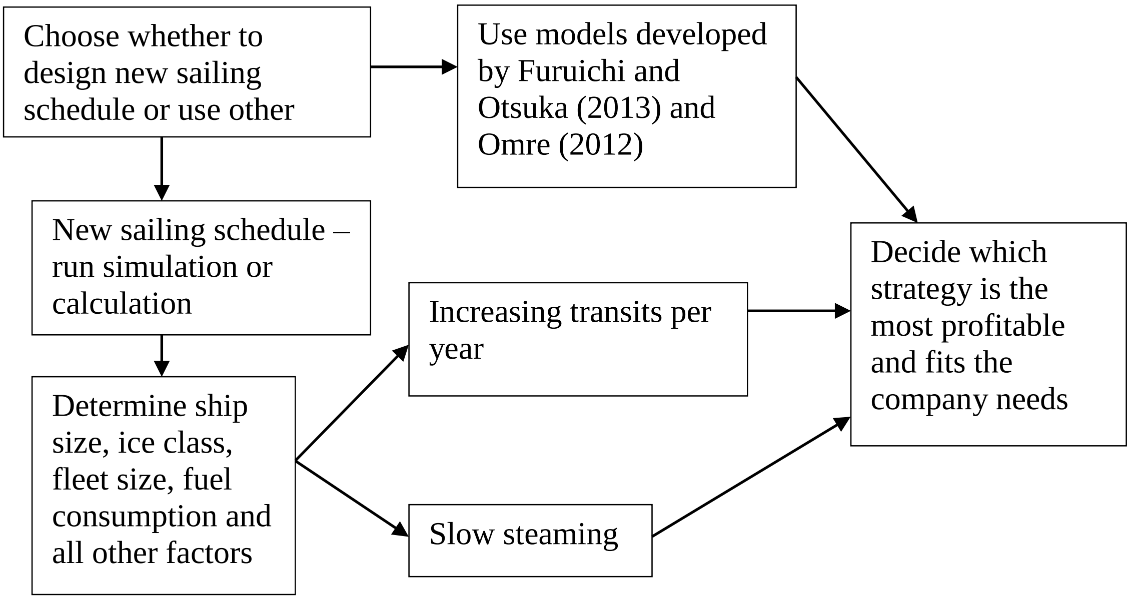


Figure 7.6: The conceptual model of new sailing schedule

The company also can implement the Fleet Composition Strategies (FCS) proposed by Bergstrom (2016), which are 1) use of multiple small or medium-sized ships to mitigate operational risks (slow steaming), or 2) use of a minimum number of large ships for maximum transport efficiency (increasing transit per year). The company will then decide which strategy is the most profitable that fits its needs. Decision-making methodologies can be used here, such as AHP, ER, VIKOR, TOPSIS, and other MCDM methods.

2) Dealing with sea ice conceptual model – Ice Mitigation Strategies conceptual model

There are three strategies that have been identified from Step 3, which are:

- The use of ships with a high ice-going capability that are able to operate independently year round;

- The use of ships with a medium ice-going capability that make use of IB assistance during the period of difficult ice conditions;
- The use of ships with a low ice-going capability. Avoidance of difficult ice conditions by limiting the operation to periods and areas with little or no ice.

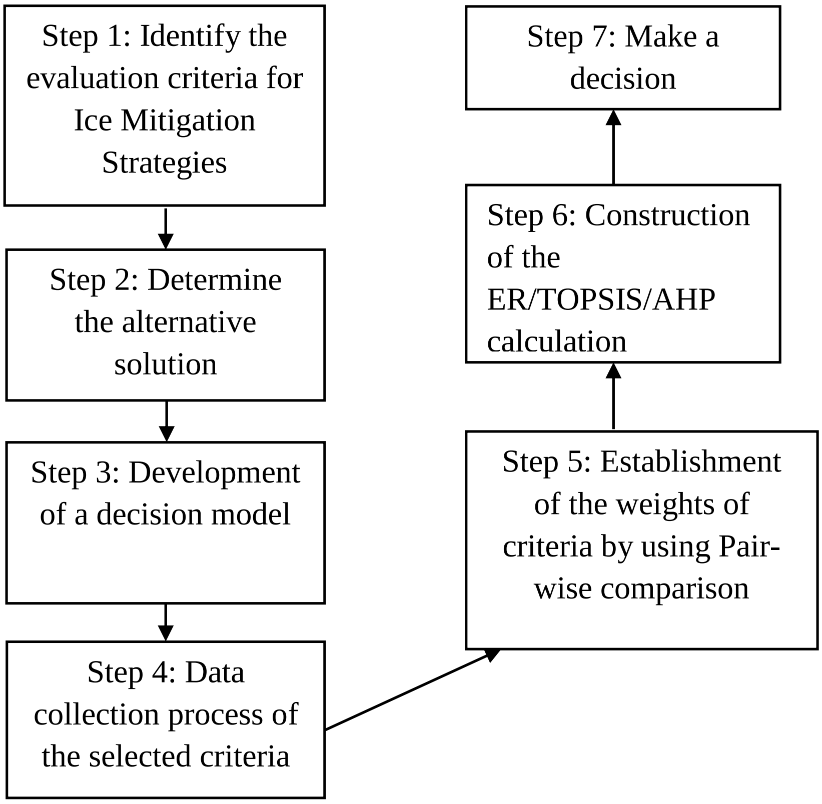


Figure 7.7: The conceptual model of ice mitigation strategies

These three strategies need to be carefully selected and many decision-making tools have been proven able to help solve this decision-making problem. The conceptual model presented here (Figure 7.7) is a classic approach of a decision-making problem which is also shown in the previous chapters of this thesis.

3) Uncertainty in behaviour of the Russian policy conceptual model

This problem may affect the profitability of the shipping companies in terms of discrimination of flag, high tariff and any other uncertainties made by the Russian government. This problem will need to have more views from other parties. However, for now, using an agreement to have a deal with the Russian government is a good approach to reduce the risks that arise from the uncertain behaviour from the Russia. Referring to Figure 7.8, this model starts with the shipping companies telling the Russian government of their interest in using the NSR as a frequent route for the company. From the previous report (Ragner, 2000), the Russian government will reduce the NSR tariff if that particular company uses the NSR frequently. They can then, create a mutually binding agreement that allows continuous use of the NSR.

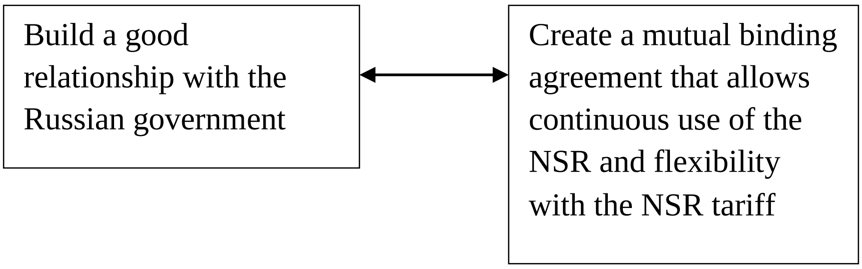


Figure 7.8: The conceptual model of dealing with uncertainty in behaviour of the Russian policy.

4) Burden of administration procedure conceptual model

The process starts with the review of the problem that has been highlighted by Ragner (2000), Verny and Grigentin (2009), Liu and Kronbak, (2010), and Erikstad and Ehlers (2012) (Figure 6.9). The NSR authority needs to review their own administrative process (permit to navigate and ship inspection), step by step and identify the process that can be removed and cut the time taken to conduct such process. Another good way to do this is by benchmarking and comparing the process with existing routes such as the Suez Canal Authority.

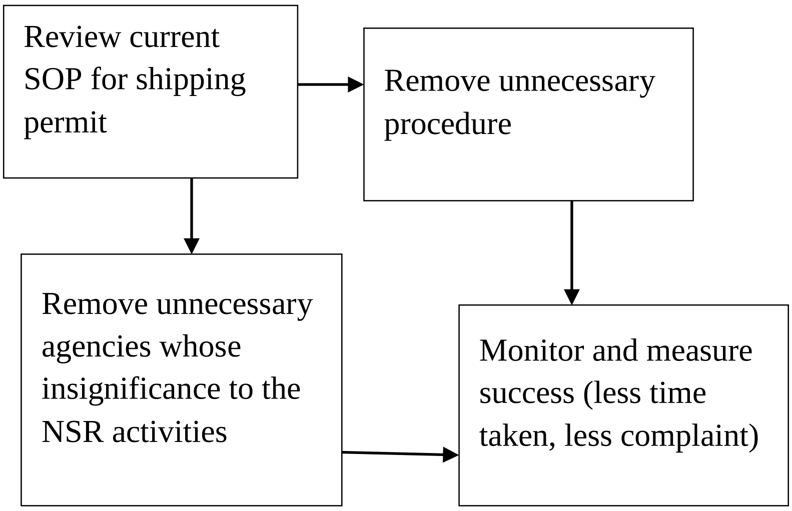


Figure 7.9: The conceptual model of reducing burden of administration procedure

5) Requirements of IB ships conceptual model

From the problem diagram, the needs of the icebreaker (IB) ships are identified. Therefore, the process starts with assessing the current availability of the IBs in terms of numbers, age, and remaining year of service (Figure 7.10). Ragner (2000) conducted an analysis of the need of

IB in summer and winter seasons of the NSR until 2015. His work can be applied to find the need of IB for another 15-20 years in the future. There are some concerns that need to be highlighted such as the cost to build IB and the types of IB needed. Diesel powered IB is suitable for coastal operations while nuclear powered IB can be used in remote sea areas. Extending the service of current IB is clearly the cheapest way to solve the problem of lack of IB. However, the service time is nowhere near compared to the newly built IB.

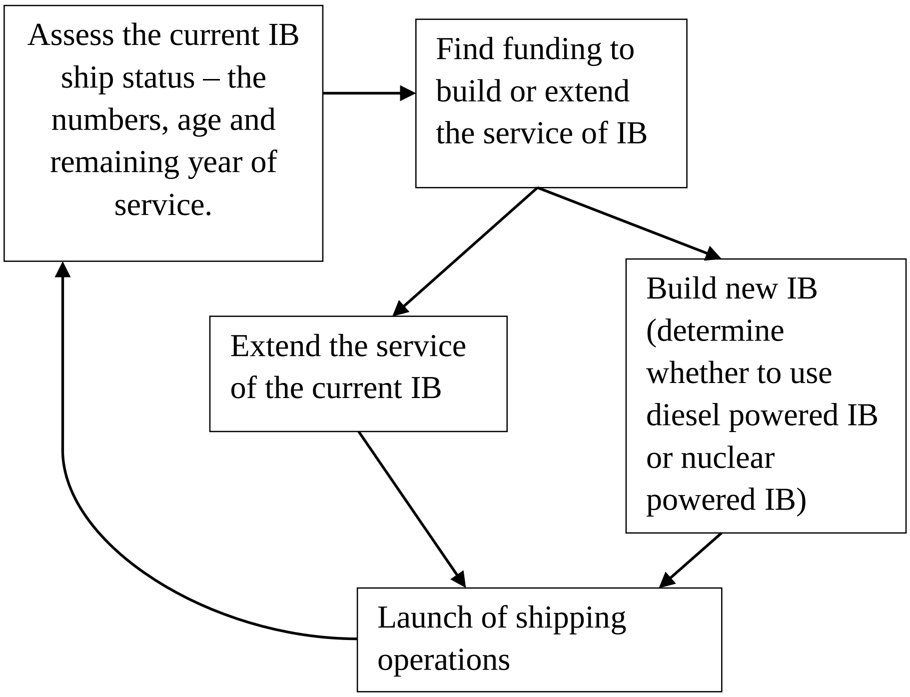


Figure 7.10: The conceptual model of requirements of IB ships

6) Empty/ballast ship after unloading (use multipurpose ship) conceptual model

Multipurpose ships can transport most goods, like containers, dry and liquid bulk, and break-bulk cargo. The ships are uniquely designed by engineers to handle any type of freight. As a result of the versatility of vessels, the crew have to be flexible with their schedule so that they can be ready to pick up any type of cargo from any port, at any time. The large sizes of multipurpose ships makes them capable of carrying vast amounts of cargo on board.

The model starts with the calculation of cost to build a new multipurpose ship or to charter a ship (Figure 7.11). After that, the best option that gives the highest profitability to the company is chosen. Then, a schedule for the ship is designed to operate and this process can be linked to the conceptual model of a new sailing schedule

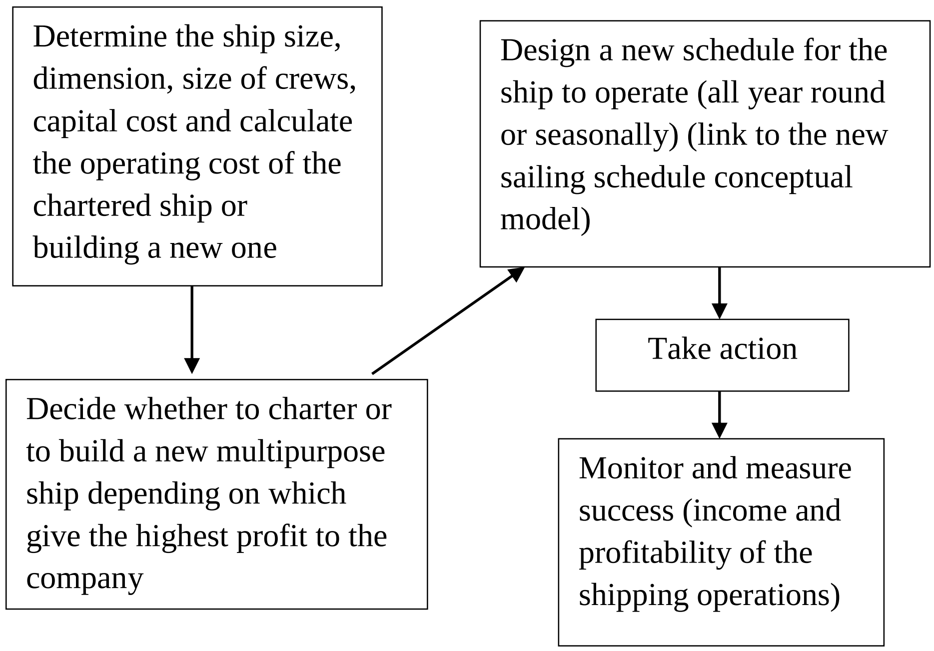


Figure 7.11: The conceptual model of dealing with empty ship after unloading

Some considerations are taken as proposed by Erikstad and Ehlers (2014) to balance the transport demand and capacity in varying operation conditions. They are:

- Varying the utilisation of the cargo capacity of the ships
- Varying the speed of the ships
- Varying the number of ships in operation
- Varying the utilisation of the capacity of port-based storage facilities
- Backhauling during periods with overcapacity
- A combination of the above listed strategies

7) No major ports along the route – stimulation of the economy of the north region conceptual model

The Arctic economic growth is focused on four key sectors – mineral resources, fisheries, logistics, and Arctic tourism – all of which require shipping, and could generate investment reaching $100bn or more in the Arctic region over the next decade (Melia *et al*., 2017). The Russian government needs to invest in the four key sectors in order to stimulate the economy of the north region particularly within the NSR. With that, the other elements such as port expansion and modernisation will take place.

Ports constitute an important economic activity in coastal areas. The higher the throughput of goods and passenger year on year, the more infrastructure, provisions, and associated services are required. These will bring varying degrees of benefit or disadvantage to the local and regional economy and to the environment. Ports are also important for the support of economic activities in the hinterland since they act as a crucial connection between sea and land transport (Dwarakish and Salim, 2015).

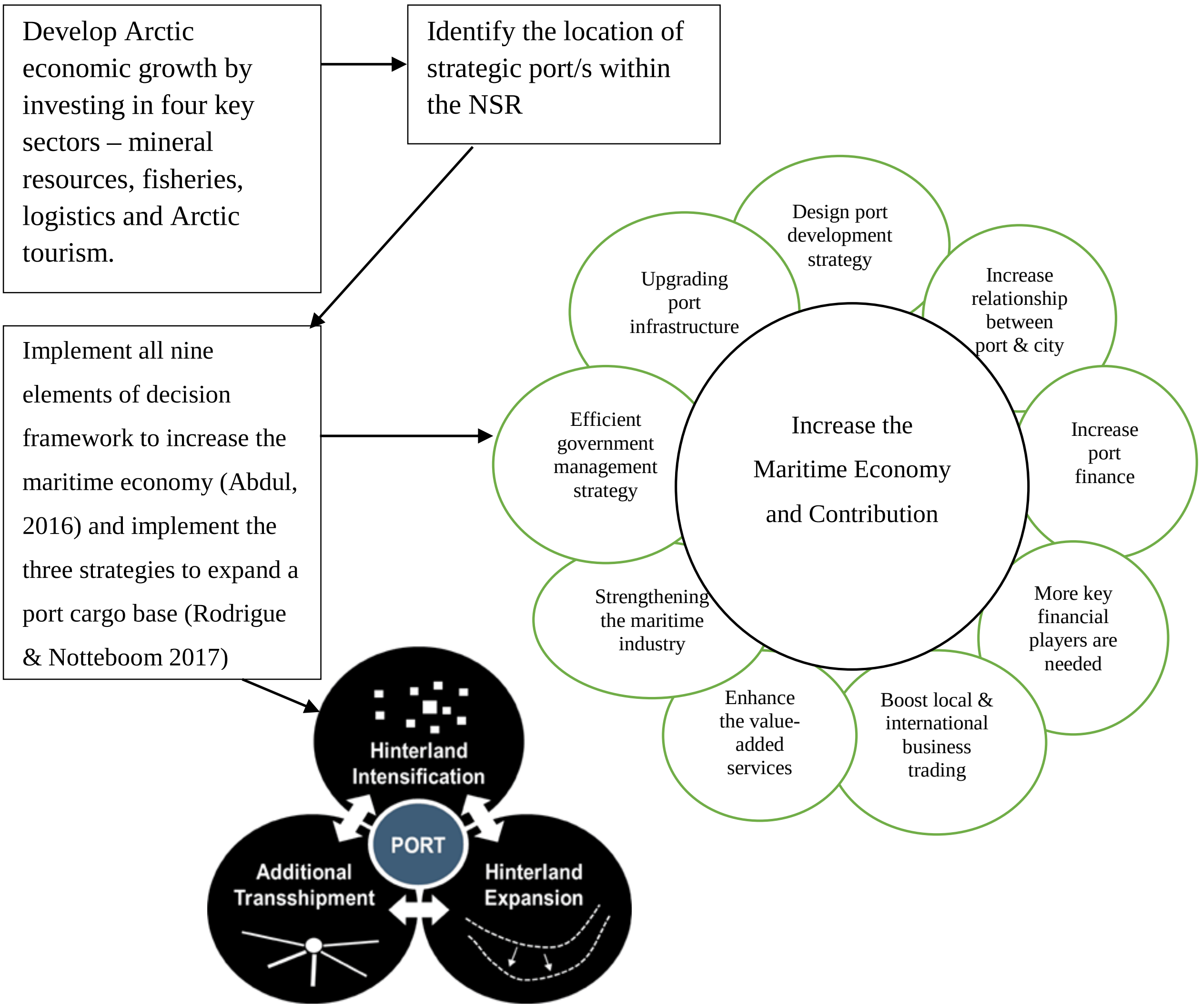


Figure 7.12: The conceptual model of stimulation of the economy of the north region

There are many researches that can be referred in order to develop and stimulate the economy of certain places. However, in this model, two pieces of literature are referred to, by Abdul Rahman, (2016) and Rodrigue and Notteboom (2017). Nevertheless, this proposed model is a simplification of many activities that can be further elaborated. For example, based on the work by Rodrigue (2017), a port can be expanded by using three strategies, which are hinterland intensification, hinterland expansion, and additional transhipment. These three strategies can be further classified for example, building roads and rail tracks and connecting them with main roads etc.

8) Modernise shipping and ports infrastructure conceptual model

This problem is a classic problem to solve using the strategic planning process. All shipping infrastructures are first analysed and assessed to have a clear status. The status of the infrastructures are well discussed in Chapter 2 of this study. The existing infrastructures only need good maintenance to keep them functioning. However, the Russian government needs to build or install any new infrastructures needed to increase the safety of the navigation in the NSR. The only problem to this issue is the big money involved and it takes many years to complete. Figure 7.13 shows the conceptual model to modernise shipping and port infrastructures in the NSR.

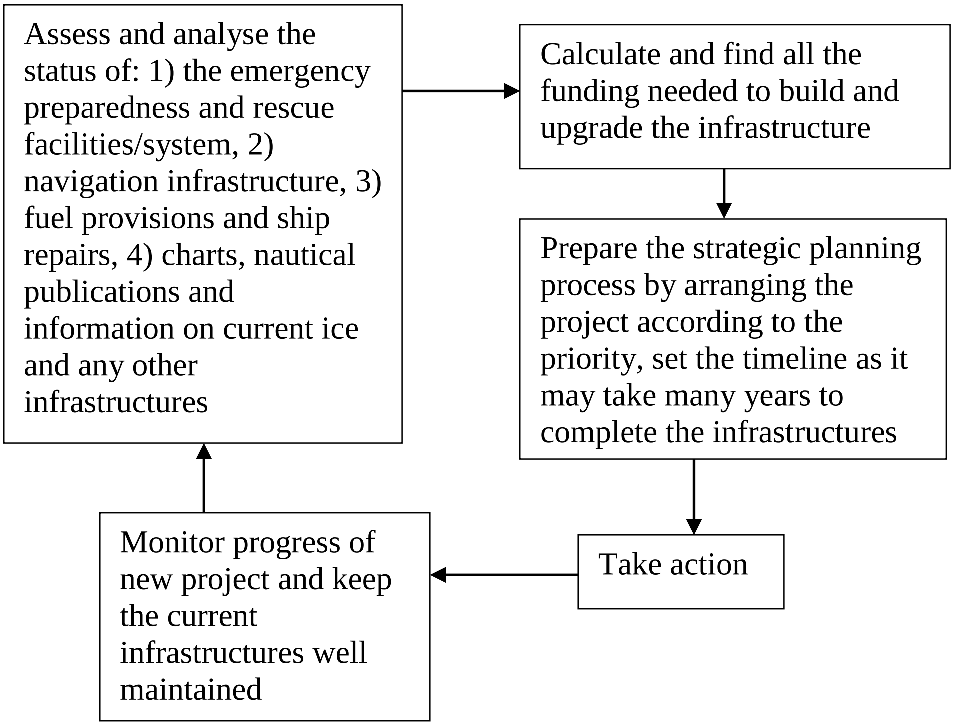


Figure 7.13: The conceptual model to modernise shipping and port infrastructures

Step 5: Compare Models with the real world and Step 6: Define Changes that are both Desirable and Feasible

In this stage, suggestion for further work and suitable resources should be made by the parties involved such as shipowner and the Russian government. However, for illustrative purposes, the problem of 'Lack of icebreaker ships' will be demonstrated here, as shown in Table 6.4. It is assumed that all suggested activities in the conceptual model for the requirement of IB system are being implemented in the real world.

Table 7.4: The comparison between conceptual models and the real world situations

	Conceptual models	**Real world**
1	Assess the current IB ship status – the numbers, age and remaining years of service.	Performed effectively. However, assessing the number and type of icebreakers needed in the future is complicated as it not only depends on cargo volumes, but also on season, routes, cargo vessel sizes etc. (Ragner, 2000).
2	Find funding to build or extend the service of IB	Fund is gathered through the Russian government. Quite difficult as the total construction cost for the IB is approximately USD 250 mln per ship (Ragner, 2000)
3	Extend the service of the current IB	Performed effectively. Two IBs will reach the end of their service life in 2012–2022, but they can be extended until 2024–2026 (Pastusiak, 2016)
4	Build new IB (determine whether diesel powered IB or nuclear powered IB)	Performed effectively (Build nuclear powered IB). Smaller diesel-electric ice-breakers can be built faster and at lower prices, but will not be particularly suited for operations along the eastern NSR with its more difficult ice-conditions, nor for the escort of large tankers (Ragner, 2000).
	(Missing part)	Need well-trained crews for Arctic operations on vessel, regular maintenance and repair.
5	Launch for shipping operations	Performed effectively.

From Table 7.4, it is noted that the conceptual model for the requirement of IB worked with the real world. All activities are performed effectively except one missing important part, which is the need for well trained-crews for Arctic operations on vessels. Therefore, this one missing activity will be added to make the conceptual model work.

Step 7: Take action to improve the problem situation

All the missing activities and problems in the conceptual models are implemented and fixed accordingly.

7.6 Conclusion

The SSM is fascinating because of its approach; rather than hunt for root causes to fix a problem, it just uses logic to define what "good" looks like and moves towards it. It is subtly different from other "problem" solving approaches and therefore can offer a refreshing alternative. Therefore, by using SSM, the NSR problems can be solved by using eight proposed solutions as shown in Figure 7.14.

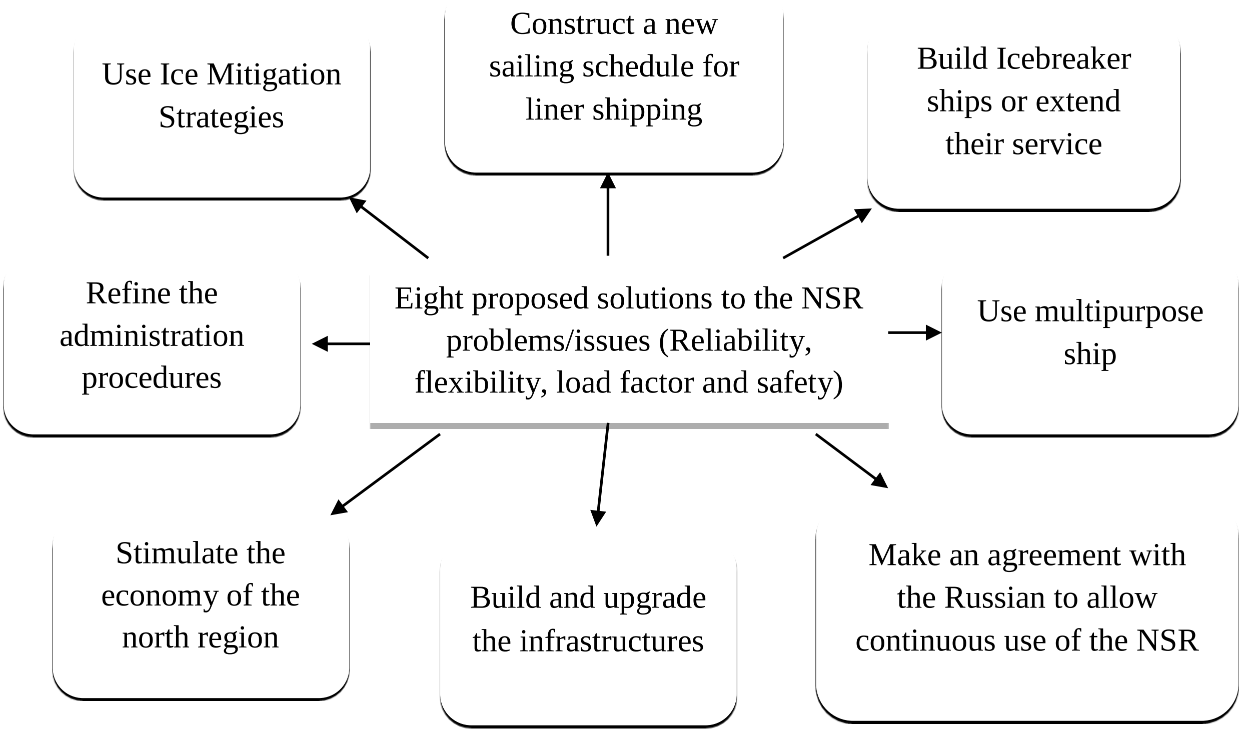


Figure 7.14: The NSR proposed solutions

These proposed solutions are the combination from literature and the researcher's points of view. Further work can be done in order to obtain more views from other stakeholders of the NSR. Nevertheless, the proposed solutions are adequate to solve the reliability, flexibility, load factor, and safety problems, which allow an increase in the number of shipping transits of the NSR. Having said that, these solutions are focused on solving the internal problems of the NSR. The external problems such as the oil price and the strategies used by other routes are not included in this research. This is because for now, the NSR needs to concentrate on its internal problems first. It is also noted that some issues such as environmental problems are not discussed in this chapter because this chapter only focuses on reliability, flexibility, load factor and safety problems which derived from the previous chapter.

CHAPTER 8:

DISCUSSION AND CONCLUSIONS

Summary

In this chapter, the integration of the research models from all chapters is discussed. The aim and objectives that have been achieved are also addressed. The contribution of the research to knowledge is also discussed. Finally, this chapter recommends possible future research work in this area.

8.1 Integration of the Research Models

In this research, the feasibility and profitability of the NSR have been explored with respect to both liner shipping (container) and tramp shipping (bulk) concentrating on routes between the Far East and Northwest Europe trade regions. Before that, a few processes of selections, and surveys were involved before the final decision can be made. This is interpreted from one chapter to another using different methodologies, parameters, and information.

The background, justification and scope of the research study have been introduced in order to give a clear picture to the reader. In addition, the aim and objectives of this research were well explained and discussed.

The aim of this research stated in Section 1.3 was the application of decision-making tools to analyse the current routes of the NSR. Accordingly, this leads to the development of decision-making techniques that formulate a platform for shipping companies to select the most cost-effective route(s) for travelling between the Far East and European regions. Five objectives are used in this research to achieve the research's aim mentioned earlier.

The first research objective is to identify the factors that influence the opening of the NSR. This factor can be anything from problems, challenges, attributes and parameters that are related to the opening and the existence of the NSR. Therefore, various sources such as journals, conference communication papers, institutional reports, books, news and master and doctorate's degree theses have been reviewed and analysed. This objective has been achieved through intensive literature surveys described and analysed in Chapter 2. In this Chapter 2, some of the MCDM methods were also reviewed.

This has been linked to the next chapter which is Chapter 3 which discussed the research method and research methodology of this thesis. Some of the MCDM methods which were reviewed in previous chapter is finally selected and the outline of the thesis is presented.

Then, this has been linked to the next chapter (Chapter 4) which aims to rank and prioritise these factors using an Analytic Hierarchy Process (AHP) method, which fulfils the second research objective of the thesis. A model has been introduced in this chapter consisting of 8 main factors and more than 65 sub-criteria and sub-sub-criteria that tell almost everything about the NSR. The 8 main criteria or factors were political, legal, economic, environmental, social, safety, technological aspects and the advantages of the NSR in comparison with other routes.

The third research objective was to investigate a number of routes along the NSR and select the most effective shipping transit route using the Evidential Reasoning (ER) method. The third research sub-objective was achieved and discussed in Chapter 5 of the thesis. A number of routes were presented within the NSR collected from past research articles. Then, a comprehensive literature survey was conducted to find the significant factors or parameters of selecting the best route within the NSR that was also gathered from the hierarchical structure from the previous chapter (Chapter 4). These parameters consist of both qualitative and quantitative factors that were used and analysed using the Intelligent Decision System Software (IDS) of Evidential Reasoning (ER) methodology. Four factors are involved in this chapter namely, environmental, distant, economic and safety which are supported by another fourteen sub-criteria. Finally, the proposed model produced valuable results for assisting shipping companies in the decision-making process concerning parameter evaluations and the importance of uncertainty in the NSR shipping passage. The ranking positions of all alternatives have been determined based on the overall assessment value. By using the selected parameters, Route 3 becomes the best shipping route within the NSR.

The fourth research objective is to select the best shipping transit route between the Far East and northwest Europe by using Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS). Such an objective has been achieved through a research study conducted in Chapter 6. Six parameters or criteria have been used for the evaluation process namely, distance, time, cost, services, safety and emissions. Then, another 10 sub-criteria were added to support the model. In general, there are two types of shipping services which are liner and tramp shipping. To replicate these two types of shipping services, two simulations were designed and constructed. These simulations are mainly used to gather all the quantitative data of the model. Qualitative data were collected from expert judgments. The best shipping route within the NSR is Route 3 (decided in Chapter 5) which was then compared with the SCR using TOPSIS methodology incorporated with AHP approach. Finally, the best shipping route was selected based on its relative closeness to the ideal solution, this was SCR.

The 5th research objective was to find solutions to enhance the use of the NSR by using Soft Systems Methodology (SSM). Such an objective has been achieved through the research conducted in Chapter 7. In chapter 6, there were 4 sub-criteria which were identified being a weak points for the NSR namely reliability, flexibility, load factor and safety. These factors, were further elaborated in Chapter 7. A number of techniques were involved such as rich picture, input-output diagram, CATWOE and conceptual model in order to find the solutions for the NSR problems and challenges. Using SSM, also allowed a comparison with the real world until the problem was finally solved. Therefore, 8 problems were identified and then, 8 solutions were suggested by using input-output diagram and conceptual model.

Overall, a number of decision making techniques have been used in order to achieve the principal objective of this research. Such techniques are based on the integration of AHP, ER, TOPSIS and SSM methodology. The developed models are dynamic and are able to be used in different situations based on uncertain situations faced by shipping companies. In the real practice, shipping companies can add or drop any criteria or parameter based on the uncertain situation faced by them. The models can also be applied in different service routes due to the flexibility of dealing with uncertainty conditions. The output of the study for each technical chapter may be different if 1) different situations are adopted, 2) the total number of experts are more or less than three, 3) different vessel characteristics are studied such as level of ice class and size of ship and different inputs are included.

8.2 Contribution of Research to Knowledge

Starting with the literature review in Chapter 2, the whole situation and the state of the NSR was understood. The research developed novel methodologies using a number of decision making techniques as shown throughout the thesis. Such techniques are capable of analysing and handling the different types of data, i.e. quantitative and qualitative data in regards to the NSR shipping. This study intends to emphasise the application of several decision-making tools or techniques and their potential to offer attractive features, which are not always achievable by traditional means.

The originalities and novelties of this research are 1) identify the need of the research because the NSR is now formally open for foreign vessels and it also has the potential to be a commercial shipping route, 2) development of methodologies which enable uncertainty faced by shipping companies to be dealt with and 3) the developed models are generic and can be applied in different circumstances. The application of the well-known decision making tools in the test cases is also considered.

This research is valuable to both academics and industry, the NSR as a new shipping route is only recently being studied, as the ice melts in the Arctic.

8.3 Limitations of Research

Much of the literature cannot be accessed and analysed simply because those papers are written in Russian. Although intensive literature surveys have been highlighted in Chapter 2, because of language barriers, the literature could be short of some information. However, the information can be added later on once the information has been obtained. Having said that, the literature survey presented in Chapter 2 is almost complete and thoroughly explains all the factors involved. Furthermore, all identified factors have been validated by an expert of the NSR.

In order to fully validate a research outcome, a proven benchmark based on previous research findings is often utilised and then a comparison between the two is conducted. As mentioned before, the academic work on the topic of the NSR especially regarding the decision making process has not been widely developed. Therefore, the available benchmark for this research is very limited. The proposed scientific models (from Chapter 4 to Chapter 6) are new in the NSR shipping. A number of new elements have been taken into account during the model development process, especially the qualitative parameters such as, safety and services. These qualitative data are considered new in this process because no other previous study has managed to combine and use them in their study.

Some of the models especially in Chapters 5 and 6 are very focused on summer shipping and limited to Arc 4 and 5 ice-class ships. The result of the test case would be different if a different ice-class ship is used and much longer time period of navigation is considered. However, this situation can be easily adapted in the model proposed and recalculated to get a new result.

In total, there were 12 experts involved in this research, which combined input both from the maritime industry and academia world. These experts were involved for obtaining qualitative data for Chapter 4, 5 and 6. Some of the experts contributed more than once. For instance, one expert was involved by giving judgements in questionnaires for Chapter 4 and Chapter 5. In total 7 experts were involved in Chapter 4, 5 experts in Chapter 5 and 3 experts in Chapter 6. However, majority of the experts (7) were from the academic background. Nevertheless, such experts also had maritime industry background. It is worth mentioning that, 5 of the experts are from UK, 2 from Norway and 1 expert each from Denmark, Canada, France, USA and Russia.

In Chapter 7 which involves SSM, all the parameters were gathered through literature surveys. The best way to use the SSM is through opinions or judgments from multiple experts. This gives a better understanding of the situations or problems for the NSR shipping. Nevertheless, the given models such as the problem diagram of the NSR, the input-output for the 8 problems and the conceptual models of the NSR are adequate to represent the real situation taking place in the NSR today, as it also uses literature surveys gathered from multiple sources.

8.4 Recommendation for Future Research

In Chapter 5, a number of routes are gathered through literature surveys. However, instead of using computer simulations, the best route could be created by using one if not many combinations of Multiple-Criteria Decision Making (MCDM) methodologies. For example, all the routes within the NSR can be divided into several loops or legs. Then, by using MCDM methods such as AHP, ANP, VIKOR and any other methods, the best route within the NSR can be established. This time, the parameters could consider more the physical features of the routes, for example the ice conditions, fog appearance, depth and width of the straits and sea, and any other related parameters. However, the data for all the parameters would be a challenge to obtain.

As highlighted in Chapter 6, only one route was considered for comparison with the NSR. In the future, perhaps, more routes such as the Arctic bridge passage or even other modes of transport can be considered such as rail transport or even pipeline. This is because, China in particular has invested heavily in “One Belt, One Road” (OBOR) (Appendix U) which can be a real competitor to the NSR. Announced by Chinese President Xi Jinping in 2013, China is currently undertaking what it considers the largest project of the century – building a network of railroads and shipping lanes linking itself with 70 countries across Asia, Africa, Europe, and Oceania (Ma, 2018). The main focuses of the projects are in infrastructure, transportation, and energy. Countries including India, Pakistan, Russia, New Zealand and Poland have all joined in the project. Together they make up at least a third of the world's GDP (Ma, 2018). Therefore, the future research also can concentrate on the future of the NSR itself.

The next thing is that it is also possible now to use the NSR without ice-breaker assistance. The Christophe de Margerie is the first and at present the only ice-breaking LNG carrier that has gone through the NSR (McGrath, 2017). This particular ship does not need to pay for the NSR fees but to build a vessel with ice-breaking capability will involve a very high capital cost. In this case, the total cost will be changed and the parameters involved would be different compared to the models, as shown in Chapters 5 and 6 of the thesis. It is worth mentioning that this particular ship (Christophe de Margerie) is owned by the Russians. Perhaps it is more of a marketing strategy to promote the NSR as opposed to considering the profitability. These new factors should be explored in future research.

In Chapter 7, many solutions have been suggested to increase the use of the NSR by using 7 steps of SSM. In other words, in this research, all the problems and conceptual models (system to improve the NSR) have been well defined, established using Step 1 to Step 4 of SSM. One conceptual model has been further discussed and improved (Step 5 to 7) which is to solve lack of Ice-breakers for shipping operations in the NSR. Therefore, this requires further research for the other 7 problems or conceptual models developed in Chapter 7 to see if the systems are working.

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Appendix A: The approximate equivalent of ice-class classification systems

		RMRS	**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 PC7	Summer navigation in Arctic waters
	1B 1C	Ice3 Ice2 Ice1		
	FSICR	**RMRS**		

Notes:

Arc9 - independent operation allowed in all Russian sea areas in all winters.

Arc8 – icebreaker escorted operation allowed in all Russian sea areas in all winters.

(Source: Daley, 2014).

Figure A2.1**:** The Approximate equivalent of ice-class classification systems.

Appendix B: Comparison between different ice-class rules for ice strengthening

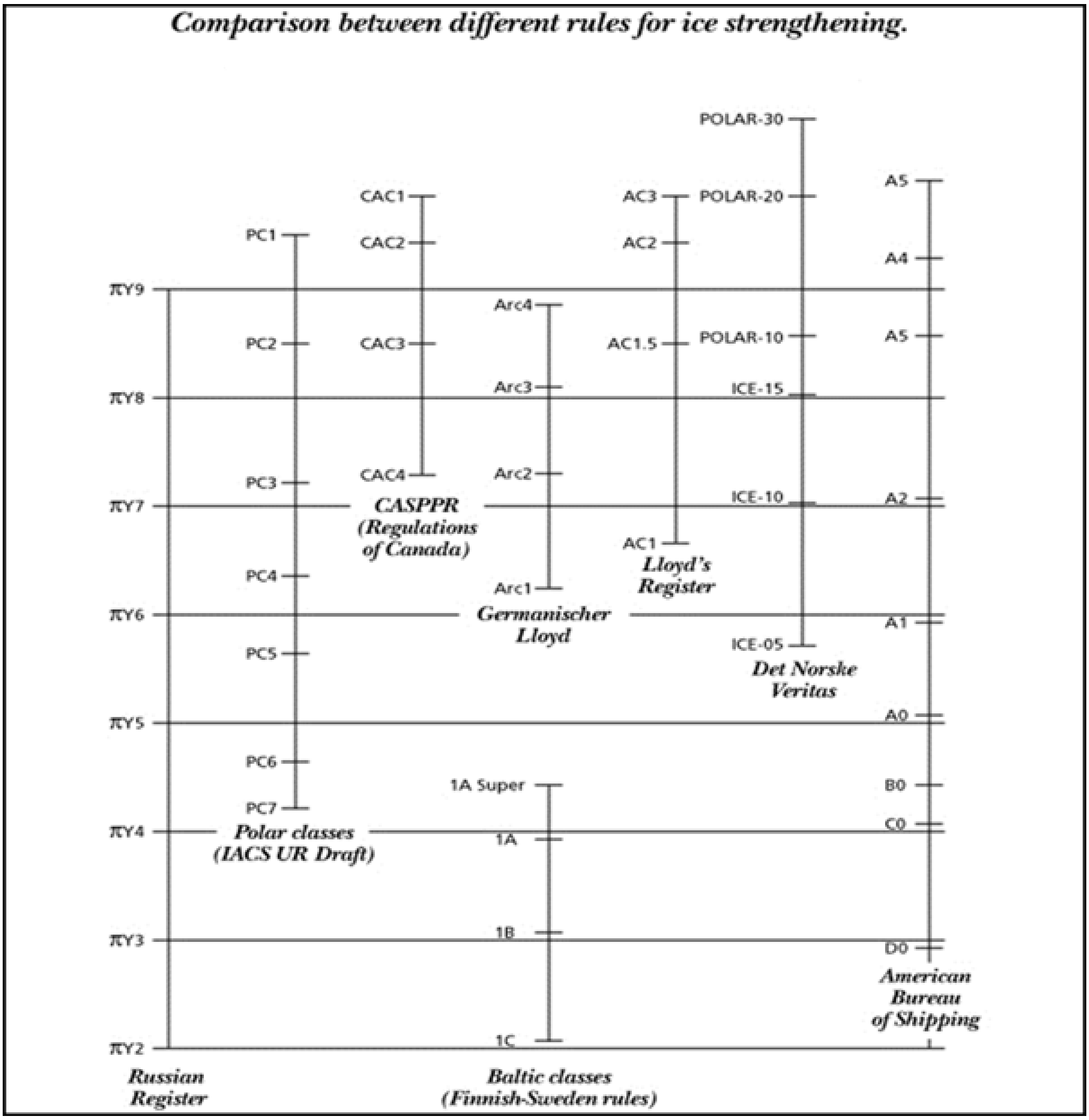

Figure A2.2: Comparison between different ice-class rules for ice strengthening

Source: Carried out by Krylov Institute in Nyseth and Bertelsen (2014)

Appendix C: Location of seaports along the NSR

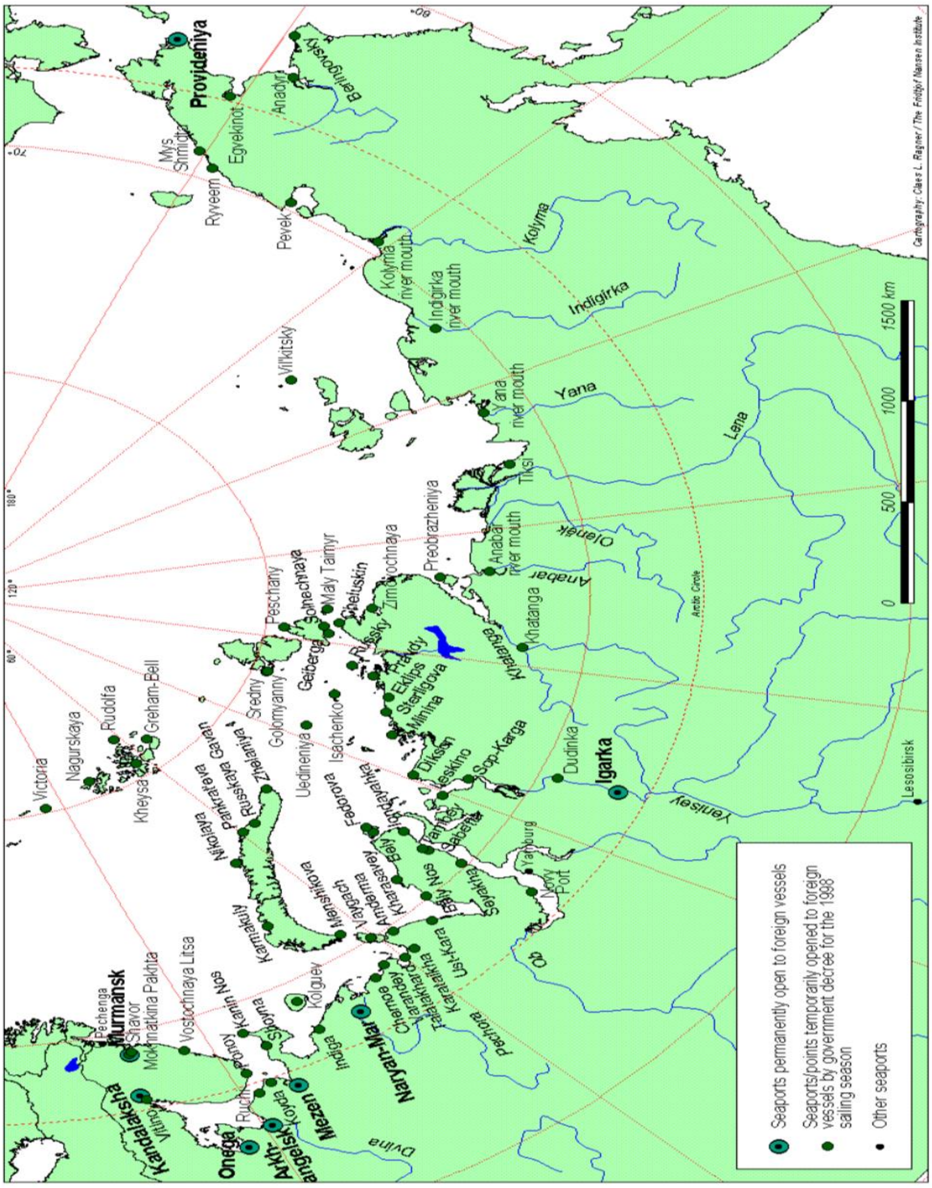

Figure A2.3: Seaports along the NSR (Source: Ragner, 2000).

Appendix D: Tool for selecting the most appropriate MCDM method to solve a problem

Scenario characteristics	**SAW**	**AHP**	**TOPSIS**	**VIKOR**	**PROMETHEE**	**MOORA**	**ELECTRE**	**ANP**	**LP**	**SIMUS**
Simple scenario										
Several scenarios										
An alternative may be in different scenarios										
Single objective										
Many objectives										
No rank reversal										
Necessity to have an optimal solution										
Several DMs (Group decision-making)										
Easiness to change the initial matrix										
Large projects involving people consultation										
Linguistic initial matrix										
Qualitative criteria										
Quantitative criteria										
Using a particular normalization procedure										
Using any normalization procedure										
Independent alternatives										
Relationship between alternatives										
Dependency between alternatives										
Many criteria										
Independent criteria (Compensatory methods)										
Relationship between criteria										
Necessity of knowing criteria validity range										
Correlation between criteria										
Necessity to express criteria pos. actions (benefits)										
Necessity to express criteria neg. actions (costs)										
Criteria duality										
Reasonable preparation time and computing time										
Clustering										
Necessity to consider externalities										
Necessity to consider joint ventures										
Necessity to use resources										
Necessity to use thresholds in resources										
Necessity to link resources										
Performance values as linear functions										

Performance values as non-lineal functions										
Integer performance values										
Decimal performance values										
Objective performance values										
Subjective performance values										
Performance values expressed as math. formulas										
Performance values in binary format										
Negative performance values										
Result needed in integers										
Results needed in decimals										
Results needed in binary format										
Necessity to evaluate criteria relative importance										
Want to use subjective weights										
Want to use objective weights										
All criteria with the same weight										
Sensitivity analysis (SA) with weights										
SA with criteria marginal values										
SA considering simultaneously all pertaining criteria										
Necessity to have graphics in SA										
No theoretical complexity										

(This is the simplified version of the interactive /automatic tool for selecting a MCDM method)

The selection tool can be assessed at https://www.researchgate.net/post/How_to_select_the_best_method_to_solve_a_MCDM_problem

Appendix E: The construction process of hierarchical structure of factors that influence the opening of the NSR

1. Legal Factor

Table A4.1: The list of Legal factors that influence the opening of the NSR

1	The legal regime of the Arctic was not established through international agreements, unlike the Antarctic regime. (Ragner 2000; Kaczynski 2012).
2	Five states has staked legal claim to territory in the Arctic based on historical claims of discovery and use, effective occupation, national identity, geographic proximity, Native use, and scientific data (Watson 2009).
3	The NSR straits should be considered international straits, with the implication that foreign vessels use them for innocent passage without notification or application to the Russian authorities (Ragner 2000; Watson 2009).
4	PC was doing too little to prevent shipping accidents and pollution with potentially catastrophic consequences for polar environments (Bennet, 2017; Bognar, 2018; Schopmans, 2019).

All Legal factors listed in Table A4.1 are then converted into hierarchy form as shown in Table A4.2

Table A4.2: Hierarchy model of Legal factors

Criteria	**Sub-criteria**
Legal Factor	Legal status of the NSR. Full Russian jurisdiction or some international status
	Border disputes in the Arctic
	Legal status of vessels and flags when transiting the NSR
	Polar Code is lacking in certain aspects

2. Economic Factor

Table A4.3: The list of Economic factors that influence the opening of the NSR

1	The NSR has incurred higher building costs for ice-classed ships (Liu and Kronbak, 2010, Kazcynski, 2012).
2	The insurance premium for such an extreme journey through the NSR is quite high (Verny and Grigentin, 2009; Chernova and Volkov, 2010; Kazcynski, 2012).
3	Both capital cost and depreciation costs are applied to yearly repayment and yearly depreciation of the capital, based on the building cost of the new ship (Furuichi and Otsuka, 2013).
4	The crew cost for the NSR shipping is higher than for conventional shipping because the NSR requires a high level of technical training for the officers (navigation in glacial waters) (Verny and Grigentin 2009).
5	Fuel cost is one of the main factors that influence the competitiveness of the NSR (Liu and Kronbak, 2010),
6	The Russian ice-breaking tariff or the NSR fees include payment for the assistance of an ice-breaker ship, meteorological forecasts and the use of communication systems (Verny and Grigentin, 2009; Liu and Kronbak, 2010; Gritsenko and Kiiski, 2016).
7	Fees for piloting are assessed separately (Liu and Kronbak, 2010; Kazcynski, 2012).

8	The economic centre of gravity of the situations in both Europe and Asia is moving northwards (Blunden, 2012). It is also called the international 'geography of places', a new discipline describing the displacement of production centres and consumer markets (Verny and Grigentin, 2009).
9	The lack of major economic centres along the NSR affects the attractiveness of the route compared to the conventional route (Liu and Kronbak, 2010).
10	The oil and gas resource of Russia's Arctic regions constitute the world's largest energy reserve outside of OPEC countries (Blunden, 2012; Hille, 2016).
11	The increase in cruise vessel traffic is one of the key concerns for many Arctic countries (Ikonen, 2017).

All Economic factors listed in Table A4.3 are then converted into hierarchy form as shown in Table A4.4

Table A4.4: Hierarchy model of Economic factors

Criteria	**Sub-criteria**	**Sub-sub criteria**
Economic Factor	Operating Cost	Capital costs (ice strengthened vessels)
		The NSR Insurance costs
		Ship depreciations
		Manning costs
	Voyage Cost	Fuel costs
		The NSR fees (Meteorological forecast & ice breaking)
		Ice pilot fees
	Commercial Aspect	Shifts in economic geography
		Lack of major economic centre along the route
		Status of natural resources in Arctic
		Tourism industry

3. Environmental Factor

Table A4.5: The list of Environmental factors that influence the opening of the NSR

1	The disappearance of summer sea ice will provide the NSR with more navigable days for shipping operations. This factor, the navigable time of the NSR together with the transit fees and the bunker prices are the most important factors that influence the use of the NSR (Liu and Kronbak, 2010).
2	Laboratory studies have shown that polar bears may die if fouled by oil (Moe and Semanov, 1999).
3	Advances in the melting of the Arctic ice have implications for zooplankton, fisheries, fish stocks, marine mammals and marine birds, which appear to be shifting northward (Eger, 2010).
4	Eide in Eide et al., (2010) listed all the operational conditions associated with NSR shipping: sea ice, icebergs, wind chills, remoteness etc.
5	The shrinking Arctic sea ice will also facilitate the seasonal use of the NSR and viability for transit container shipping (Xu et al., 2011). Summer shipping usually begins in mid-June and runs until mid-October (Otsuka and Furuichi, 2013).

6	According to Ragner (2000), the main physical constraints to NSR shipping are the shallow seas and straits along most of the route.
7	According to Molenaar (2014), marine shipping has the following actual and potential impacts on the marine environment and marine biodiversity as follows: • Shipping practices and incidents leading to accidental discharges of polluting substances (cargo or fuel) or physical impact on components of the marine ecosystem (e.g., on the benthos and larger marine mammals). • Operational discharges (cargo residues, fuel residues (sludge), (incineration of garbage and sewage), and emissions (CO2, NOX and SOX). • Introduction of alien organisms through ballast-water exchanges or attachment to vessels' hulls (e.g. in crevices). • Other navigation impacts (noise pollution and other forms of impacts on, or interference with, marine species potentially causing, for instance, disruption of behaviour, abandonment, or trampling of the young by fleeing animals or displacement from their usual habitat).

All Environmental factors listed in Table A4.5 are then converted into hierarchy form as shown in Table A4.6

Table A4.6: Hierarchy model of Environmental factors

Environmental Factor	Disappearing of summer sea ice	More navigable days for shipping operations
		Possible extinction of Polar bears
		Some Arctic fisheries will be affected
	Challenges to operation	Operational conditions like wind chills, darkness in winter, sea ice & ice bergs, high latitudes and etc.
		Seasonality of operations (Navigable for 2 to 4 months in eastern part of the NSR :without ice breaking assistance)
		Shallow seas & straits (Vessel size restriction in coastal route) (VFBC)
	Impact on the marine environment and marine biodiversity	Accidental discharges of polluting substances (cargo or fuel)
		Operational discharges (cargo residues, fuel residues),garbage and sewage and emissions (CO_2, NO_2 SO_2)
		Navigation impacts (noise pollution and interference with marine species that cause disruption of behaviour and etc.)
		Introduction of alien organisms through ballast water exchanges or attachment to vessel hulls.

4. Social Factor

Table A4.7: The list of Social factors that influence the opening of the NSR

1	According to Goodman (2014), the NSR shipping activities will affect the indigenous people of the Arctic region regarding the loss of food sources, loss of housing, loss of culture and bring disease to the people.
2	However, there are positive advantages in supplying the Northern population with fuel, provisions, commodities and goods because it will bring much-needed specialists to the local communities and provide workplaces for the local communities (Ragner 2000).

All Social factors listed in Table A4.7 are then converted into hierarchy form as shown in Table A4.8

Table A4.8: Hierarchy model of Social factors

Criteria	**Sub-criteria**
Social Factor (Indigenous People) (SF)	Loss of food source (SFA)
	Loss of housing (SFB)
	Disease (SFC)
	Loss of culture (SFD)
	Stimulation of economic activity of people in the north region (SFE)

5. Technological Factor

Table A4.9: The list of Technological factors that influence the opening of the NSR

1	With a highly advanced fleet of icebreaking ships and a broad range of advanced marine technology, the Russians have the experience and technological capability to move ships virtually anywhere in the Arctic during the summer months (Mulherin, 1996; Ragner, 2000; Kaczynski, 2012).
2	This Double-Acting Ship (DAS) concept is designed to operate ahead in open water and astern in heavy ice conditions. The actual bow form can be optimised for the selected route and the superior ice going performance when running astern reduces the need to use icebreaker assistance. The benefit from the freedom in bow form design is that the DAS has much better open water characteristics compared to conventional ice going vessels (Kurimo, 2011).
3	Simple technology, like the use of aerial drones to locate free and fast ice, should not be underestimated. Aerial drones are easy to fly and readily mounted with cameras that record the trip, adopting a bird’s eye view.

All Technological factors listed in Table A4.9 are then converted into hierarchy form as shown in Table A4.10

Table A4.10: Hierarchy model of Technological factors

Criteria	**Sub-criteria**
Technological Factor	Advanced ice breaking technology
	New ship technology/design
	Aerial drones will be used to spot free and fast ice

6. Safety Factor

Table A4.11: The list of Safety factors that influence the opening of the NSR

1	An extensive ports and shipping infrastructure including a cargo base currently exist along the NSR (Mulherin, 1996) (Appendix C shows all the seaports along the NSR). However, the state of infrastructure is incomplete and deteriorating (Kaczynski, 2012; Ho, 2011; Moe and Jensen, 2010).
2	Erikstad and Ehlers, (2012) also reported that there is no land-based infrastructure, such as rescue centres or repair yards, along the NSR, especially when considering the draft limitations of larger vessels. The nearest Russian ports where repairs can be performed are located far away in Murmansk and Vladivostok which, practically speaking, is outside the NSR.
3	The present standards for Escape, Evacuation and Rescue (EER) will need to be modified in order to cater for the Arctic (Eide, et al., 2010). The uncertainty and the risk connected to the NSR are, among other factors, due to limited accident preparedness as a ship in distress might have difficulties in receiving assistance from rescue teams and icebreakers within a short time.
4	About 2,500 nm of Siberian coast between the Bering Strait and the Port of Murmansk are mostly uninhabited, so no stopovers are possible (Verny and Grigentin, 2009).
5	Sailing across the Arctic Ocean will require improvements in a suite of safety issues, including charting and monitoring, and the control of ship movements in the Arctic (AMSA, 2009).
6	Eide et al., (2010) reported regarding radio and satellite communications which are not satisfactory. The continued development of detailed (near) real-time ice information delivered directly to the vessel by satellite could realistically enable vessels to execute local and tactical navigation themselves in the future (Ragner, 2000).
7	The NSR also requires a high level of technical training for the officers responsible for sailing the vessels (navigation in glacial waters) (Verny and Grigentin, 2009).

All Safety factors listed in Table A4.11 are then converted into hierarchy form as shown in Table A4.12

Table A4.12: Hierarchy model of Safety factors

Criteria	**Sub-criteria**	**Sub-sub-criteria**
Safety Factor	Status of shipping and port infrastructure	Status of search and rescue facilities
		Status of availability of international port along the route
		Status of ships repair and maintenance facilities
	Status of navigational aids facilities	Charting and monitoring
		Radio and satellite communications and emergency response
		Observational networks and forecast for weather, icing, waves and sea ice
	Training for crew for Arctic operations	

7. Advantages of the NSR in comparison to other alternatives

Table A4.13: The list of Advantages of the NSR in comparison to other alternatives that influence the opening of the NSR

1	The NSR provides a shorter distance between Europe, North America and Asia in comparison with other routes, which could translate into significant cost savings (Drent, 1993; Verny and Grigentin, 2009; Erikstad and Ehers, 2012).
2	According to Erikstad and Ehlers (2012), the benefits of a shorter route can be exploited in two different ways. First, to increase the number of round trips that can be made annually, thus increasing the freight income of the vessels. Secondly, the benefit can be taken by slow-steaming on the shorter distance, which will result in considerable fuel savings, as well as having the additional benefit of reduced emissions of CO_2. (Erikstad and Ehlers, 2012).
3	Eide et al., (2010), reported that for shippers to choose the NSR, the benefits must be substantial and outweigh the disadvantages. These benefits may be realised in less travelling distance, which can substantially reduce fuel costs, and shorter travelling time, which may translate into higher income due to lower inventory-holding costs and increased productivity. Emission reductions may also result in reduced costs, assuming that future external damage and costs incurred by ship emissions can be internalised (Eide et al., 2010).
4	The NSR located high within the Arctic region with its distribution of sea ice and harsh environment will not incur piracy or threats of terrorism
5	A further advantage of the NSR is that there is no vessel size restriction further north of the NSR. While the coastal route of the NSR may limit the size of the ship, further north will provide a better choice for larger vessels to transit.

All Advantages of the NSR in comparison to other alternatives listed in Table A4.13 are then converted into hierarchy form as shown in Table A4.14

Table A4.14: Hierarchy model of Advantages of the NSR in comparison to other alternatives

Criteria	**Sub-criteria**	**Sub-sub-criteria**
Advantages of the NSR in comparison to other alternatives	Shorter route	Saving in time
		Saving in expenses
		Increase the number of round trips
		Reduced air emissions from ships
	No piracy/terrorism threat	
	No vessel size restriction for further north route of the NSR	

Appendix F: A set of questionnaire for pair-wise comparisons

Part B: The most important factor that influence the opening of the NSR

Goal: *To select the most important factor that influence the opening of the NSR*

1) Political Factor (PF)

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Political Factor (PF)** compared to the **Legal Factor (LF)**?																	
To achieve the above goal how important is the **Political Factor (PF)** compared to the **Economic Factor (EF)**?																	
To achieve the above goal how important is the **Political Factor (PF)** compared to the **Environmental Factor (VF)**?																	
To achieve the above goal how important is the **Political Factor (PF)** compared to the **Social Factor (SF)**?																	
To achieve the above goal how important is the **Political Factor (PF)** compared to the **Technological Factor (TF)**?																	
To achieve the above goal how important is the **Political Factor (PF)** compared to the **Safety Factor (FF)**?																	
To achieve the above goal how important is the **Political Factor (PF)** compared to the **Advantages of the NSR (AF)**?																	

2) Legal Factor (LF)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Legal Factor (LF)** compared to the **Economic Factor (EF)**?																	
To achieve the above goal how important is the **Legal Factor (LF)** compared to the **Environmental Factor (VF)**?																	
To achieve the above goal how important is the **Legal Factor (LF)** compared to the **Social Factor (SF)**?																	
To achieve the above goal how important is the **Legal Factor (LF)** compared to the **Technological Factor (TF)**?																	
To achieve the above goal how important is the **Legal Factor (LF)** compared to the **Safety Factor (FF)**?																	
To achieve the above goal how important is the **Legal Factor (LF)** compared to the **Advantages of the NSR (AF)**?																	

3) Economic Factor (EC)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Economic Factor (EF)** compared to the **Environmental Factor (VF)**?																	
To achieve the above goal how important is the **Economic Factor (EF)** compared to the **Social Factor (SF)**?																	
To achieve the above goal how important is the **Economic Factor (EF)** compared to the **Technological Factor (TF)**?																	
To achieve the above goal how important is the **Economic Factor (EF)** compared to the **Safety Factor (FF)**?																	
To achieve the above goal how important is the **Economic Factor (EF)** compared to the **Advantages of the NSR (AF)**?																	

4) Environmental Factor (VF)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Environmental Factor (VF)** compared to the **Social Factor (SF)**?																	
To achieve the above goal how important is the **Environmental Factor (VF)** compared to the **Technological Factor (TF)**?																	
To achieve the above goal how important is the **Environmental Factor (VF)** compared to the **Safety Factor (FF)**?																	
To achieve the above goal how important is the **Environmental Factor (VF)** compared to the **Advantages of the NSR (AF)**?																	

5) Social Factor (SF)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Social Factor (SF)** compared to the **Technological Factor (TF)**?																	
To achieve the above goal how important is the **Social Factor (SF)** compared to the **Safety Factor (FF)**?																	
To achieve the above goal how important is the **Social Factor (SF)** compared to the **Advantages of the NSR (AF)**?																	

6) Technological Factor (TF)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Technological Factor (TF)** compared to the **Safety Factor (FF)**?																	
To achieve the above goal how important is the **Technological Factor (TF)** compared to the **Advantages of the NSR (AF)**?																	

7) Safety Factor (FF)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Safety Factor (FF)** compared to the **Advantages of the NSR (AF)**?																	

Part C: Political Factor (PF)

Goal: *To select the most important factor influencing the Political Factor (PF)*

1) Campaign Effort (PFA)

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Campaign Effort (PFA)** compared to the **Administration Procedures (PFB)**?																	
To achieve the above goal how important is the **Campaign Effort (PFA)** compared to the **Foreign Affairs (PFC)**?																	

2) Administration Procedures (PFB)

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Administration Procedure (PFB)** compared to the **Foreign Affairs (PFC)?**																	

Part D: Campaign Effort (PFA)

Goal: *To select the most important factor influencing the Campaign Effort (PFA).*

1) Promotion by the Russians (PFAA)

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Promotion by the Russians (PFAA)** compared to the **Collaboration with other countries (PFAB)**?																	
To achieve the above goal how important is the **Promotion by the Russians (PFAA)** compared to the **Level of Russian state investment on the infrastructure (PFAC)**?																	

2) Collaboration with other countries (PFAB)

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Collaboration with other countries (PFAB)** compared to the **Level of Russian state investment on the infrastructure (PFAC)?**																	

Part E: Administration Procedures (PFB)

Goal: *To select the most important factor influencing the Administration Procedures (PFB).*

1) No ship deviation without Russian permission (PFBA)

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **No ship deviation without Russian permission (PFBA**) compared to the **Ship owners need to submit their request to use the NSR 4 months in advance (PFBB)?**																	
To achieve the above goal how important is the **No ship deviation without Russian permission (PFBA**) compared to the **Mandatory local inspection of the vessel even though the vessel fulfil the requirements (PFBC)?**																	

2) Ship owners need to submit their request to use the NSR 4 months in advance (PFBB)

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Ship owners need to submit their request to use the NSR 4 months in advance (PFBB)** compared to the **Mandatory local inspection of the vessel even though the vessel fulfil the requirements (PFBC)?**																	

Part F: Foreign Affairs (PFC)

Goal: *To select the most important factor influencing the Foreign Affairs (PFC).*

1) Political risks and uncertainties involved (PFCA) [1]

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Political risks and uncertainties involved (PFCA)** compared to the **Increasing militarization of the Arctic by the Russian Government (PFCB)**?																	
To achieve the above goal how important is the **Political risks and uncertainties involved (PFCA)** compared to the **Changes in international political configuration and relations (PFCC)** [2]?																	
To achieve the above goal how important is the **Political risks and uncertainties involved (PFCA)** compared to the **Unpredictable behaviour of the Russian Government in relation to selected users of the NSR (PFCD)**?																	

[1]Because the NSR is in the Russian waters

[2]Between major world actors and Arctic Ocean coastal states and between Russian and Western powers

2) Increasing militarization of the Arctic by the Russian Government (PFCB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Increasing militarization of the Arctic by the Russian Government (PFCB)** compared to the **Changes in international political configuration and relations (PFCC)**?																	
To achieve the above goal how important is the **Increasing militarization of the Arctic by the Russian Government (PFCB)** compared to the **Unpredictable behaviour of the Russian Government in relation to selected users of the NSR (PFCD)**?																	

3) Changes in international political configuration and relations (PFCC)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Changes in international political configuration and relations (PFCC)** compared to the **Unpredictable behaviour of the Russian Government in relation to selected users of the NSR (PFCD)**?																	

Part G: Legal Factor (LF)

Goal: *To select the most important factor influencing the Legal Factor (LF).*

1) Legal Status of the NSR (LFA) [3]

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Legal Status of the NSR (LFA)** compared to the **Border disputes in the Arctic (LFB)** [4]?																	
To achieve the above goal how important is the **Legal Status of the NSR (LFA)** compared to the **Legal status of vessels and flags when transiting the NSR (LFC)**?																	
To achieve the above goal how important is the **Legal Status of the NSR (LFA)** compared to the **No internationally legally binding requirements for ship designs and ice class ship (LFD)** [5]?																	

[3] It is now under full Russian jurisdiction but certain countries claimed it should be some international status of the route

[4] Disputes between Russia, USA, Canada, Denmark and Norway

[5] Currently the regulations are forced by the Russians

2) Border disputes in the Arctic (LFB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Border disputes in the Arctic (LFB)** compared to the **Legal status of vessels and flags when transiting the NSR (LFC)**?																	
To achieve the above goal how important is the **Border disputes in the Arctic (LFB)** compared to the **No internationally legally binding requirements for ship designs and ice class ship (LFD)**?																	

3) Legal status of vessels and flags when transiting the NSR (LFC)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Legal status of vessels and flags when transiting the NSR (LFC)** compared to the **No internationally legally binding requirements for ship designs and ice class ship (LFD)**?																	

Part H: Economic Factor (EF)

Goal: *To select the most important factor that influences the Economic Factor (EF).*

1) Operating Costs (EFA)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Operating Costs (EFA)** compared to the **Voyage Costs (EFB)**?																	
To achieve the above goal how important is the **Operating Costs (EFA)** compared to the **Commercial Aspect (EFC)**?																	

2) Voyage Costs (EFB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Voyage Costs (EFB)** compared to the **Commercial Aspect (EFC)**?																	

Part I: Operating costs (EFA)

Goal: *To select the most important factor that influences the Operating Costs (EFA).*

1) Capital Costs (EFAA) [6]

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Capital costs (EFAA)** compared to **The NSR Insurance Costs (EFAB)** [7]?																	
To achieve the above goal how important is the **Capital costs (EFAA)** compared to the **Ship depreciation (EFAC)**?																	
To achieve the above goal how important is the **Capital costs (EFAA)** compared to the **Manning costs (EFAD)**?																	

[6] The cost of buying or loan repayment of ice strengthened vessels or ice class ships.

[7] Consist of P&I insurance, hull & machinery insurance and other insurance (war risk, strike and etc.)

2) The NSR insurance costs (EFAB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is **The NSR insurance costs (EFAB)** compared to the **Ship depreciation (EFAC)**?																	
To achieve the above goal how important is **The NSR insurance costs (EFAB)** compared to the **Manning costs (EFAD)**?																	

3) Ship depreciation (EFAC)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is **Ship depreciation (EFAC)** compared to the **Manning costs (EFAD)**?																	

Part J: Voyage costs (EFB)

Goal: *To select the most important factor that influences the Voyage costs (EFB).*

1) Fuel costs (EFBA)

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Fuel costs (EFBA)** compared to **The NSR fees (EFBB)** [8]?																	
To achieve the above goal how important is the **Fuel costs (EFBA)** compared to the **Ice pilot fees (EFBC)**?																	

2) The NSR fees (EFBB)

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is **The NSR fees (EFBB)** compared to the **Ice pilot fees (EFBC)**?																	

[8] The NSR fees consists of meteorological forecast and ice breaking services

Part K: Commercial aspect (EFC)

Goal: *To select the most important factor that influences the Commercial aspect (EFC).*

1) Shifts in economic geography (EFCA) [9]

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Shifts in economic geography (EFCA)** compared to the **Lack of major economic centre along the NSR (EFCB)**?																	
To achieve the above goal how important is the **Shifts in economic geography (EFCA)** compared to the **Status of natural resources in the Arctic (EFCC)** [10]?																	
To achieve the above goal how important is the **Shifts in economic geography (EFCA)** compared to the **Tourism industry in the Arctic (EFCD)**?																	

[9] The displacement of production centres and consumer markets are moving northwards. In Europe, the movements is from the west to the north-east with the development of central and eastern Europe and the German economic boom and in Asia from the south-east to the north, with the growth of China.

[10] The oil and gas resource of Russia's Arctic regions constitute the world's largest energy reserve outside OPEC (Organization of the Petroleum Exporting Countries)

2) Lack of major economic centre along the NSR (EFCB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Lack of major economic centre along the NSR (EFCB)** compared to the **Status of natural resources in the Arctic (EFCC)**?																	
To achieve the above goal how important is the **Lack of major economic centre along the NSR (EFCB)** compared to the **Tourism industry in the Arctic (EFCD)**?																	

3) Status of natural resources in the Arctic (EFCC)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Status of natural resources in the Arctic (EFCC))** compared to the **Tourism industry in the Arctic (EFCD)**?																	

Part L: Environmental Factor (VF)

Goal: *To select the most important factor that influences the Environmental Factor (VF).*

1) Disappearing of summer sea ice (VFA)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Disappearing of summer sea ice (VFA)** compared to the **Challenges to operation (VFB)**?																	
To achieve the above goal how important is the **Disappearing of summer sea ice (VFA)** compared to the **Impact on the marine environment and marine biodiversity (VFC)**?																	

2) Challenges to operation (VFB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Challenges to operation (VFB)** compared to the **Impact on the marine environment and marine biodiversity (VFC)**?																	

Part M: Disappearing of summer sea ice (VFA)

Goal: *To select the most important factor that influences the Disappearing of summer sea ice (VFA).*

1) More navigable days for shipping operations (VFAA)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **More navigable days for shipping operations (VFAA)** compared to the **Possible extinction of Polar bears (VFAB)**?																	
To achieve the above goal how important is the **More navigable days for shipping operations (VFAA)** compared to the **Some Arctic fisheries will be affected (VFAC)**?																	

2) Possible extinction of Polar bears (VFAB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Possible extinction of Polar bears (VFAB)** compared to the **Some Arctic fisheries will be affected (VFAC)**?																	

Part N: Challenges to operation (VFB)

Goal: *To select the most important factor that influences the Challenges to operation (VFB).*

1) Operational conditions (VFBA) [11]

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Operational conditions (VFBA)** compared to the **Seasonality of operations (VFBB)** [12]?																	
To achieve the above goal how important is the **Operational conditions (VFBA)** compared to the **Shallow seas and straits (VFBC)** [13]?																	

2) Seasonality of operations (VFBB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Seasonality of operations (VFBB)** compared to the **Shallow seas and straits (VFBC)**?																	

[11] Operational conditions like wind chills, darkness in winter, sea ice and ice bergs, high latitude and etc.

[12] The NSR is navigable for 2 to 4 months in eastern part of the NSR

[13] The shallowness of the straits especially in the coastal route can limits the draft and size of ships

Part O: Impact on the marine environment and marine biodiversity (VFC)

Goal: *To select the most important factor that influences the Impact on the marine environment and marine biodiversity (VFC).*

1) Accidental discharges of polluting substances (VFCA) [14]

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Accidental discharges of polluting substances (VFCA)** compared to the **operational discharges, garbage, sewage and emissions (VFCB)**?																	
To achieve the above goal how important is the **Accidental discharges of polluting substances (VFCA)** compared to the **Navigation impacts (VFCC)** [15]?																	
To achieve the above goal how important is the **Accidental discharges of polluting substances (VFCA)** compared to the **Introduction of alien organisms (VFCD)**?																	

[14] The polluting substances such as cargo or fuel

[15] It is a noise pollution and interference with marine species that cause disruption of behaviour and etc.

2) Operational discharges, garbage, sewage and emissions (VFCB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **operational discharges, garbage, sewage and emissions (VFCB)** compared to the **Navigation impacts (VFCC)**?																	
To achieve the above goal how important is the **operational discharges, garbage, sewage and emissions (VFCB)** compared to the **Introduction of alien organisms (VFCD)**?																	

3) Navigation impacts (VFCC)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Navigation impacts (VFCC)** compared to the **Introduction of alien organisms (VFCD)**?																	

Part P: Social Factor (Indigenous People) (SF)

Goal: *To select the most important factor that influences the Social Factor (Indigenous People) (SF).*

1) Loss of food source (SFA)

	Unimportant								**Equally Important**	**Important**							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Loss of food source (SFA)** compared to the **Loss of housing (SFB)**?																	
To achieve the above goal how important is the **Loss of food source (SFA)** compared to the **Disease (SFC)**?																	
To achieve the above goal how important is the **Loss of food source (SFA)** compared to the **Loss of culture (SFD)**?																	
To achieve the above goal how important is the **Loss of food source (SFA)** compared to the **Stimulation of economic activity of people in the North region (SFE)**?																	

2) Loss of housing (SFB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Loss of housing (SFB)** compared to the **Disease (SFC)**?																	
To achieve the above goal how important is the **Loss of housing (SFB)** compared to the **Loss of culture (SFD)**?																	
To achieve the above goal how important is the **Loss of housing (SFB)** compared to the **Stimulation of economic activity of people in the North region (SFE)**?																	

3) Disease (SFC)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Disease (SFC)** compared to the **Loss of culture (SFD)**?																	
To achieve the above goal how important is the **Disease (SFC)** compared to the **Stimulation of economic activity of people in the North region (SFE)**?																	

4) Loss of culture (SFD)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Loss of culture (SFD)** compared to the **Stimulation of economic activity of people in the North region (SFE)**?																	

Part Q: Technological Factor (TF)

Goal: *To select the most important factor that influences the Technological Factor (TF).*

1) Advanced ice breaking technology (TFA) [16]

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Advanced ice breaking technology (TFA)** compared to the **New ship technology or design (TFB) [17]**?																	
To achieve the above goal how important is the **Advanced ice breaking technology (TFA)** compared to the **Aerial drones can be used to spot free and fast ice (TFC) [18]**?																	

[16] The Russia has nuclear-powered icebreakers with the experience and technological capabilities in the Arctic

[17] The development of a double-acting vessel able to move stern forward to break through heavy ice, much in the manner of ice breaker

[18] Aerial drones are already in use by fishermen to spot schools of fish and it is also possible to spot free and fast ice

2) New ship technology or design (TFB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **New ship technology or design (TFB)** compared to the **Aerial drones can be used to spot free and fast ice (TFC)**?																	

Part R: Safety Factor (FF)

Goal: *To select the most important factor that influences the Safety Factor (FF).*

1) Status of shipping and port infrastructure (FFA)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Status of shipping and port infrastructure (FFA)** compared to the **Status of navigational aids facilities (FFB)**?																	
To achieve the above goal how important is the **Status of shipping and port infrastructure (FFA)** compared to the **Training for crew for the Arctic operations (FFC)**?																	

2) Status of navigational aids facilities (FFB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Status of navigational aids facilities (FFB)** compared to the **Training for crew for the Arctic operations (FFC)**?																	

Part S: Status of shipping and port infrastructure (FFA)

Goal: *To select the most important factor that influences the Status of shipping and port infrastructure (FFA).*

1) Status of search and rescue facilities (FFAA)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Status of search and rescue facilities (FFAA)** compared to the **Status of availability of international port along the route (FFAB)**?																	
To achieve the above goal how important is the **Status of search and rescue facilities (FFAA)** compared to the **Status of ships repair and maintenance facilities (FFAC)**?																	

2) Status of availability of international port along the route (FFAB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Status of availability of international port along the route (FFAB)** compared to the **Status of ships repair and maintenance facilities (FFAC)**?																	

Part T: Status of navigational aids facilities (FFB)

Goal: *To select the most important factor that influences the Status of navigational aids facilities (FFB).*

1) Charting and monitoring (FFBA)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Charting and monitoring (FFBA)** compared to the **Radio and satellite communications and emergency response (FFBB)**?																	
To achieve the above goal how important is the **Charting and monitoring (FFBA)** compared to the **Observational networks and forecast (FFBC)**?																	

2) Radio and satellite communications and emergency response (FFBB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Radio and satellite communications and emergency response (FFBB)** compared to the **Observational networks and forecast (FFBC)**?																	

Part U: Advantages of the NSR in comparison to other alternatives (AF)

Goal: *To select the most important factor that influences the Advantages of the NSR in comparison to other alternatives (AF).*

1) Shorter route (AFA)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Shorter route (AFA)** compared to the **No piracy or terrorism threat (AFB)**?																	
To achieve the above goal how important is the **Shorter route (AFA)** compared to the **No vessel size restriction for further north route of the NSR (AFC)**?																	

2) No piracy or terrorism threat (AFB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **No piracy or terrorism threat (AFB)** compared to the **No vessel size restriction for further north route of the NSR (AFC)**?																	

Part V: Shorter route (AFA)

Goal: *To select the most important factor that influences the Shorter route (AFA)*

1) Saving in time (AFAA)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Saving in time (AFAA)** compared to the **Saving in expenses (AFAB)**?																	
To achieve the above goal how important is the **Saving in time (AFAA)** compared to the **Increase the number of roundtrips (AFAC)**?																	
To achieve the above goal how important is the **Saving in time (AFAA)** compared to the **Reduced of air emissions (AFAD)**?																	

2) Saving in expenses (AFAB)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Saving in expenses (AFAB)** compared to the **Increase the number of roundtrips (AFAC)**?																	
To achieve the above goal how important is the **Saving in expenses (AFAB)** compared to the **Reduced of air emissions (AFAD)**?																	

3) Increase the number of roundtrips (AFAC)

	Unimportant								Equally Important	Important							
	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
To achieve the above goal how important is the **Increase the number of roundtrips (AFAC)** compared to the **Reduced of air emissions (AFAD)**?																	

This is the end of the questionnaire. Thank you very much for your help.

Appendix G: Background information of experts (Chapter 4)

Table A4.15: Background information of experts involved in Chapter 4

Experts	Background information
Expert 1	Maritime Lecturer at a United Kingdom University. He has been involved in the maritime and marine industry for more than 20 years.
Expert 2	Associate Professor of Maritime Logistics at a Norwegian University. 24 years combined maritime experience, from the shipping industry and academia
Expert 3	Associate Professor at a Danish University specialized in transport system analysis and strategic transport planning with special focus on maritime transport and spatial modelling (geographical information systems).
Expert 4	Professor in ArcticNet and Institute Hydro-Quebec in Environment, Development and Society (IEDS) at a Canadian University. He has done a lot of research in the field of water management and the Arctic such as the impacts of climate change on Arctic governance, particularly with respect to navigation, natural resources and sovereignty disputes.
Expert 5	Specialist in engineering system, marine technology and engineering services in a leading classification society
Expert 6	Senior specialist engineer at a leading classification society. He was a marine engineer in Shell International Trading and Shipping Corporation and before that, he was marine engineer in Pakistan National Shipping Corporation.
Expert 7	Project engineer, engineering system at a leading classification society. He was a safety and risk consultant and safety engineer.

Appendix H: Sensitivity Analysis for Chapter 4

Table A4.16: Sensitivity analysis of 10% increased of weight values

Criteria	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking
EF	0.2353	1	0.2113	1	0.2117	1	0.2120	1	0.2122	1	0.2126	1	0.2131	1	0.2131	1
AF	0.1797	2	0.2011	2	0.1806	2	0.1809	2	0.1811	2	0.1815	2	0.1820	2	0.1820	2
FF	0.1497	3	0.1502	3	0.1681	3	0.1509	3	0.1511	3	0.1515	3	0.1520	3	0.1520	3
PF	0.1305	4	0.1310	4	0.1314	4	0.1470	4	0.1319	4	0.1323	4	0.1328	4	0.1328	4
TF	0.1144	5	0.1149	5	0.1153	5	0.1156	5	0.1292	5	0.1162	5	0.1167	5	0.1167	5
VF	0.0850	6	0.0855	6	0.0859	6	0.0862	6	0.0864	6	0.0970	6	0.0873	6	0.0873	6
LF	0.0551	7	0.0556	7	0.0560	7	0.0563	7	0.0565	7	0.0569	7	0.0640	7	0.0574	7
SF	0.0499	8	0.0504	8	0.0508	8	0.0511	8	0.0513	8	0.0517	8	0.0522	8	0.0583	8

Table A.17: Sensitivity analysis of 20% increased of weight values

Criteria	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking	Weight	Ranking
EF	0.2567	1	0.2087	2	0.2095	1	0.2101	1	0.2105	1	0.2114	1	0.2122	1	0.2124	1
AF	0.1767	2	0.2194	1	0.1784	3	0.1790	2	0.1794	2	0.1803	2	0.1811	2	0.1813	2
FF	0.1467	3	0.1476	3	0.1834	2	0.1490	3	0.1494	3	0.1503	3	0.1511	3	0.1513	3
PF	0.1275	4	0.1284	4	0.1292	4	0.1603	4	0.1302	5	0.1311	4	0.1319	4	0.1321	4
TF	0.1114	5	0.1123	5	0.1131	5	0.1137	5	0.1410	4	0.1150	5	0.1158	5	0.1160	5
VF	0.0820	6	0.0829	6	0.0837	6	0.0843	6	0.0847	6	0.0881	6	0.0864	6	0.0866	6
LF	0.0521	7	0.0530	7	0.0538	7	0.0544	7	0.0548	7	0.0557	7	0.0698	7	0.0567	8
SF	0.0469	8	0.0478	8	0.0486	8	0.0492	8	0.0496	8	0.0505	8	0.0513	8	0.0636	7

Appendix I: Screening process of factors for selecting the best route

All criteria will be analysed according to the factors of selecting the best route proposed by Rodrigue (2013). Each sub-criterion or sub-sub-criterion must be at least related to one of the three factors as follows:

1) Cost minimization (CM)
2) Efficiency maximization (EM)
3) Least damage to the environment (LE)

Then, those related criteria is analyse whether there are constant or fixed parameters or variable parameters.

Table A5.1: The process of selecting factors of the best route and parameter basis

Level 1	**Level 2**	**Level 3**	**The criteria related to the factors of selecting the best route**	**Parameter**
Criteria	**Sub-criteria**	**Sub-sub-criteria**		
Political Factor (PF)	Campaign Effort (PFA)	Promotion by the Russians (PFAA)	Not related	-
		Collaboration with other countries (PFAB)	Not related	-
		Level of Russian state investment on the infrastructure (PFAC)	Related (EM)	Fixed
	Administration Procedures (PFB)	No ship deviation without Russian permission (PFBA)	Related (EM)	Fixed
		Ship owners need to submit their request to use the NSR 4 months in advance (PFBB)	Related (EM)	Fixed
		Mandatory local inspection of the vessel even though the vessels fulfils the requirements (PFBC)	Related (EM)	Fixed
	Foreign Affairs (PFC)	Political risks and uncertainties because the NSR is in Russian territorial water (coastal route) (PFCA)	Related (EM)	Fixed
		Increasing militarization of the Arctic by the Russian Government (PFCB)	Related (EM)	Fixed
		Changes in international political/strategic configuration and relations between major world actors and Arctic ocean coastal states (PFCC)	Related (EM)	Fixed

		Unpredictable behaviour of the Russian Government (selected prospective users of the NSR) (PFCD)	Related (EM)	Fixed
Legal Factor (LF)	Legal status of the NSR. Full Russian jurisdiction or some international status (LFA)		Related (EM)	Fixed
	Border disputes in the Arctic (LFB)		Not related	-
	Legal status of vessels and flags when transiting the NSR (LFC)		Related (EM)	Fixed
	No international legally binding requirements for ship designs & ice class ship (LFD)		Not related	-
Economic Factor (EF)	Operating cost (EFA)	Capital costs (ice strengthened vessels) (EFAA)	Related (CM)	Fixed
		The NSR Insurance costs (EFAB)	Related (CM)	Fixed
		Ship depreciation (EFAC)	Related (CM)	Fixed
		Manning costs (EFAD)	Related (CM)	Fixed
	Voyage cost (EFB)	Fuel costs (EFBA)	Related (CM)	Variable
		The NSR fees (Meteorological forecast & ice breaking) (EFBB)	Related (CM)	Variable
		Ice pilot fees (EFBC)	Related (CM)	Variable
	Commercial Aspect (EFC)	Shifts in economic geography (EFCA)	Not related	-
		Lack of major economic centre along the route (EFCB)	Related (EM)	Fixed
		Status of natural resources in Arctic (EFCC)	Not related	-
		Tourism industry (EFCD)	Not related	-
Environmental Factor (VF)	Disappearing of summer sea ice (VFA)	More navigable days for shipping operations (VFAA)	Related (CM)	Variable
		Possible extinction of Polar bears (VFAB)	Related (LE)	Fixed
		Some Arctic fisheries will be affected (VFAC)	Related (LE)	Fixed
	Challenges to operation (VFB)	Operational conditions like wind chills, darkness in winter, sea ice & ice bergs, high latitudes and etc. (VFBA)	Related (EM)	Variable

		Seasonality of operations (Navigable for 2 to 4 months in eastern part of the NSR :without ice breaking assistance) (VFBB)	Related (EM)	Fixed
		Shallow seas & straits (Vessel size restriction in coastal route) (VFBC)	Related (EM)	Variable
	Impact on the marine environment and marine biodiversity (VFC)	Accidental discharges of polluting substances (cargo or fuel) (VFCA)	Related (LE)	Fixed
		Operational discharges (cargo residues, fuel residues),garbage and sewage and emissions (CO_2, NO_2 SO_2) (VFCB)	Related (LE)	Fixed
		Navigation impacts (noise pollution and interference with marine species that cause disruption of behaviour and etc.)(VFCC)	Related (LE)	Fixed
		Introduction of alien organisms through ballast water exchanges or attachment to vessel hulls. (VFCD)	Related (LE)	Fixed
Social Factor (Indigenous People) (SF)	Loss of food source (SFA)		Related (LE)	Fixed
	Loss of housing (SFB)		Related (LE)	Fixed
	Disease (SFC)		Related (LE)	Fixed
	Loss of culture (SFD)		Related (LE)	Fixed
	Stimulation of economic activity of people in the north region (SFE)		Not related	-
Technological Factor (TF)	Advanced ice breaking technology (TFA)		Related (EM)	Fixed
	New ship technology/design (TFB)		Related (EM)	Fixed
	Aerial drones will be used to spot free and fast ice (TFC)		Related (EM)	Fixed
Safety Factor (FF)	Status of shipping and port infrastructure (FFA)	Status of search and rescue facilities (FFAA)	Related (EM)	Variable
		Status of availability of international port along the route (FFAB)	Related (EM)	Variable

		Status of ships repair and maintenance facilities (FFAC)	Related (EM)	Variable
	Status of navigational aids facilities (FFB)	Charting and monitoring (FFBA)	Related (EM)	Variable
		Radio and satellite communications and emergency response (FFBB)	Related (EM)	Variable
		Observational networks and forecast for weather, icing, waves and sea ice(FFBC)	Related (EM)	Variable
	Training for crew for Arctic operations (FFC)		Related (EM)	Fixed
Advantages of the NSR in comparison to other alternatives (AF)	Shorter route (AFA)	Saving in time(AFAA)	Related (CM)	Variable
		Saving in expenses (AFAB)	Related (CM)	Variable
		Increase the number of roundtrips (AFAC)	Related (CM)	Variable
		Reduced air emissions from ships (AFAD)	Related (LE)	Variable
	No piracy/terrorism threat (AFB)		Related (EM)	Fixed
	No vessel size restriction for further north route of the NSR (AFC)		Related (EM)	Fixed

Appendix J: The general information of ship for the test case

Table A5.2: The general information of ship (MV Yong Sheng) for the test case. (Source: marinetraffic.com)

General Vessel Information			
Name:	Yong Sheng	**Length:**	160 m x 23 m
Flag:	Hong Kong SAR of China	**Draught (min/avg/max):**	5.3 m / 6.4 m/ 9.0 m
IMO:	9243813	**Speed (avg/max):**	11.3 kn / 16.6 kn
MMSI:	477265600	**Year Built:**	2002
Callsign:	VRCA4	**Deadweight:**	19461 tons
Gross Tonnage:	14357	**Vessel Type:**	General cargo vessel
Owner:	COSCO Shipping Co Ltd	**Classification Society:**	Lloyd's Register
Ice Class:	1A (Arc 4)	**Person Capacity:**	14
Engine Description			
Engine:	7.860 kW	**Bow Thruster:**	750 kW
Gears:	Pitch	**Stern Thruster:**	no
Propeller:	1 rechts	**Rudder:**	1 Blades, normal

Appendix K: A questionnaire for obtaining the belief degree values

Part A: Belief Degree Concept

The goal of this study is to analyse and making comparison between the shipping routes with the aim to selecting the most effective shipping route within the NSR. Therefore, the qualitative criteria are the parameters that need to be evaluated by using a Belief Degree Concept.

An expert is required to give a possible judgment to all questions based on his/her expertise and experience in the shipping industry. An expert only have to answer for the particular sub-criteria only (that need subjective judgement) because most of the sub-criteria are using quantitative data.

Please put the belief degree values of each designated criterion with respect to all alternatives. The belief degree concept can be understood by looking at the example below.

Belief degree of criterion of the 'Car price' with respect to all alternatives

Alternatives	Car Price				
	Expensive	Reasonably Expensive	Average	Reasonably Cheap	Cheapest
Ford	0.2	0.6	0.2		
Volvo		0.7	0.3		
BMW	0.75	0.25			
Skoda			0.5	0.4	

Explanation:

An expert state that the price of the Ford is 20% sure it is expensive, 60% sure it is reasonably expensive and 20% sure it is average. In the statement, expensive, reasonably expensive and average denote distinctive evaluation grades and the percentage values 20% and 60% are referred to as degrees of belief, which indicate the extents that the corresponding grades are assessed to. The above assessment can be expressed as the following expectation:

> The car price for Ford is *{(0.2, Expensive), (0.6, Reasonably Expensive), (0.2, Average)}*
> *Volvo: {(0.7, Reasonably Expensive), (0.3, Average)}.*
> *BMW*: *{(0.75, Expensive), (0.25, Reasonably Expensive)}*
> *Skoda: {(0.5, Average), (0.4, Reasonably Cheap)}.*

The total score for each judgement of alternative should be less or equal to 1. For example, the total score for BMW is 0.75 + 0.25 = 1, however for Skoda, the total score is 0.5 + 0.4 = 0.9, so there is 0.1 missing information which is likely to acquire in real life decision problems and may result from the lack of data and evidence (incompleteness) or the inability of the assessor to provide precise judgements due to the novelty and complexity of the problem in question.

To increase the consistency and reduce subjectivity in this assessment, the standard of each assessment grades are defined as follows (e.g. Operational Condition criterion):

Very good – all the subjective judgements and numerical measurements relating to the *operational condition* of a route within the NSR fall in the most desirable regions.

Good - all the subjective judgements and numerical measurements relating to the *operational condition* of a route within the NSR are favourable but not very good.

Average - all the subjective judgements and numerical measurements relating to the *operational condition* of a route within the NSR are at the satisfactory level.

Poor - all the subjective judgements and numerical measurements relating to the *operational condition* of a route within the NSR are satisfactory but below the average.

Very poor - all the subjective judgements and numerical measurements relating to the *operational condition* of a route within the NSR satisfy only the relevant lowest standard.

This definition of grades are also apply to other criteria (Charting and monitoring, radio & satellite communications, observational network and forecast and search and rescue facilities).

Hence, based on your judgement, please put the degree of belief value for all the question below:

1) Belief degree of the criterion "Operational condition[1]" with respect to all alternatives

Alternative	Operational condition				
	Very good	Good	Average	Poor	Very poor
Route 1					
Route 2					
Route 3					
Route 4					

[1] Operational conditions like wind chills, darkness in winter, sea ice and ice bergs, high latitude and etc. in current years in summer season only.

2) Belief degree of the criterion “Charting and monitoring” with respect to all alternatives

Alternative	Charting and monitoring				
	Very good	Good	Average	Poor	Very poor
Route 1					
Route 2					
Route 3					
Route 4					

3) Belief degree of the criterion “Radio & satellite communications[2]” with respect to all alternatives

Alternative	Radio & satellite communications				
	Very good	Good	Average	Poor	Very poor
Route 1					
Route 2					
Route 3					
Route 4					

[2]The satellite (Inmarsat & VSAT systems) have little or no coverage at all in the Arctic especially in the North Pole.

4) Belief degree of the criterion “Observational networks and forecast[3]” with respect to all alternatives

Alternative	Observational networks and forecast				
	Very good	Good	Average	Poor	Very poor
Route 1					
Route 2					
Route 3					
Route 4					

[3]Observational networks and forecasts for weather, icing, waves, and sea ice.

5) Belief degree of the criterion “Search and rescue (SAR) facilities” with respect to all alternatives

Alternative	Search and rescue (SAR) facilities				
	Very good	Good	Average	Poor	Very poor
Route 1					
Route 2					
Route 3					
Route 4					

End of the questionnaire

Appendix L: The calculation of journey time

The calculation of journey time for Route 2, 3 and 4

Route 2 = $\frac{2998}{14\ x\ 24}$

= **<u>8.92 days</u>**

Route 3 = $\frac{2892}{14\ x\ 24}$

= **<u>8.61 days</u>**

For Route 4, it is assumed that 45% of the route are still in ice and the average speed is 6 knot, while the rest of it will be 14 knot.

Route 4 (without ice) = $\frac{1501}{14\ x\ 24}$

= 4.47 days

Route 4 (with ice) = $\frac{1228}{6\ x\ 24}$

= 8.53 days

Total journey time for route 4 is 4.47 + 8.53 = **<u>13 days</u>**

Appendix M: The calculation of the number of round trips

The calculation of the number of round trips

Route 2

Nd = 141, where for UIC = 70 days and FIC = 71 days

Tpi = 2 days,   n = 2 ports,

D = 2998 nm of total distance. UIC = 2253 nm + 745 nm (FIC),

V = 12 knots (UIC) and 14 knots (FIC)

$$\text{Roundtrips Route 2} = \frac{70\ (UIC)}{(2x2)+\left(\frac{2253}{12\ x\ 24}\right)+\left(\frac{745\ (FIC)}{14\ x\ 24}\right)} + \frac{71\ (FIC)}{(2x2)+\left(\frac{2998}{14\ x\ 24}\right)}$$

= 4.9857 + 5.4 = **<u>10.48 trips in one season</u>**

Route 3

Nd = 110, where for UIC = 55 days and FIC = 55 days

Tpi = 2 days   n = 2 ports

D = 2892 nm of total distance. UIC = 2062 nm + 830 nm (FIC),

V = 12 knots (UIC) and 14 knots (FIC)

$$\text{Roundtrips Route 3} = \frac{55\ (UIC)}{(2x2)+\left(\frac{2062}{12\ x\ 24}\right)+\left(\frac{830\ (FIC)}{14\ x\ 24}\right)} + \frac{55\ (FIC)}{(2x2)+\left(\frac{2892}{14\ x\ 24}\right)}$$

= 4.0352 + 4.36 = **<u>8.40 trips in one season</u>**

<u>Route 4</u>

For Route 4, only highly capable icebreaker ship can pass through this route.

Nd = 70 days   Tpi = 2 days   n = 2 ports

D = 2729 nm (total distance), 1501 nm is in FIC and another 1228 nm is in the ice route (UIC).

V = 6 knots (Baskin *et al.*, 1998) in ice and 14 knots for free from ice route.

$$\text{Roundtrips Route 4} = \frac{70}{(2x2)+\left(\frac{1228}{6\ x\ 24}\right)+\left(\frac{1501}{14\ x\ 24}\right)}$$

= **<u>4.12 trips in one season</u>**

Appendix N: The calculation of CO_2 emissions

The calculation of CO_2 emission for each route within the NSR

Route 1

$$= 3.17 \text{ x} \left\{\left[30\ x\ \left(\frac{14}{16.6}\right)^3 + 8.4\right]\ x\ \frac{3048}{24\ x\ 14}\right\}$$

= 3.17 x 26.3962 x 9.0714

= **759.0584 kg/voyage**

Route 2

$$= 3.17 \text{ x} \left\{\left[30\ x\ \left(\frac{14}{16.6}\right)^3 + 8.4\right]\ x\ \frac{2998}{24\ x\ 14}\right\}$$

= 3.17 x 26.3962 x 8.9226

= **746.6071 kg/voyage**

Route 3

$$= 3.17 \text{ x} \left\{\left[30\ x\ \left(\frac{14}{16.6}\right)^3 + 8.4\right]\ x\ \frac{2892}{24\ x\ 14}\right\}$$

= 3.17 x 26.3962 x 8.6071

= **720.2073 kg/voyage**

Appendix O : Background information of experts (Chapter 5)

Table A5.3 : Background information of experts involved in ER questionnaire

Experts	Background information
Expert 1	A researcher in Central Marine Research and Design Institute (CNIIMF) in Russia. Created in 1929, is the leading scientific organisation of the Russian Federation in the field of maritime transport, dealing with almost all the problems of the industry: the development of the fleet and ports, the design of the transport and service and auxiliary vessels fleet technology transportation of goods, the economy of the Navy, the technical operation of vessels and port handling equipment, radiation safety, labour protection, development of Arctic marine transport systems, ice-breaking and nuclear fleet,
Expert 2	Professor in ArcticNet and Institute Hydro-Quebec in Environment, Development and Society (IEDS) at a Canadian University. He has done a lot of research in the field of water management and the Arctic such as the impacts of climate change on Arctic governance, particularly with respect to navigation, natural resources and sovereignty disputes.
Expert 3	Research Associate at Arctic Technology department in a Norwegian University. Her recent works are: **SAMCoT** - (2011-2019) Sustainable Arctic Marine and Coastal Technology **SITRA** - (2015-2018) Safety of Industrial Development and transportation Routes in the Arctic **MARPART** – (2014-2017) Maritime preparedness in the high north – institutional partnership and coordination **FIMA** (2015-2017) - Field studies and modelling of sea state, drift ice, ice actions and methods of icebergs management on the Arctic shelf
Expert 4	A Professor at Department of Ocean Operations and Civil Engineering in Norwegian University of Science and Technology. He trained as a master mariner at Tromsø University College and has a Deck Officer Certificate Class 1. He has varied experience from different types of ships operating in arctic waters – including voyages in the Northeast and Northwest passages and to the North Pole. His MSc thesis at the Norwegian Institute of Technology in 1989 was related to nautical aspects of ship operations on the Northern Sea Route in Russia. After many years at sea he started his academic career as a lecturer at Aalesund University College in 1991, and qualified there as Professor in 2004. Since 2007 he has also been Adjunct Professor in ice navigation at the University of Tromsø, and has been responsible for theoretical- and field courses in ice navigation at this university. In addition, he has dedicated a lot of work to developing simulators and textbooks for advanced navigation and ship handling.
Expert 5	PhD candidate in International relations at Sciences Po in Paris, France. She graduated in Political Science from Sciences Po and holds a MA in Geography from the Sorbonne University. Arctic politics has always been of special interest to her and she is involved in Arctic-specific projects such as the French Association of Polar Early Career Scientist. She previously took part of the Arctic-FROST network and the Young Scientist Workshop from Arctic Frontiers Conference. She also worked as a research assistant in Arctic politics in two think tanks. Now, her PhD dissertation is dealing with regional governance and international cooperation in the Arctic, focusing on the role of the Arctic Council.

Appendix P: The values of quantitative and qualitative data for all routes within the NSR

Table A5.4: Assessment of the basic attributes of the routes within the NSR

Criteria	**Route 1**	**Route 2**	**Route 3**
The number of navigable days	146	141	110
The Shallowest strait (m)	12.5	30	30
Journey time (days)	9.07	8.92	8.61
The number of roundtrips	10.68	10.48	8.40
CO_2 emissions (KG/voyage)	759.0584	746.6071	720.2073
Fuel costs (USD)	63 807.45	62 752.20	60 571. 35
The NSR fees (USD)	98 539.552	114 961.664	114 961.664
The Ice pilot fees (USD)	5054.22	4515.83	4132.22
Operational conditions	(0.0, 0.14, 0.3, 0.34, 0.22)	(0.14, 0.22, 0.4, 0.24, 0.0)	(0.18, 0.42, 0.18, 0.22, 0.0)
Charting & monitoring	(0.02, 0.12, 0.44, 0.22, 0.2)	(0.02, 0.22, 0.38, 0.18, 0.2)	(0.02, 0.4, 0.36, 0.22, 0.0)
Radio & Satellite communications	(0.02, 0.08, 0.22, 0.42, 0.2)	(0.0, 0.16, 0.32, 0.22, 0.22)	(0.04, 0.26, 0.26, 0.36, 0.0)
Observational network & forecast	(0.0, 0.06, 0.2, 0.4, 0.26)	(0.0, 0.24, 0.18, 0.28, 0.24)	(0.0, 0.28, 0.38, 0.26, 0.02)
Search & rescue facilities	(0.0, 0.14, 0.2, 0.42, 0.2)	(0.0, 0.28, 0.3, 0.34, 0.0)	(0.02, 0.34, 0.5, 0.06, 0.0)

Appendix Q: Sensitivity analysis for Chapter 5

Table A5.5: Sensitivity analysis of main criteria with 10% increased of weight values

Main Criteria	Original weight	EVF 10%	DSF 10%	ECF 10%	STF 10%
EVF	15.7	17.27	14.81	14.49	14.99
DSF	26.7	26.18	29.37	25.49	25.99
ECF	36.4	35.88	35.51	40.04	35.69
STF	21.2	20.68	20.31	19.99	23.32
	Score of the alternatives				
	R1	**R1**	**R1**	**R1**	**R1**
	0.3617	0.3667	0.3504	0.351	0.3705
	R2	**R2**	**R2**	**R2**	**R2**
	0.4215	0.4263	0.4209	0.4057	0.4249
	R3	**R3**	**R3**	**R3**	**R3**
	0.662	0.6567	0.6719	0.6707	0.6557

Table A5.6: Sensitivity analysis of main criteria with 20% increased of weight values

Main Criteria	Original weight	EVF 20%	DSF 20%	ECF 20%	STF 20%
EVF	15.7	18.84	13.92	13.27	14.28
DSF	26.7	26.65	32.04	24.27	25.29
ECF	36.4	35.35	34.62	43.68	34.99
STF	21.2	20.15	19.42	18.77	25.44
	Score of the alternatives				
	R1	**R1**	**R1**	**R1**	**R1**
	0.3617	0.3692	0.3391	0.351	0.3796
	R2	**R2**	**R2**	**R2**	**R2**
	0.4215	0.4315	0.4204	0.4057	0.4285
	R3	**R3**	**R3**	**R3**	**R3**
	0.662	0.6536	0.6818	0.6707	0.6492

Appendix R : Summary of the models of NSR shipping considered for the review from 1999-2016

Table A6.1: Models of NSR shipping considered for the review from 1999-2016

Year	Authors	Title	Medium	Objective	Route	Type of ship	Origin-destination	Period of navigation
1999	Ramsland, T. R.	Economic Evaluation of NSR Commercial Shipping	INSROP Working Paper No. 140	Compare the actual cost component differential of the routes	NSR & SCR	General cargo ship - 40 000 dwt	Northwest Europe – Far East Asia	Year-round
1999	Kamesaki, K., Kishi, S., Yamauchi, Y.	Simulation of NSR Navigation Based on Year Round and Seasonal Operation Scenarios	INSROP Working Paper 8, Oslo:WP-164	Compare transportation costs for yearly service. Ships can use both routes depending on ice conditions	NSR & SCR	Handy Max 50 900 dwt for Suez route (general cargo). Three ice-class ship types for the NSR route: 25 000 dwt with high ice class PC4-PC5) (general cargo) – 40 000 dwt with PC4-PC5 high ice-class (general cargo) – 50 000 dwt with medium ice class (bulk – PC7)	Hamburg – Yokohama	Year -round
2012	Omre, A.	An economic transport system of the next generation integrating the northern and southern passage.	Master Thesis. Norwegian University of Science and Technology	Combining the NSR with the SCR. The NSR is only used as an alternative in the navigation season between August	NSR & SCR	Ice-class containership – 3800 TEU	Yokohama - Rotterdam	Year-round NSR in summer

				and the end of November.				
2012	Ueta, H., & Goda, H.	Chapter 3: Commercial Perspective of the Northern Sea Route	2012 Research Project Outcome of The Japan Institute of International Affairs "Arctic Governance and Japan's Diplomatic Strategy"	Economic assessment on one way trip for container ship and bulk carrier	NSR & SCR	Containership scenario: NSR – 4000 TEU and SCR – 8000 TEU (no ice class mentioned) Bulk carrier scenario: no ship size mentioned	Containership – Yokohama to Rotterdam, Bulk carrier – Kirkenes (Norway) to Qingdao (China)	Single voyage for both scenario in summer
2013	Otsuka, N. & Furuichi, M.	Study on Feasibility of the Northern Sea Route from Recent Voyages	Proceedings of the 22nd International Conference on Port and Ocean Engineering under Arctic Conditions. June 9-13, Espoo, Finland	Shipping cost comparison	NSR, Panama & SCR	Three types of ship used: 1. Bulk – ice-class IA (75 000 dwt), 2. LNG – (not specified) 100, 244 GT. 3. Refrigerated Cargo ship – (not specified) 12 383GT	Bulk –Murmask NSR – Rizhaou & Itaqui – Panama-Rizhou LNG – Hammerfest Tobata (between NSR & Suez) Cargo ship – Tamakomai – St.Petersburg (NSR & Suez)	June – November (summer)
2013	Furuichi, M. & Otsuka, N.	Cost Analysis of the Northern Sea Route and the Conventional Route Shipping	Proceedings of the IAME 2013 Conference July 3-5, Marseille, France	Compare transportation cost for containerships based on NSR-Suez Combined Shipping and Suez shipping	NSR & SCR	Five types of containership: 4000 TEU Ice Class (not specified) for NSR-Suez combined Shipping. 4000, 6000, 8000 & 15000 TEU for Suez shipping.	Yokohama – Hamburg	Year-round with 2 scenarios: NSR 105 days combined with Suez, 260 days compare

								with Suez 365 days
2014	Raza, Z. & Schoyen, H.	A Comparative study of the Northern Sea Route (NSR) in Commercial and Environmental Perspective with Focus on LNG Shipping	6th International Conference on Maritime Transport 2014 at Universitat Politecnica de Catalunya, Barcelona, Spain	Comparisons of transport cost components and CO2 emissions for the full round voyage	NSR & SCR	84 682 dwt of LNG – 1A ice-class ship	Hammerfest (Norway) – Tobata (Japan)	Full round voyage in summer
2014	HSVA	Calculation of fuel consumption per mile for various ship types and ice conditions in past, present and future	Arctic Climate Change, Economy and Society (ACCESS), Project co-funded by the European Commission within the Seventh Framework Programme(2007-2013)	Calculate travelling time, fuel consumption and gas emissions	NSR	One bulk carrier (1A) , two tanker (1A & 1A super), two LNG tanker (both 1A ice class but with different power)	Port of Murmansk to Bering Strait	Simulation from 1960 to 2040, months of April, July, September & November
2014	Lassere, F.	Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector	Transportation Research Part A. 66, 144-161	Study the direct costs compared with revenue-generating cargo	NSR, NWP & SCR	4500 TEU containership with 1AS-class ship (ice class)	Rotterdam – Shanghai & Rotterdam – Yokohama	May – November (180 days)
2015	Chang, K.Y. *et al*.	Route Planning and Cost Analysis for Travelling through the Arctic Northeast Passage Using Public 3D GIS	International Journal of Geographic Information Science	Distance calculated using a 3D GIS. Compare cost efficiency.	NSR and SCR	Bulk carrier (no ship size and ice class mentioned)	Major ports in Asia (Busan, Tokyo, Shanghai, Hong Kong, Kaohsiung) to Rotterdam	Single trip/voyage

2015	Moon, D., Kim, D. & Lee, E.	A Study on Competitiveness of Sea Transport by Comparing International Transport Routes between Korea and EU	The Asian Journal of Shipping and Logistics 31 (1) 1-20	Assess the competitiveness of 6 major transport routes between Korea and Europe using TOPSIS	Route 1: Trans Korea Railway (TKR) and Trans Siberia Railway (TSR), R2: Busan-Vostochny –TSR, Route 3: Busan-Vladivostok-Vostochny-TSR, R4: Busan-Vanino-TSR, R5: Busan-Suez_Europe-Berlin R6: Busan-Arctic Ocean-Europe-Berlin	Rail –Route 1 Sea+Rail- Route 2,3 & 4 Sea – Route 5 &6	Busan –Berlin	Single trip/voyage
2016	Zhang, Y. et al.	Shipping efficiency comparison between NSR and the conventional Aisa-Europe shipping route via Suez Canal	Journal of Transport Geography	This study first develops a profit estimation model for containership and oil tanker then proceed to compare the shipping efficiency for Asia-Europe market	NSR and SCR	Containerships Panamax Arc 4 - NSR New Panamax - SCR Tankers Aframax Arc 4 - NSR VLCC open water vessel for SCR	Containerships – Shanghai to Rotterdam Tankers – Mizushima to Mongstad	Single trip/voyage (summer time)

2016	Faury, O. & Cariou, P.	The Northern Sea route competitiveness for oil tankers	Transportation Research Part A	The comparison is based on potential cost and transit time savings that change on a monthly basis according to sailing conditions and the area along the NSR.	NSR and SCR	1A Ice-Class Panamax tanker - NSR Panamax tanker - SCR.	Murmansk (Russia) to Daesan (South Korea)	Monthly basis for whole year
2016	Zhaou, H. et al.	Study on China – EU container shipping network in the context of Northern Sea Route	Journal of Transport Geography	This paper assesses the potential of the NSR based on designing a multi-port multi-trip liner service by establishing a two-stage optimization model	NSR and SCR (combining NSR and SCR) use NSR in summer time and then SCR in winter	4800 TEU containership. No ice - class mentioned	Rotterdam to Shanghai	Roundtrip

Appendix S : Background information of experts (Chapter 6)

Table A6.2 : Background information of experts involved in Chapter 6

Expert 1	Associate Director, Marine Policy & Professor at an American University. He is focused on technology policy innovation for 21st Century freight systems, with a focus on international shipping and coastal marine policy. He has more than 20 years' experience providing engineering, technology, and policy studies to industry, government, and other organizations. Among more than 175 publications, he co-authored the 2000 IMO Study on Greenhouse Gases from Ships, the Second IMO Greenhouse Gas Study 2009, and the IMO Greenhouse Gas Study 2014.
Expert 2	Professor in ArcticNet and Institute Hydro-Quebec in Environment, Development and Society (IEDS) at a Canadian University. He has done a lot of research in the field of water management and the Arctic such as the impacts of climate change on Arctic governance, particularly with respect to navigation, natural resources and sovereignty disputes.
Expert 3	Associate Professor of Maritime Logistics at a Norwegian University. 24 years combined maritime experience, from the shipping industry and academia. He published more than 150 publications regarding maritime transportation and logistics.

Appendix T: TOPSIS calculation for tramp shipping scenario

Step 1: Estimate the weight of each criterion

Table 6.12 in the thesis shows the weighing vector values of all criteria for Tramp Shipping. The new weights (normalised weighting vectors) of all the sub-criteria are calculated after obtaining the weighting vector values of all the main criteria and sub-criteria.

Table A6.3 summarises the final weighting values of all the sub-criteria by incorporating the weighting vector values of all the main criteria.

Table A6.3: The normalised weighting vector values of all criteria for tramp shipping

	DE	TT	TC	TS					SY		EM		
Weight (wj)				**RY**	**FY**	**QY**	**LF**	**CS**	**TF**	**FS**	**CO**	**NO**	**SO**
	0.1484	0.1015	0.2083	0.0434	0.0307	0.0180	0.0181	0.0206	0.1578	0.1578	0.0380	0.0243	0.0331

Step 2: Construct the normalised decision matrix, R_{ij}

The normalised decision matrix of the test case is computed using Equation 6.1 in association with a set of data in Table 6.12.

Table A6.4 summarised the normalised decision matrix value.

Table A6.4: The normalised decision matrix value for tramp shipping

	DE	TT	TC	TS					SY		EM		
				RY	**FY**	**QY**	**LF**	**CS**	**TF**	**FS**	**CO**	**NO**	**SO**
NSR	0.4993	0.5576	0.6387	0.3052	0.2595	0.8575	0.4329	0.8575	0.2796	0.2796	0.5057	0.5145	0.5145
SCR	0.8664	0.8301	0.7695	0.9523	0.9657	0.5145	0.9015	0.5145	0.9601	0.9601	0.8627	0.8575	0.8575

Step 3: Calculate the weighted normalised decision matrix, V_{ij}

The weighted normalised decision matrix of this test case is calculated by using Equation 6.2.

The output of the calculation is obtained as shown in Table A6.5.

Table A6.5: The weighted normalised decision matrix for tramp shipping

	DE	TT	TC	TS					SY		EM		
				RY	**FY**	**QY**	**LF**	**CS**	**TF**	**FS**	**CO**	**NO**	**SO**
NSR	0.0741	0.0566	0.1330	0.0132	0.0080	0.0154	0.0078	0.0177	0.0441	0.0441	0.0192	0.0125	0.0170
SCR	0.1286	0.0843	0.1603	0.0413	0.0296	0.0093	0.0163	0.0106	0.1515	0.1515	0.0328	0.0208	0.0284

Step 4: Determine the positive (PIS), V^+ and negative ideal solutions (NIS), V^-

Based on the output values in Table A6.4 in association with the goal of each sub-criterion described in Table 6.5, the positive and negative ideal solutions are determined respectively. In this test case, the values of $\{(max_j V_{ij} \mid j \in J)\}$ and $\{min_j V_{ij} \mid j \in J')\}$ belong to the positive ideal solution (Table A6.5) and Equations 6.3 is referred.

Table A6.6: The positive ideal solution (PIS), V^+ for tramp shipping

	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Cost	Cost	Cost
	DE	**TT**	**TC**	**TS**					**SY**		**EM**		
				RY	**FY**	**QY**	**LF**	**CS**	**TF**	**FS**	**CO**	**NO**	**SO**
NSR	0.0741	0.0566	0.1330	0.0132	0.0080	0.0154	0.0078	0.0177	0.0441	0.0441	0.0192	0.0125	0.0170
SCR	0.1286	0.0843	0.1603	0.0413	0.0296	0.0093	0.0163	0.0106	0.1515	0.1515	0.0328	0.0208	0.0284

The goal of each criterion in the NIS will be changed to the opposite of the PIS. For instance, from 'Benefit' to 'Cost' and the other way around. The values of $\{min_j V_{ij} \mid j \in J')\}$ and $\{(max_j V_{ij} \mid j \in J)\}$ belong to the negative ideal solution (Table A6.6) and Equations 6.4 is referred.

Table A6.7: The negative ideal solution (NIS), V^- for tramp shipping

	Benefit	Benefit	Benefit	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Benefit	Benefit	Benefit
	DE	**TT**	**TC**	**TS**					**SY**		**EM**		
				RY	**FY**	**QY**	**LF**	**CS**	**TF**	**FS**	**CO**	**NO**	**SO**
NSR	0.0741	0.0566	0.1330	0.0132	0.0080	0.0154	0.0078	0.0177	0.0441	0.0441	0.0192	0.0125	0.0170
SCR	0.1286	0.0843	0.1603	0.0413	0.0296	0.0093	0.0163	0.0106	0.1515	0.1515	0.0328	0.0208	0.0284

Step 5: Calculate the distance separation measures for PIS, D^+_i and NIS, D^-_i

The distance separation is divided into two parts which are related to the PIS and NIS. The D^+_i is computed using Equation 6.5, while the D^-_i is calculated using Equation 6.6. Table A6.8 summarises the values of the distance separation and closeness of each alternative.

Table A6.8: The distance separation and closeness values of each alternatives for tramp shipping

	D^+	D^-
NSR	0.1562	0.0703
SCR	0.0703	0.1562

Step 6: Calculate the relative closeness to the ideal solution (RC_i^+)

Since this study has only two alternatives, therefore Equation 6.7 can be used to find the relative closeness to the ideal solution. The best shipping route will be chosen by shipping companies based on the RC_i^+ value closest to the one which has the shortest distance from the positive ideal solution point and the farthest distance from the negative ideal solution point. Referring to the alternative 'NSR' as example and the D^+ and D^- value from Table A6.6 the value of RC_i^+ is computed as follows:

$$RC_i^+{}_{NSR} = \frac{0.0703}{0.1562 + 0.0703} = 0.3105$$

$$RC_i^+{}_{SCR} = \frac{0.1562}{0.0703 + 0.1562} = 0.6895$$

Table A6.9: The value of RC_i^+ for tramp shipping

RC_i^+	**Tramp shipping**
NSR	0.3105
SCR	0.6895

Step 7: Rank the preference alternatives

Based on Table A6.9, it is clearly that the value of RC_i^+ for the SCR is closer to one or larger than the NSR. This indicates that, the SCR has been proven to be the best route for transit shipping compared to the NSR.

Appendix U: The map of China’s Belt and Road Initiative

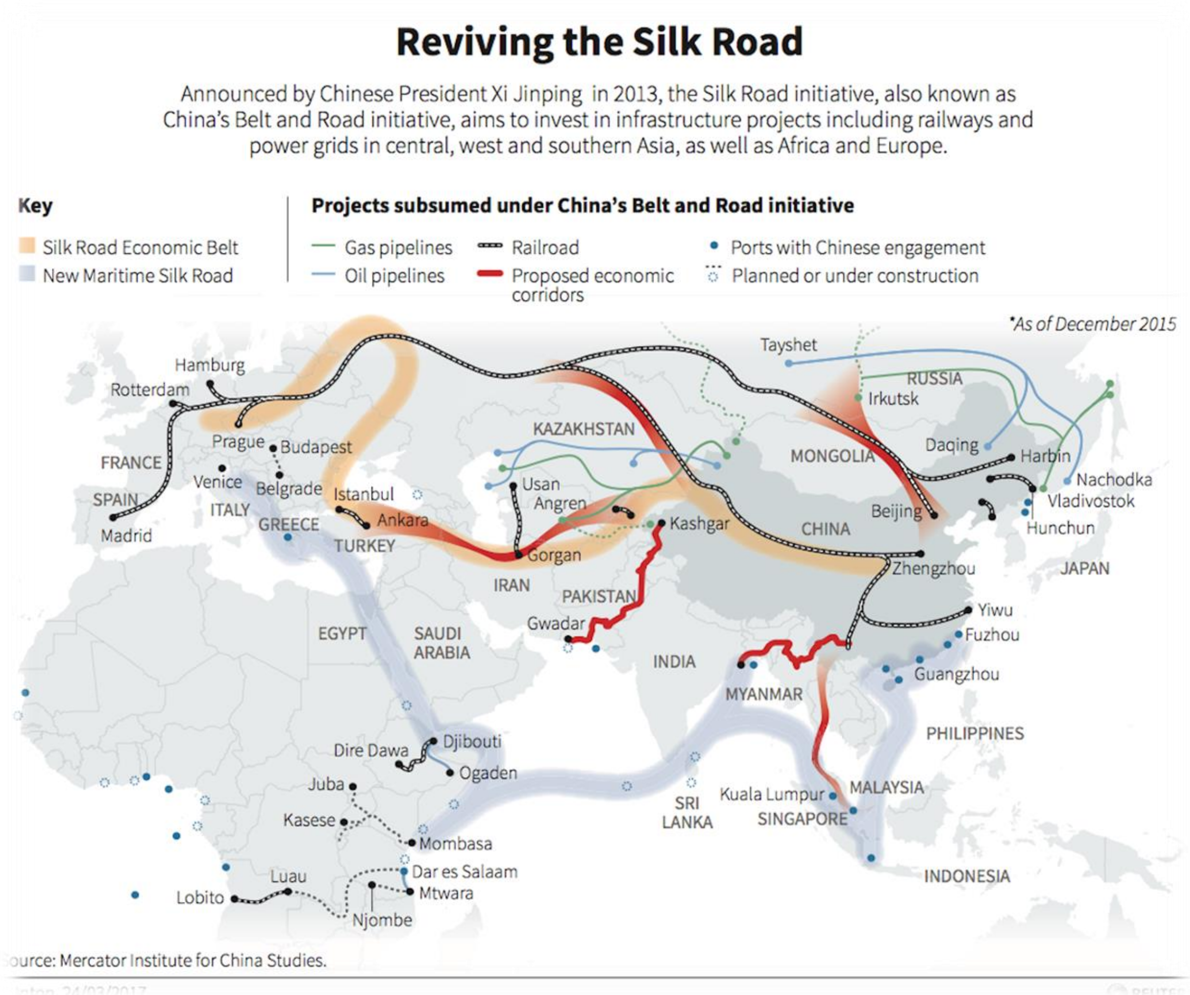

Figure A8.1: The map of China’s Belt and Road Initiative

(Source: Business Insider, 2018)