Economic Feasibility of Shipping Containers Through the Arctic

by

Russell Pollock

B.S. Naval Architecture and Marine Engineering
Webb Institute, 2008

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Abstract

As the Arctic ice cover continues to retreat, the possibility of regular transit through the Arctic becomes an increasing reality. Liner companies could take advantage of distance savings (up to 4000 nautical miles less than existing routes) available from transit through the Arctic by offering faster port-to-port voyage times while simultaneously reducing voyage expenses.

The purpose of the study is to investigate the economic feasibility of a liner service with shipping routes through the Arctic. To accomplish this, information pertaining to Arctic conditions, containerships and icebreakers, and container ports was collected and used to build a model that estimates the expense and time of port-to-port voyages through the Arctic. Different combinations of vessels, routes, and speeds through the Arctic were evaluated with the model. The expense and time of the Arctic voyages were then compared to the equivalent existing liner routes.

The likelihood of year-round reliable containership service through the Arctic in the future depends on one's perspective. One the one hand, it won't happen for decades due to the presence of ice. Current predictions of a largely ice-free Arctic range from 2030 to later than 2100. On the other hand, if some favorable assumptions are made, it deserves serious consideration once minimally ice-strengthened containerships are able to be reliably escorted through the Arctic at a speed of 10kts.

Thesis Supervisor: Henry S. Marcus
Title: Professor of Marine Systems

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Executive Summary

As the Arctic ice cover continues to retreat, the possibility of regular transit through the Arctic becomes an increasing reality. Liner companies could take advantage of distance savings (up to 4000 nautical miles less than existing routes) available from transit through the Arctic by offering faster port-to-port voyage times while simultaneously reducing voyage expenses.

The purpose of the study is to investigate the economic feasibility of a liner service with shipping routes through the Arctic. To accomplish this, information pertaining to Arctic conditions, containerships and icebreakers, and container ports was collected and used to build a model that estimates the expense and time of port-to-port voyages through the Arctic. Different combinations of vessels, routes, and speeds through the Arctic were evaluated with the model. The expense and time of the Arctic voyages were then compared to the equivalent existing liner routes. The primary conclusions from the study are:

- Routes that achieve significant distance savings through Arctic transit, such as Northern Asia to Northern Europe, have the potential to offer a lower voyage cost and substantially lower voyage time than corresponding existing routes.
- Present day Arctic conditions allow for these advantages during summer months only. Ice conditions during at least the four most severe winter months greatly increase voyage expenses and transit times, eliminating the possibility of current year-round consistent liner schedules.
- Arctic conditions need to allow an average speed through the Arctic of at least 10 knots during all times of the year before regular service through the Arctic begins to look attractive.

Arctic Routes

There are three routes that can be used to cross the Arctic Ocean: the Northern Sea Route (NSR), the Northwest Passage (NWP), and the polar route—directly over the North Pole.

The Northern Sea Route follows the northern coast of Russia. It currently has the most favorable ice conditions for transit and is nearly ice-free four months of the year. Resultantly, the model created in this study uses the NSR. Portions of the NSR have been in use since the 1930's when the former U.S.S.R. used it to supply towns along the Siberian coast. Nearly all commercial use ended with the collapse of the U.S.S.R. Portions of the NSR are currently used for mineral transport from Russian mines. Russia is currently trying to persuade the United Nations that the Arctic seabed is on the Eurasian continental shelf which would provide weight to Russia's desire to claim territorial waters extending to and including the North Pole.

A northwestern passage from Europe to the Far East was sought as early as the 15th Century. Existence of what is known today as the Northwest Passage was proven in the 1800s but not transited non-stop until 1944. The NWP, which leads through the Canadian Arctic Archipelago and above the northern coast of Alaska, has not been used for commercial transport due to severe, unpredictable ice conditions and has historically been less navigable than the NSR. Canada has declared control over most of the NWP, a claim not recognized by the United States or the European Union who view the NWP as an international strait. The designation of international strait implies a "right of passage" through any territorial waters.

If the Arctic ice cap continues to decrease in size, it may be possible in the future to sail directly over the North Pole. Such a route would be outside the control of Russia and Canada and would avoid the relatively shallow waters in portions of the NSR and NWP.

Vessels

Several different types of containerships, as well as a dedicated icebreaker, were used in this study. Icebreaking, minimally ice-strengthened, and standard containerships were used in different alternatives for Arctic transit. Two sizes of containership (750 TEU and 5000 TEU) were investigated.

There are currently five nominally 750 TEU icebreaking containerships in continuous use today in the Arctic. The designer of the vessels, Aker Arctic, also has a conceptual design for a 5000 TEU icebreaking containership that is based on the 750 TEU vessels. The icebreaking containership is capable of independent operation in ice but is at least twice as expensive to build as a standard containership.

The minimally ice-strengthened containership used in the study is ice-strengthened according to ABS Ice Class A1. When travelling through ice-covered waters, it is escorted by an icebreaker. The ice-strengthened containership has the same principal characteristics as the standard containership with the exception of additional steel and equipment added to the hull according to the ice class.

The standard containership was primarily used in the study to calculate the voyage expense and time for existing liner routes. Principal characteristics and operational expenses for the 750 TEU and 5000 TEU standard containerships were provided by industry sources.

The 5000 TEU vessel's predicted ice capabilities were used to model an icebreaker escort for alternatives using a minimally ice-strengthened containership. If the ice-strengthened containership will encounter ice during its voyage, it is escorted by an icebreaker.

While two different sizes of containerships were analyzed with the model, this study focuses on the larger 5000 TEU containership. The 750 TEU containership was found to be too small to be viable for trans-ocean voyages. The 5000 TEU containership is significantly less expensive to own/operate on a per container basis because of the economies of scale.

Cases

Theoretical alternatives were created using favorable Arctic conditions in order to show what conditions will be necessary to make Arctic routes attractive to container services. Of all the alternatives evaluated, the most relevant are listed below.

Case 6: **Standard Containership, Suez Canal, 22.2kts**

This base case uses an existing route and is used to evaluate the Arctic cases.

Case 5: **Standard Containership, NSR, Unescorted, 22.2kts**

While certainly not possible in present-day conditions, this is the best possible case as it is allows a standard containership to operate at service speed through the shorter Arctic route.

Case 4: **Ice-strengthened Containership, NSR, Unescorted, 22.2kts**

This case is the same as the previous with the exception of slightly higher capital and operating costs due to the ice-strengthening.

Case 3: **8 months Ice-strengthened Containership, NSR, Unescorted, 22.2kts**
4 months Transshipment to Icebreaking Containership, 6.5kts

During the 4 winter months, the ice-strengthened containership delivers containers to a port close to the Arctic, where they are transshipped to an icebreaking containership for delivery to a port on the other side of the Arctic. The containers are then loaded on another ice-strengthened containership for delivery to the destination port.

Case 1a: **8 months Ice-strengthened Containership, NSR, Unescorted, 22.2kts**
4 months Ice-strengthened Containership, NSR, Icebreaker Escort, 17.5kts

The last three cases are the least capital intensive alternatives while ice is present in the NSR. An ice-strengthened containership is escorted through the Arctic at the service speed of the icebreaker. While this is not realistic today, it is used to demonstrate sensitivity to speed.

Case 1b: **8 months Ice-strengthened Containership, NSR, Unescorted, 22.2kts**
4 months Ice-strengthened Containership, NSR, Icebreaker Escort, 10kts

When an ice-strengthened containership can be escorted at 10kts or more during every part of the year, Arctic liner routes become potentially attractive alternatives to existing routes. Even if the containership lies at anchor, slow steams, or makes an extra port call to account for the 6.5 day time difference between the 8mo speed and 4mo speed, it is faster to use the NSR than the corresponding existing route. If the icebreaker escort is fully subsidized, significantly lower expenses are incurred over the base.

Case 1c: **8 months Ice-strengthened Containership, NSR, Unescorted, 22.2kts**
4 months Ice-strengthened Containership, NSR, Icebreaker Escort, 5.5kts

A containership averaging 5.5kts through the Arctic during the winter months cannot provide regular container service year round because the winter voyage time is twice that of the voyage time if the vessel makes 22.2kts. 5kts is the current average speed of the 5000 TEU containership through the Arctic during the 4 worst winter months.

All cases start with the same origin and destination ports, the same fuel oil price, and the same number of containers. The last three cases, Cases 1a-1c, were analyzed with and without the cost of an icebreaker escort to take into account the possibility of a government subsidized escort. To investigate the effect of fuel price on the relative expense of Arctic transit, alternatives were evaluated at $250, $500, and $1000 per ton. Many assumptions were made in the analysis and it is acknowledged that different conclusions may be reached if different assumptions are used. The model was specifically created to allow users the ability to evaluate the effect of their own assumptions. The Arctic cases oversimplify real-world operations and are not intended to be interpreted as presently realistic alternatives.

Concluding Comments

Containership owners and operators should be particularly interested in watching the presence of oil tankers and LNG carriers in the Arctic. As the ice cover melts, a strong desire has emerged to search for and recover natural resources in the Arctic. Containerships will be able to take advantage of the support infrastructure developed to service the petroleum industry and learn from their operational experience in the Arctic.

The likelihood of year-round reliable containership service through the Arctic in the future depends on one's perspective. One the one hand, it won't happen for decades due to the presence of ice. Current predictions of a largely ice-free Arctic range from 2030 to later than 2100. On the other hand, if some favorable assumptions are made, it deserves serious consideration once minimally ice-strengthened containerships are able to be reliably escorted through the Arctic at a speed of 10kts.

Table of Contents

Table of Contents 9
List of Tables and Figures 11
Definitions and Nomenclature 12
1.0 Chapter 1: Introduction 13
1.1 Objectives 13
1.2 Tasks 13
1.3 History 15
1.4 Background 16
2.0 Chapter 2: Description of Scenarios 17
2.1 Scenario 1: Ice-strengthened Containership, Icebreaker Escort 17
2.2 Scenario 2: Icebreaking Containership 17
2.3 Scenario 3: Standard Containership, Transshipment to Icebreaking Containership 18
2.4 Scenario 4: Standard Containership, Unescorted 18
2.5 Scenario 5: Standard Containership, Canal Route 18
3.0 Chapter 3: Ports and Shipping Routes 19
3.1 Origin-Destination Ports 19
3.2 Selected Routes 20
3.3 Transshipment Ports 21
3.3.1 Port of Adak, Alaska 21
3.3.2 Port of Murmansk, Russia 21
3.3.3 Additional Considerations 22
4.0 Vessels 23
4.1 Standard Containership 23
4.2 Icebreaking Containership 23
4.3 Ice-strengthened Containership 24
4.4 Aker DAPPB Concept 25
4.5 Icebreaker Escort 26
5.0 Analysis 27
5.1 Model 27
5.2 Present Day 27
5.3 Hypothetical Cases 29
5.2.1 Case 6: Standard Containership, Suez Canal, 22.2kts 30
5.2.2 Case 5: Standard Containership, NSR, Unescorted, 22.2kts 30
5.2.3 Case 4: Ice-strengthened Containership, NSR, Unescorted, 22.2kts 32
5.2.4 Case 3: 8mo Ice-strengthened Containership, 4mo Transshipment 33
5.2.5 Case 1a: Ice-strengthened, 8mo Unescorted 22.2kts, 4mo Escorted 17.5kts 35
5.2.6 Case 1b: Ice-strengthened, 8mo Unescorted 22.2kts, 4mo Escorted 10kts 37
5.2.7 Case 1c: Ice-strengthened, 8mo Unescorted 22.2kts, 4mo Escorted 5.5kts 39
5.2.8 Case to Case Comparison 41

5.3 Requirements for Commercially Viable Liner Service Through NSR 42
6.0 Conclusions 45
6.1 Considerations in Real World 45
6.1.1 Vessel Limitations 45
6.1.2 Navigational and Operational Issues 45
6.1.3 Governmental Policy 47
6.2 Future of Arctic Shipping 48
Bibliography 50
Sources Consulted 51
Appendix A: Model User Manual 52
A.1 Opening the Model 52
A.2 Entering General Inputs 53
A.3 Viewing Model Results 54
A.4 Viewing Vessel Information 54
A.5 Viewing Port Information 54
A.6 Viewing Route Information 54
Appendix B: Selected Model Sheets 56
Appendix C: Favorable Assumptions 69
Appendix D: Vessel Characteristics 70

List of Tables and Figures

Table 1.1: List of Scenarios....14
Table 3.1: Route Distance Comparison 20
Table 4.1: Standard Containership Characteristics 23
Table 4.2: 5000 TEU Icebreaking Containership Characteristics 24

Figure 1.1: *Norilsk Nickel* 16
Figure 4.1: Representative Containership 23
Figure 5.1: Present Day Expenses 28
Figure 5.2: Present Day Voyage Times 28
Figure 5.3: Present Day Average Expenses....29
Figure 5.4: Case 5 Voyage Expenses....31
Figure 5.5: Case 5 Voyage Time 31
Figure 5.6: Case 4 Voyage Expenses....32
Figure 5.7: Case 4 Voyage Time 33
Figure 5.8: Case 3 Expenses 34
Figure 5.9: Case 3 Voyage Time 35
Figure 5.10: Case 1a Expenses (Paid Escort)....36
Figure 5.11: Case 1a Expenses (Free Escort)....37
Figure 5.12: Case 1a Voyage Time....37
Figure 5.13: Case 1b Expenses (Paid Escort)....38
Figure 5.14: Case 1b Expenses (Free Escort) 39
Figure 5.15: Case 1b Voyage Time 39
Figure 5.16: Case 1c Expenses (Paid Escort) 40
Figure 5.17: Case 1c Expenses (Free Escort)....41
Figure 5.18: Case 1c Voyage Time....41
Figure 5.19: Case Average Expense....42
Figure 5.20: Case 1b, Constant Voyage Times 43
Figure 5.21: Case 1b Expense, Constant Voyage Times 44
Figure 6.1: Deck Ice Removal 46
Figure 6.2: Nighttime Visibility....47
Figure 6.3: *Sevmorput*....48

Definitions and Nomenclature

hr	Hour
km	Kilometer
kt	nm/hr
nm	Nautical mile, 1.852km
kW	Kilowatt
m	Meter
t	Metric ton
dwt	Deadweight
TEU	Twenty foot Equivalent Unit
LOA	Length Over All
LBP	Length Between Perpendiculars
B	Beam
D	Depth
T	Draft
Standard Containership	Non ice-classed containership
NSR	Northern Sea Route
NWP	Northwest Passage

1.0 Chapter 1: Introduction

1.1 Objectives

The objectives of this research project are: (1) to identify alternative scenarios for moving containers through the Arctic, (2) to study the ship designs and economics involved in each scenario, and (3) to point to the key issues that should be monitored for future development. The purpose of these objectives is to investigate the economic feasibility of using Arctic shipping routes to transport containers from origin to destination port. The process by which these objectives will be realized is detailed below.

1.2 Tasks

The first portion of this project involves collecting research related to Arctic shipping and identifying relative information. Particular attention was given to any work involving container shipping through the Arctic, as there is little published information in this area. Projections of less-severe ice conditions in the future shed light on the increasing attractiveness of transporting containers through the Arctic. Sea trials of new Arctic vessel designs, such as Aker Arctic's Double Acting Ship (DAS), have validated preliminary performance predictions. Studying past works related to Arctic shipping provided data inputs for the analysis and aided in the creation of realistic operating scenarios. Section 1.3 highlights a few recent developments in Arctic shipping.

After reviewing the collected literature, alternative operating scenarios were identified and investigated. Four Arctic scenarios were created and will be compared to a base scenario using traditional shipping routes. Table 1.1 gives brief descriptions of the five scenarios created for the analysis. A detailed description of each scenario may be found in Chapter 2.

Table 1.1: List of Scenarios

Scenario	Description
Scenario 1	Use of an ice-strengthened containership with an icebreaker escort through ice-covered areas.
Scenario 2	Use of an icebreaking containership in open and ice-covered waters.
Scenario 3	Use of a standard containership from origin port to transshipment port. Use of an icebreaking containership through the Arctic to second transshipment port. Use of standard containership from transshipment port to destination.
Scenario 4	Use of standard containership for the entire voyage under the assumption that, in the future, there will be open water year-round in Arctic shipping routes.
Scenario 5	Base scenario. Use of standard containership on traditional canal route appropriate for the origin-destination port pair.

To best illustrate the potential advantage of shipping containers through the Arctic, origin-destination ports were chosen that have Arctic routes significantly shorter than the regularly used existing canal routes. Chapter 3 discusses the chosen origin-destination ports, transshipment ports, and shipping routes.

The final step in the data gathering process was to identify vessel designs needed for each scenario and obtain their associated capital and operating expenses. Vessel data was acquired from industry sources and previous research. A description of the vessels used in the study may be found in Chapter 4.

After information on ports, routes, and containerships was collected, a computer model was created to analyze the alternative scenarios. The data was then entered in the model to compare the characteristics of each scenario. The model allows for a comparison of scenarios for a selected shipping route and time of year, which dictates the speed of an icebreaking vessel. An overview of the computer model and instructions for use may be found in Appendix A.

The analysis, found in Chapter 5, was performed using the computer model to evaluate the scenarios at each route and month combination. Criteria for evaluation will include items such as capital expense, fuel costs, operating expenses, length of voyage, and total cost per Twenty foot Equivalent Unit (TEU) shipped. Conclusions in Chapter 6 regarding the feasibility of each scenario were drawn from the results of the analysis.

1.3 History

Sea trade between Europe and the Far East led to the desire to find a shorter trade route in the 15th century. After North America succeeded in blocking Columbus's western voyage to India, England sent John Cabot in search of a Northwest sea passage to Asia in 1497. Similarly, the English began looking for northeast sea route to China and India in the 1550s. Henry Hudson, for whom Hudson Bay is named, explored parts of what are today the Northwest Passage (NWP) and the Northern Sea Route (NSR). The Russian Great Northern Expeditions mapped much of the coast and waters along the NSR from 1733-1742. Swede Nils A. E. Nordenskiöld became the first person to transit the NSR by sea in 1879. The NWP was first transited by sea in 1906 after Roald Amundsen's arduous three-year voyage. It was not until 1944 that a Royal Canadian Mounted Police schooner sailed through the NWP for the first time without becoming stuck in ice during the winter season. The Administration of the Northern Sea Route was officially established by the U.S.S.R. in 1932 and supported commercial transit until the breakup of the Soviet Union, after which NSR traffic rapidly declined. The NWP has yet to be used for commercial transport, as it has historically been less navigable than the NSR.

1.4 Background

In September of 2008, the NWP and NSR were simultaneously open for the first time since satellite observation began in the 1970s [1]. As the extent of Arctic sea ice continues to shrink, the feasibility of commercial shipping through the Arctic Ocean becomes an increasing reality. Norilsk Nickel, a Russian mining company, recently built an icebreaking containership (Figure 1.1) to transport metallurgical products from Dudinka to Murmansk, Russia. By early 2009, the company had five of these vessels capable of independent year-round operation on their routes [2]. Since 2002, Fortum, a Nordic energy company, has been operating two 106,000 dwt icebreaking tankers year-round in the Baltic Sea [3]. Container services will be able to take advantage of shorter Arctic routes between ports and the absence of canal fees as Arctic ice cover continues to shrink.

Figure 1.1: *Norilsk Nickel*

Source: Aker Arctic Technology, Inc.

2.0 Chapter 2: Description of Scenarios

In the decades ahead, a container service through the Arctic may take on any number of forms. This study captures a broad range of possibilities by looking at five operating scenarios. Scenarios vary by vessel type, use of transshipment ports or non-stop service, and assisted or unassisted transit through ice-covered waters. All scenarios use current ice conditions as simulated by the Aker *Arctic Shuttle Container Link* study. Scenarios may be infeasible in current Arctic ice conditions, but become viable and attractive as conditions become less severe. A base scenario using a standard containership sailing on the appropriate canal route is included for comparison.

2.1 Scenario 1: Ice-strengthened Containership, Icebreaker Escort

A containership with ice strengthening travelling through the Arctic will need an icebreaker escort when it reaches heavily ice-covered waters. The capital costs associated with this scenario are only slightly greater than those of the base scenario due to added weight involved with added hull steel and adaption of machineries to the Arctic environment. However, total transit costs associated with the use of one, possibly two, icebreaker escorts will be high.

2.2 Scenario 2: Icebreaking Containership

Currently, an icebreaking containership is the only vessel capable of solitary year-round Arctic container transport. Despite this distinction, Aker Arctic estimates speeds below 3kts in portions of the NSR during the coldest month of the year [4]. An icebreaking containership has high capital and operating costs, but avoids the expense of an escort and should be the fastest vessel for transporting containers through ice-covered waters.

2.3 Scenario 3: Standard Containership, Transshipment to Icebreaking Containership

Transshipment allows ice-classed vessels to remain in the Arctic, where they operate most cost-efficiently. A particularly appealing aspect of the use of transshipment ports is that any containership can be used to deliver cargo to the port for Arctic transport. A non ice-classed containership will sail to a (future) transshipment port close to the Arctic, such as Murmansk, Russia, or Adak, Alaska, where its cargo will be unloaded and transferred to an icebreaking containership of the same capacity. The icebreaking containership will carry containers to a transshipment port on the other side of the Arctic, where the process is reversed. This scenario assumes the existence of transshipment ports along the chosen route.

2.4 Scenario 4: Standard Containership, Unescorted

Scenario 4 represents the extreme case of ice-free Arctic transit. Such a case may be realized in the future if the extent of Arctic ice continues to decrease. This scenario will show the significant transit time savings of Arctic routes when compared to corresponding traditional routes, as the standard containership will operate at speeds in excess of 22kts in ice-free waters instead of breaking heavy ice at 3kts.

2.5 Scenario 5: Standard Containership, Canal Route

The Arctic scenarios will be compared to Scenario 5, which can be thought of as a base scenario. It will model the shortest shipping route, i.e. Panama or Suez canals, for a given origin/destination port pair. For instance, from Hamburg to Yokohama, the route will lead through the Suez Canal. A route from Seattle to Rotterdam will use the Panama Canal. The scenario will incur canal fees and wait times, factors irrelevant to the Arctic scenarios.

3.0 Chapter 3: Ports and Shipping Routes

Overseas container liner services are characterized by fast, consistent, year-round transport of goods. Notwithstanding storms or machinery breakdowns, containership companies are expected to be unwavering in their schedule. Many current routes are dependent on either the Panama or Suez canals. A closing of one of these would seriously impact international shipping. Arctic routes offer shorter distances between existing origin-destination ports and eliminate the dependency on canals.

> "In the 21st century, Arctic seaways have the potential to serve as a major avenue for shipping between these continents (Asia, Europe, and North America), as explorers envisioned as early as 500 years ago." [5]

In the future, container liners could use the NSR and NWP to shorten transit times, reduce fuel costs, increase frequency of service, and avoid canal congestion.

3.1 Origin-Destination Ports

Container liner operators could see large benefits in using Arctic routes between the following regions: Northern Asia to Northern Europe, US West Coast to Northern Europe, and Northern Asia to the US East Coast. Arctic routes offer significant reductions in distance when compared to the current canal routes (Table 3.1). A direct container service between Yokohama and Rotterdam could reduce the route distance by 3600 nm by sailing through the NSR rather than following the normal Suez Canal route. For a given origin-destination pair, the shortest Arctic and canal route were chosen. For instance, the base scenario for the Yokohama – Rotterdam port pair will use the Suez Canal route instead of the longer Panama Canal route.

Table 3.1: Route Distance Comparison

TRADE ROUTE AND REPRESENTATIVE PORT PAIR	PANAMA CANAL	SUEZ CANAL	NORTHERN SEA ROUTE	NORTHWEST PASSAGE	MINIMUM DISTANCE SAVINGS
N ASIA – N EUROPE *Yokohama – Rotterdam*	12,500	11,070	***7,090***	N/A	***3,980***
SE ASIA – N EUROPE *Singapore – Rotterdam*	N/A	***9,070***	10,370	N/A	**1,300**
PNW – N EUROPE *Seattle – Rotterdam*	8,840	N/A	***7,100***	N/A	***1,740***
PSW – N EUROPE *Los Angeles-Rotterdam*	8,030	N/A	***7,750***	N/A	**280**
N ASIA – EAST COAST *Yokohama – New York*	9,800	N/A	N/A	***7,560***	**2,240**
SE ASIA – EAST COAST *Singapore – New York*	12,690	*10,150*	N/A	10,450	N/A

Source: Adapted from Alaska Regional Ports Study

3.2 Selected Routes

Routes were chosen for the analysis based on the port pairs that had the biggest difference in distances between the canal routes and Arctic routes. Yokohama – Rotterdam and Seattle – Rotterdam were chosen because their shipping routes through the Arctic have significantly shorter distances than the canal route alternatives and trade between the ports is large enough to justify regular container service. The Seattle – Rotterdam base route uses the Panama Canal. Transit and wait times and canal fees are based on the existing canal infrastructure, as opposed to the canal after the expansion project is completed. Routes using the NWP were not included because unpredictable ice conditions in the passage make speed estimations unreliable. However, as the Arctic ice cover continues to shrink, the NWP may be a viable route in the future.

3.3 Transshipment Ports

The use of transshipment ports allows for dedicated vessels serving Arctic routes. Ice-classed vessels operating in open water typically have higher operating costs than non ice-classed vessels because of the compromise between performance in ice and open water. A transshipment port is ideally located on an Arctic shipping route near the Arctic yet in a region with open water year-round. Standard containerships can sail in ice-free waters and load/unload containers at transshipment ports. Ice-classed containerships can transport containers between transshipment ports, limiting the operational area of these vessels to the region in which they were designed to operate. Representative potential transshipment ports are discussed below.

3.3.1 Port of Adak, Alaska

Adak, a former Cold War naval air station in the Aleutian Islands, is well-situated as a North Pacific transshipment port. The Navy closed the station in 1997 leaving an enormous airbase and port facility largely unused. Currently owned by the Aleut Corporation, the existing port facilities built by the Navy would easily allow for the construction of a large container terminal. As a naval air station, Adak was home to over 6,000 people; according to the 2000 census, 316 people were living on Adak. A transshipment port would revitalize Adak and take advantage of many pre-existing facilities on the island.

3.3.2 Port of Murmansk, Russia

One of the few Arctic ports that are continually ice-free, Murmansk lies at the western edge of the NSR. According to Alexander Dmitriev, Captain of the Port in Murmansk, a new container terminal has been proposed as part of a recent port development plan in anticipation of transshipment operations [6]. Construction is expected to begin this year [7].

3.3.3 Additional Considerations

In addition to those listed above, other ports deserve further research. Iceland is situated halfway between the eastern edge of the NWP and western edge of the NSR. A port in Iceland could serve as a transshipment facility for NSR traffic bound for the US or Europe and NWP traffic bound for Europe. Ports of northern Europe are close enough to the NSR to consider the elimination of a transshipment port for NSR traffic headed to ports such as Rotterdam, Hamburg, and Antwerp.

4.0 Vessels

4.1 Standard Containership

Information on the non ice-classed containership used in the scenarios was provided by an industry source. The nominally 5000 TEU vessel's principal characteristics are shown in Table 4.1. Figure 4.1 shows a containership representative of the vessel described in the table.

Table 4.1: Standard Containership Characteristics

LOA (m)	294
LBP (m)	283
B (m)	32.2
D (m)	21.8
T (m)	13.5
TEU	4,800
MCR (kW)	51,390
Max Speed (kts)	25

Source: Industry

Figure 4.1: Representative Containership

Source: http://containerinfo.co.ohost.de

4.2 Icebreaking Containership

The icebreaking containership used in the analysis is the Aker Arctic 5,000 TEU Arctic Container Vessel concept used in the "Arctic Shuttle Container Link from Alaska US to Europe" study. The design is based on Aker's Double Acting Ship (DAS) design (Figure 1.1). A general arrangement and lines plan of the 5,000 TEU DAS concept are contained in Appendix D. In open water and light ice conditions, the vessel sails bow-first. When greater icebreaking capability is needed, the vessel operates with the icebreaking stern leading the way. The rationale behind the unconventional design is that it allows better open water performance than traditional icebreakers. The DAS concept uses azimuthing thrusters, rather than conventional shafted propellers as a means of propulsion. When operating stern-first, additional icebreaking performance is gained from the "flushing" action of the thrusters. The propeller wash of the thrusters moves broken ice away from the hull, clearing a path for the ship. Principal characteristics of the 5000 TEU icebreaking containership may be found in Table 4.2.

Table 4.2: 5000 TEU Icebreaking Containership Characteristics

LOA (m)	281
LBP (m)	269
B (m)	34.6
D (m)	21.3
T (m)	13.5
DWT (t) at 9m draft	68,000
TEU	5,000
Shaft Power (kW)	35,000
Max Speed (kts)	19

Source: Arctic Shuttle Container Link Study

4.3 Ice-strengthened Containership

The range of capabilities defined by "ice-strengthened" classifications ranges from vessels with practically non-existent ice capabilities to dedicated icebreakers capable of unassisted operation anywhere in the world. Rob Dvorak's 2009 Graduate thesis, *Engineering* *and Economic Implications of Ice-Classed Containerships*, contains a detailed analysis of regulatory ice classes. This study will use ABS ice class A1 because it gives a good balance between ice performance and operating cost. A heavily ice-strengthened containership was deemed undesirable for the purposes of this study because it would closely match the icebreaking containership. The characteristics of the ice-strengthened containership will be very similar to those of the standard containership with the exception of increased weight for the hull and adaption of machineries to the Arctic environment. Compared to a standard containership, the ice-strengthened containership will have an approximately 2-3% increase in weight, a 1-2% increase in construction cost, and a 1-2% increase in fuel and operating costs [8]. There is no increase in power requirements. Thus, the capital cost and operating characteristics of an ice-strengthened containership will be slightly higher than that of a standard containership.

4.4 Aker DAPPB Concept

The Double Acting Pusher Puller Barge concept developed by Aker Arctic and Wartsila aims to reduce the compromise between open water and icebreaking performance and operating cost of an icebreaking cargo ship [9]. Similar to Aker Arctic's Double Acting Ship (DAS) design, the DAPPB is an integrated tug barge (ITB) that will be pushed through open water by a pusher tug and pulled through the ice by an icebreaking tug. The bow of the barge is designed for open water performance, while the icebreaking puller tug is optimized for ice conditions. The DAPPB is advertized as an oil tanker, but could also be designed as a container barge. The DAPPB may be a future possibility for Arctic container shipping, but the concept needs further development before sufficient operational characteristics may be gathered.

4.5 Icebreaker Escort

Scenario 1 uses icebreakers as escorts through the Arctic region. The capabilities and expenses of the 5000 TEU Icebreaking Containership are used to approximate a dedicated icebreaker.

5.0 Analysis

5.1 Model

The model used to perform the analysis was created using Microsoft Excel. It is composed of spreadsheets that contain data concerning routes, ports, vessels, and cargo. Appendix A contains instructions for using the model as well as selected spreadsheets from the model. Containerships of 5000 TEU and 750 TEU are used in each scenario to show the effect of scale on the shipping expenses. In addition to the sheets displaying the scenarios for the two containership sizes, the 'Comparison' sheet contains graphical comparisons of the 5000 TEU scenarios, the 'Cases' sheet contains the hypothetical cases constructed for Section 5.3, and the 'Data Justification' sheet lists the source or rationale for data used in the model. An electronic copy of the model is submitted with the report.

5.2 Present Day

The two most important factors in the feasibility of an Arctic route are the total voyage expense and seasonal time variability. If the voyage time fluctuates by more than a day or two, a regular container service would be difficult to establish because additional ships would have to be used during periods of long voyage times in order to keep the same route capacity. As can be seen in Figure 5.1, Scenarios 1 and 2 incur similar expenses to the base scenario for 6 months of the year. Their voyage times are relatively constant and much shorter than the base case for the same 6 months (Figure 5.2). For the remaining half of the year, however, both voyage expenses and time increase substantially.

July through December, NSR conditions are favorable enough for Scenarios 1 and 2 to allow 5 day shorter voyages for nominally the same expense as the base route, but the poor conditions from January to June would currently prohibit a competitive year-round container service. Even if the time variability were overlooked, Figure 5.3 shows that the existing Suez Canal route is less expensive over the course of a year. There is currently too much ice cover in the NSR to allow its establishment as a viable alternative to existing routes.

Figure 5.1: Present Day Expenses

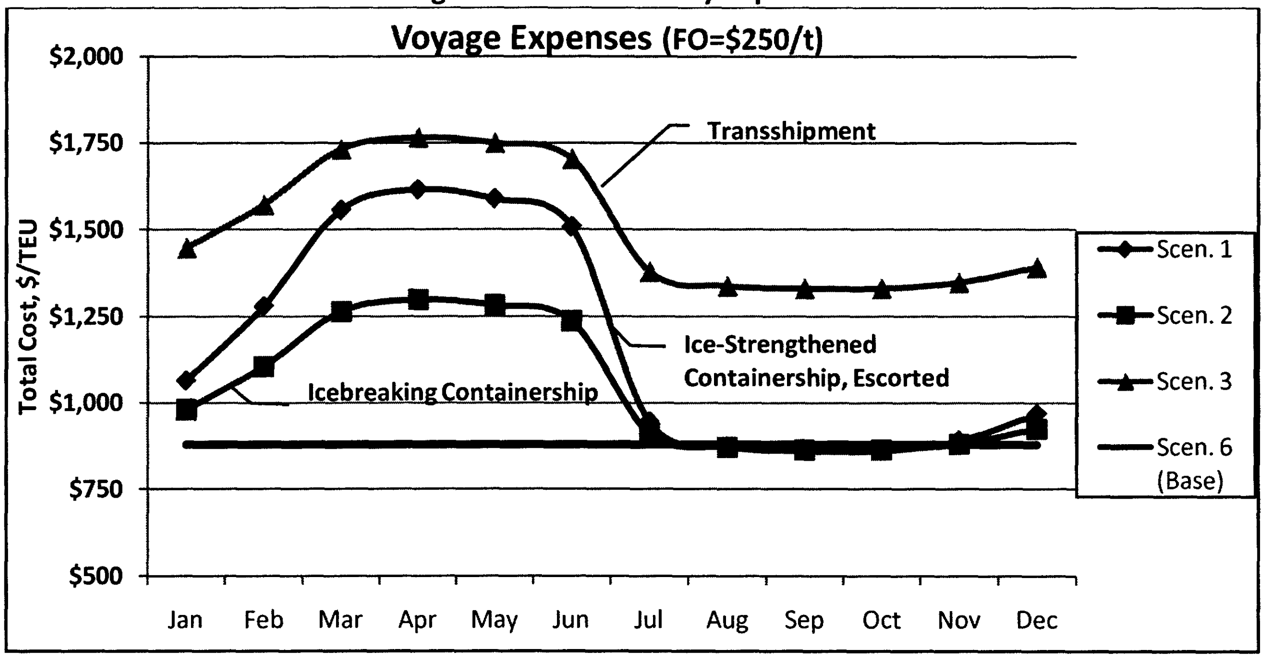


Figure 5.2: Present Day Voyage Times

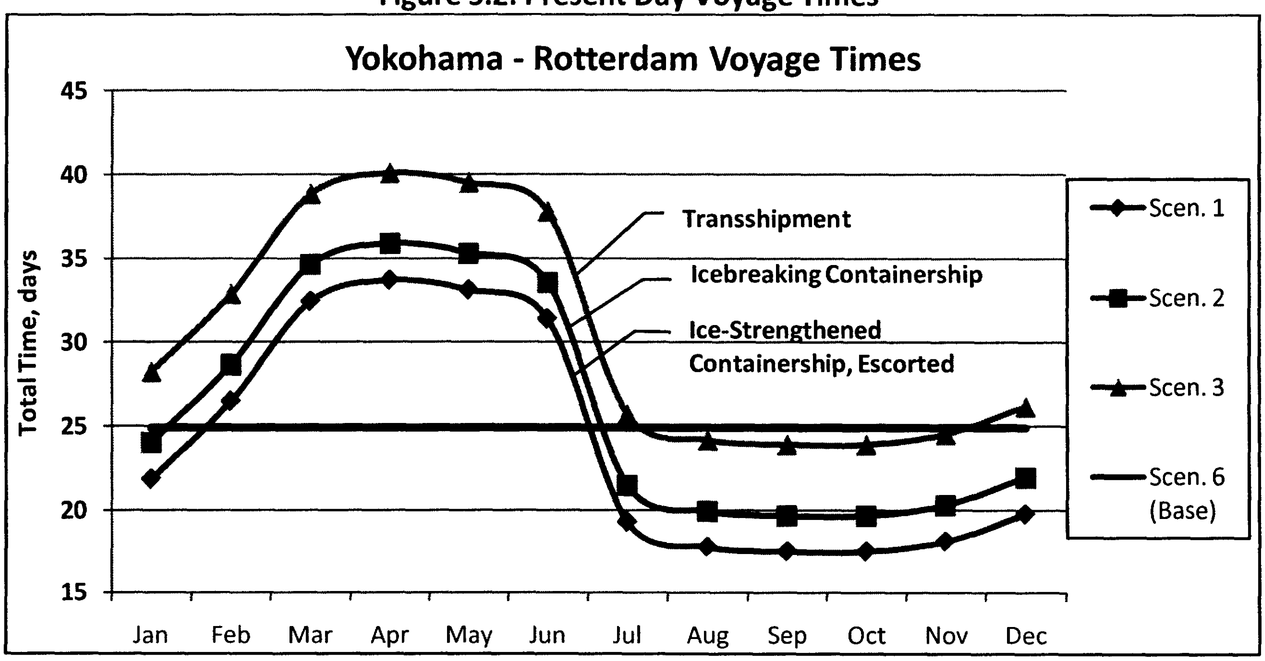
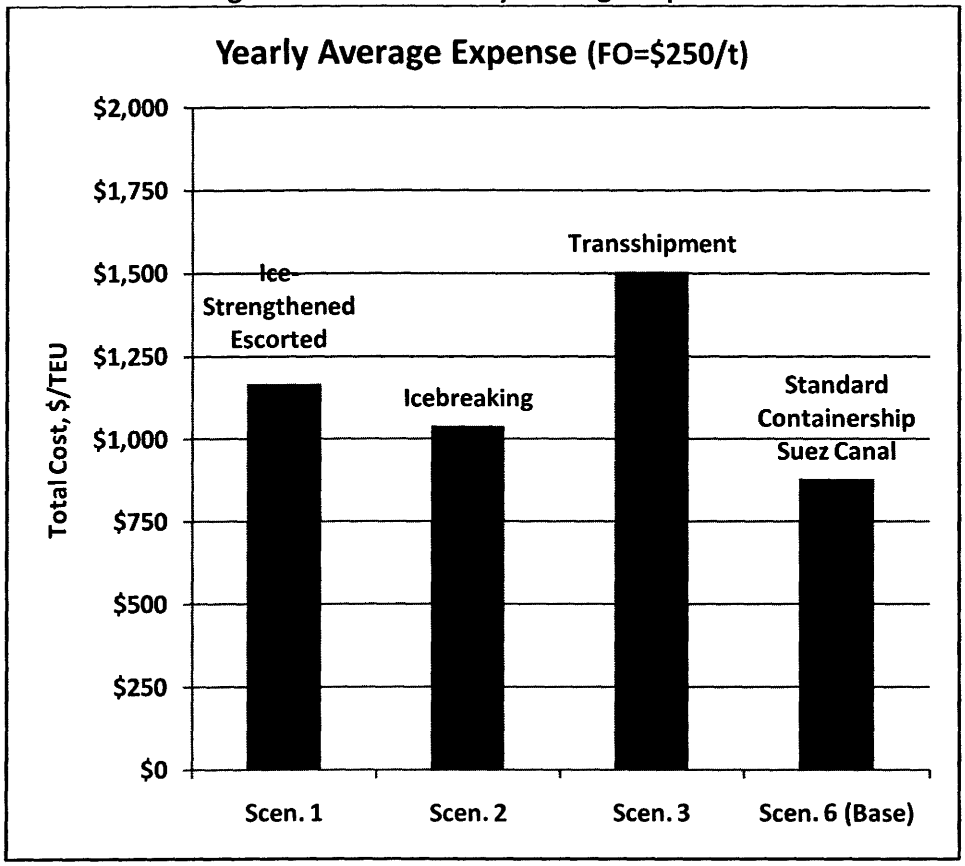


Figure 5.3: Present Day Average Expenses



5.3 Hypothetical Cases

As shown in Section 5.2, current conditions make regular Arctic liner service commercially infeasible. The following hypothetical cases purposely use favorable assumptions to show what conditions are needed for Arctic container routes to become attractive alternatives to existing routes. Appendix C contains a list of major assumptions. All cases were constructed by modifying data in the present-day scenarios. The numbers used to describe the cases match the most similar present-day scenarios. All cases use Yokohama and Rotterdam as origin and destination ports, vessels with a nominal capacity of 5000 TEU at an 85% load factor, and a fuel oil cost of $500/t.

If Arctic ice cover decreases year after year, eventually the NSR will be ice-free 12 months out of the year. Cases 5 and 4 exemplify the time and expense of transit through an ice-free NSR. Before Arctic conditions could develop that permit operations as described in Cases 5 and 4, the NSR would be largely ice-free for most of the year but be obstructed by ice during the coldest portion of the year. Cases 3 and 1 simplify this by assuming ice-free transit 8 months out of the year and the need for icebreaking capability 4 months out of the year. In other words, the NSR is ice-free for 8 months and obstructed by ice for 4 months.

5.2.1 Case 6: Standard Containership, Suez Canal, 22.2kts

Case 6 represents the voyage time and expenses for a 5000 TEU standard containership sailing from Yokohama to Rotterdam via the Suez Canal. This base case represents a current route that the following cases may be compared to. Most liner routes have intermediate stops that serve many smaller ports between the main origin and destination. Case 6 uses a two-port voyage to simplify the model and make the case directly comparable to the Arctic cases. Costs and time associated with passage through the Suez Canal are included in this case. With the exception of canal transit, the containership runs at 22.2kts from port to port. The one-way voyage expense of $1,082/TEU and time of 24.9 days is constant throughout the year and shown for comparison in the figured describing the cases below.

5.2.2 Case 5: Standard Containership, NSR, Unescorted, 22.2kts

Case 5 is the "best case" voyage that illustrates the time and cost savings possible if the NSR was ice-free. As in Case 6, the values are constant due to the hypothetical absence of ice. Figure 5.4 shows a difference of $310/TEU between Case 5 and Case 6. This substantial savings is due to two factors: a shorter route and no Suez Canal tolls. The Arctic route reduces the voyage distance by 4,000nm (Table 3.1), resulting in a decrease in voyage time of 9 days (Figure 5.5). If there were regular liner services operating under the conditions of Cases 5 and 6, the

5,000 TEU standard containership would be capable of 4 more round-trip voyages, or 40,000 more TEU moved, per year using the NSR than the same vessel using the existing Suez Canal route. If the NSR were to become continually ice-free, many container routes could be significantly shortened through its use.

Figure 5.4: Case 5 Voyage Expenses

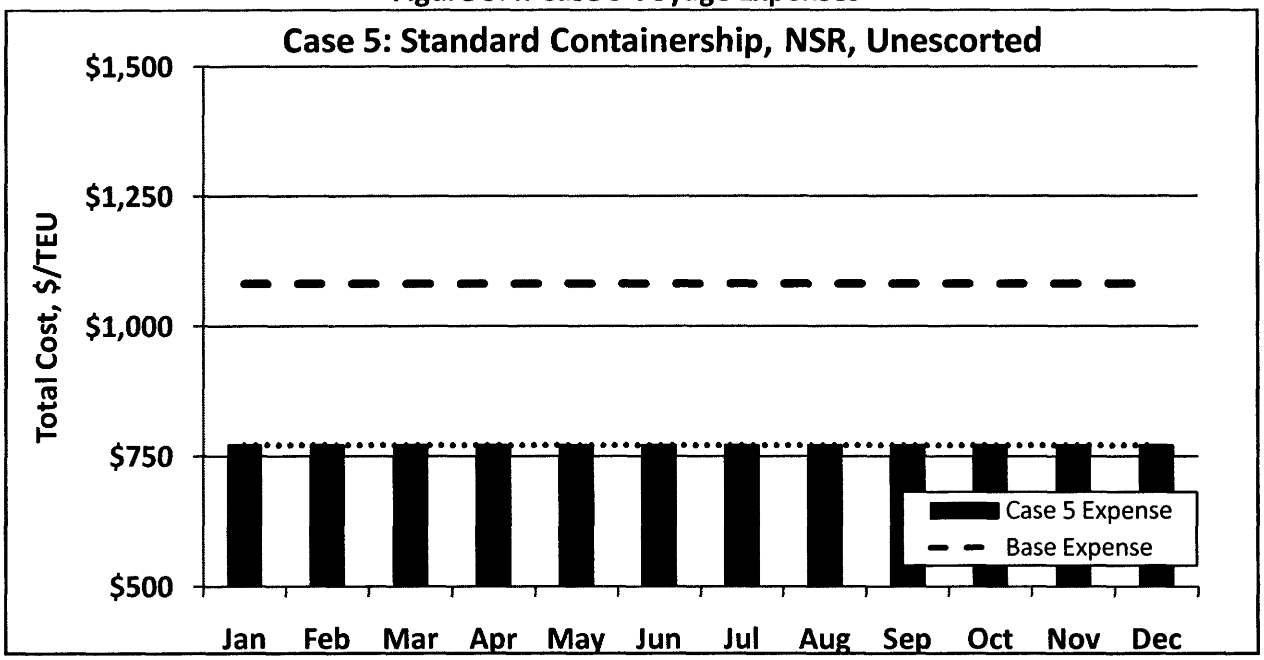
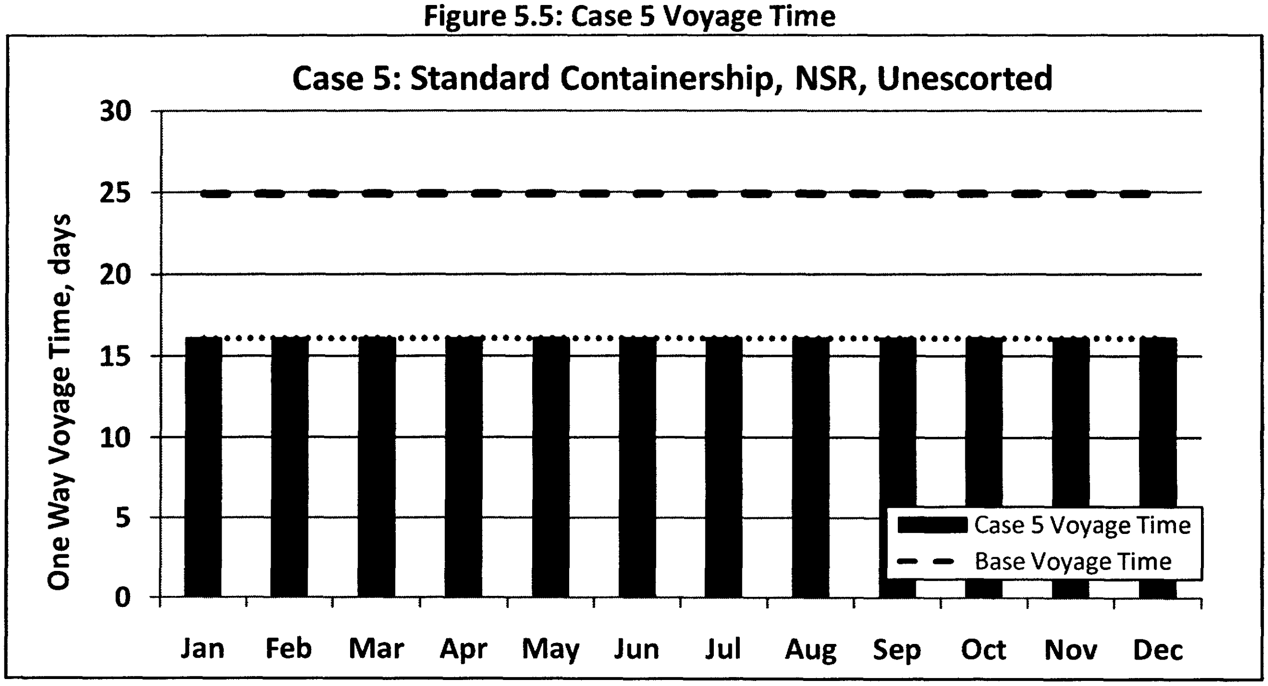


Figure 5.5: Case 5 Voyage Time



5.2.3 Case 4: Ice-strengthened Containership, NSR, Unescorted, 22.2kts

Use of an ice-strengthened containership is the single difference between Case 5 and Case 4. The accepted definition of "ice-free waters" is waters that are less than 10% covered by ice; therefore, the term can be very misleading. Operations of an ice-strengthened containership would be much less affected by a small presence of ice because of a reinforced hull. Figure 5.6 and Figure 5.7 show the voyage expenses and time associated with Case 4. The slightly higher capital and operating expenses lead to a $10/TEU increase in voyage expenses over Case 5. As the speeds of both ships are equal, voyage times are the same for Cases 4 and 5.

Figure 5.6: Case 4 Voyage Expenses

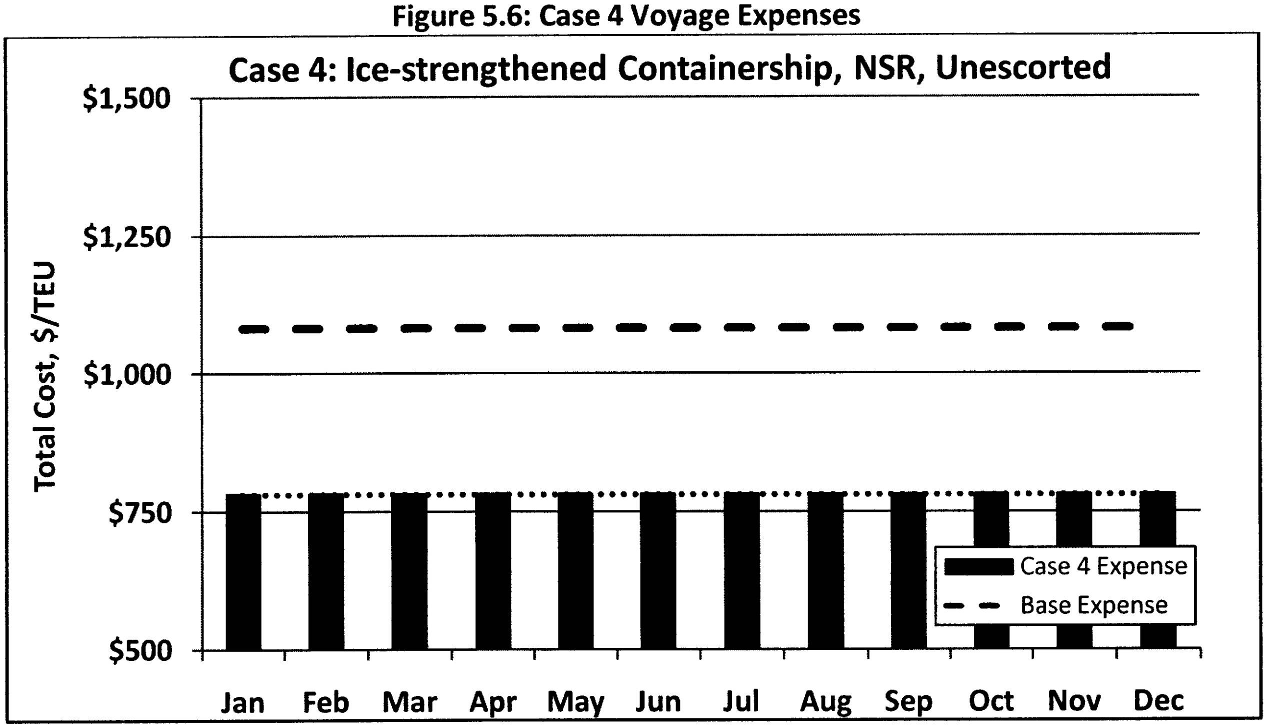
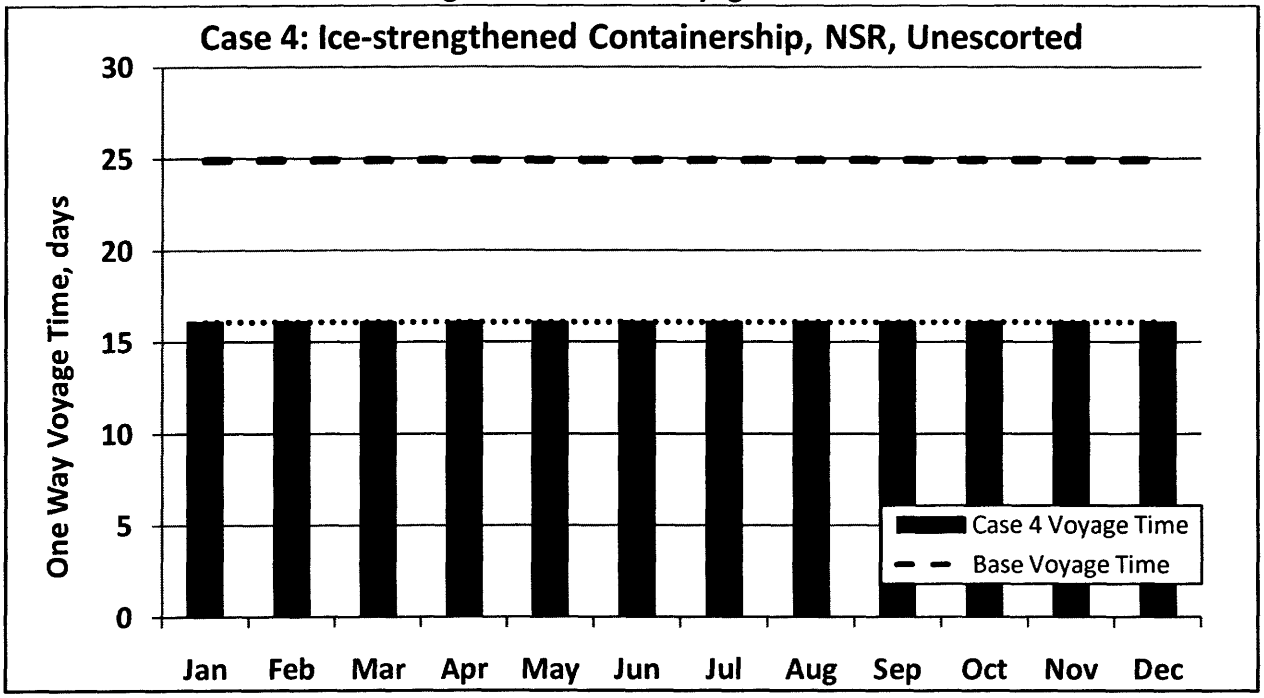


Figure 5.7: Case 4 Voyage Time



5.2.4 Case 3: 8mo Ice-strengthened Containership, 4mo Transshipment

Cases 4 and 5 show the potential time and cost savings possible if there was effectively no ice in the NSR. From an Arctic shipping perspective, they represent the best possible situation that is far from realistic today.

Case 3 simulates ice conditions 4 months out of the year and ice-free conditions for the remaining 8 months. An ice-strengthened containership is used to transport containers from origin to destination, as in Case 4, during the ice-free months. The remaining 4 months, an ice-strengthened containership delivers containers to a hypothetical port in Adak, Alaska where they are transshipped to an icebreaking containership for transit through the NSR to Murmansk, Russia. An ice-strengthened containership then delivers the containers from Murmansk to Rotterdam.

As can be seen in Figure 5.8 and Figure 5.9, operation in ice significantly increases voyage expenses and time. Three components lead to the increase in expenses. First, the 23 day increase in voyage time due to reduced speeds through ice and two transshipment port calls more than doubles the total voyage time. Assuming year-round use of the icebreaking containership, the total daily expense of ownership and operation is more than $33,000 above that of the standard containership (Appendix A, 'Vessels' sheet). If the icebreaking containership is idle for a portion of the year, expenses would drastically increase above what is assumed in the calculation. The final component of increased expenses comes from calling at the two transshipment ports. Interestingly, the average voyage time of Case 3 is slightly lower than the base case. However, the average cost of shipping containers as described in Case 3 is $123/TEU more than the existing (Base) route, which alone makes Case 3 an unattractive alternative.

Figure 5.8: Case 3 Expenses

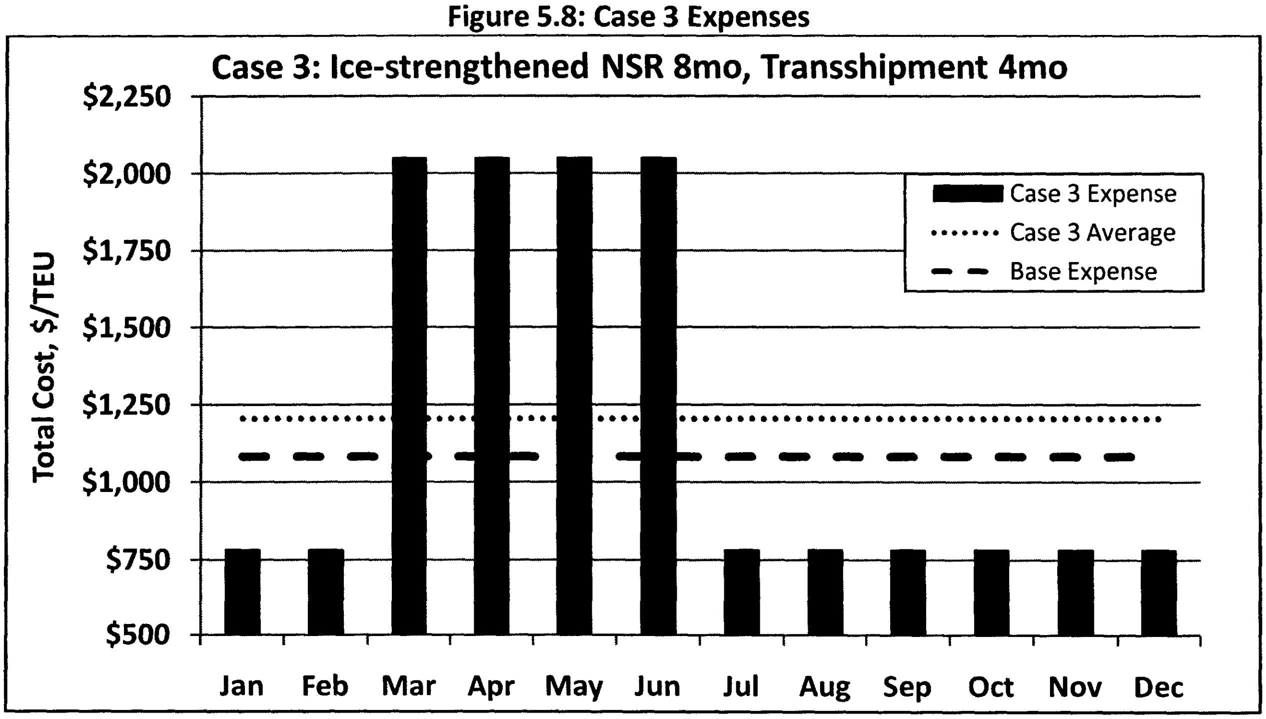
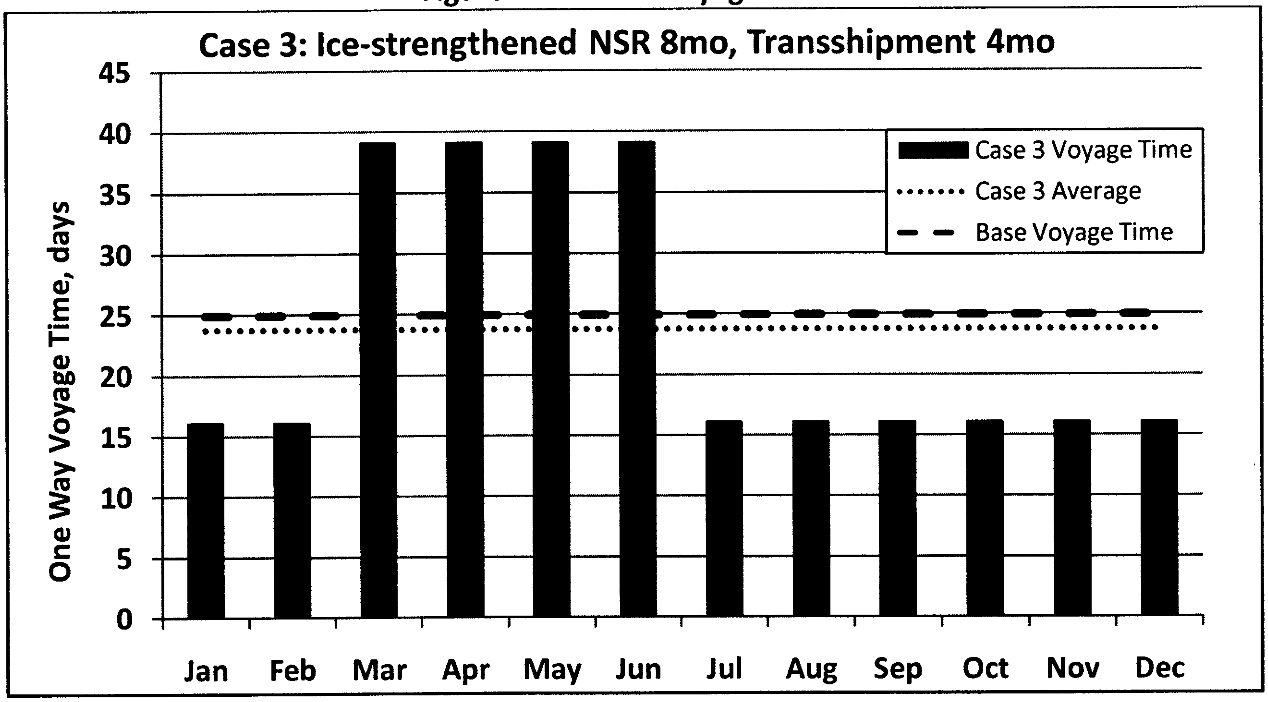


Figure 5.9: Case 3 Voyage Time



5.2.5 Case 1a: Ice-strengthened, 8mo Unescorted 22.2kts, 4mo Escorted 17.5kts

Using an icebreaker to escort an ice-strengthened containership through ice-covered waters is an alternative to an icebreaking containership. Cases 1a through 1c are identical except for the NSR transit speed during the 4 months of ice. The variations of speed in Case 1 show the overall voyage cost and time sensitivity to NSR transit speed. To show the effect of the escort cost, the expense of each "sub-case" is shown with and without the escort fee. The daily cost of owning and operating an icebreaking containership is used to approximate the escort fee (Appendix A, 'Vessels' sheet).

Case 1a uses an ice-strengthened containership year-round with a 17.5kts escort through the NSR during the 4 months of ice. While 17.5kts is unrealistic with the given ice conditions, Figure 5.10 shows that at such a speed, Case 1a has lower voyage expenses than the base case. If there was no escort fee, perhaps to promote use of the NSR, Figure 5.11 shows that the only cost difference between Case 1a and Case 4 is due to the slower transit speed through the NSR.

The variability in one-way voyage time between ice and ice-free months is about 1.5 days which is small enough to allow a regular year-round service without adding additional vessels during the ice-covered portion of the year. If Arctic conditions develop in the future that allow an average speed through the NSR similar to that of Case 1a, year-round regular service could be established that allows for one-way voyages 8 days shorter than the existing Suez Canal route offers.

Figure 5.10: Case 1a Expenses (Paid Escort)

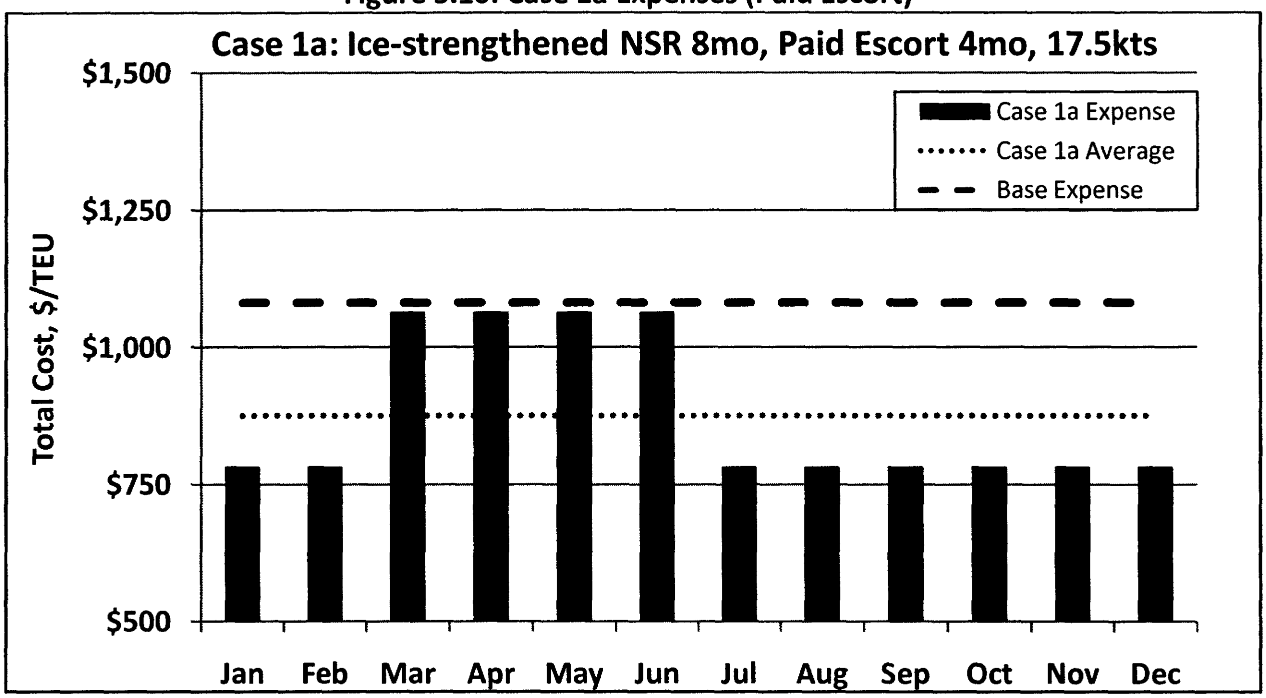


Figure 5.11: Case 1a Expenses (Free Escort)

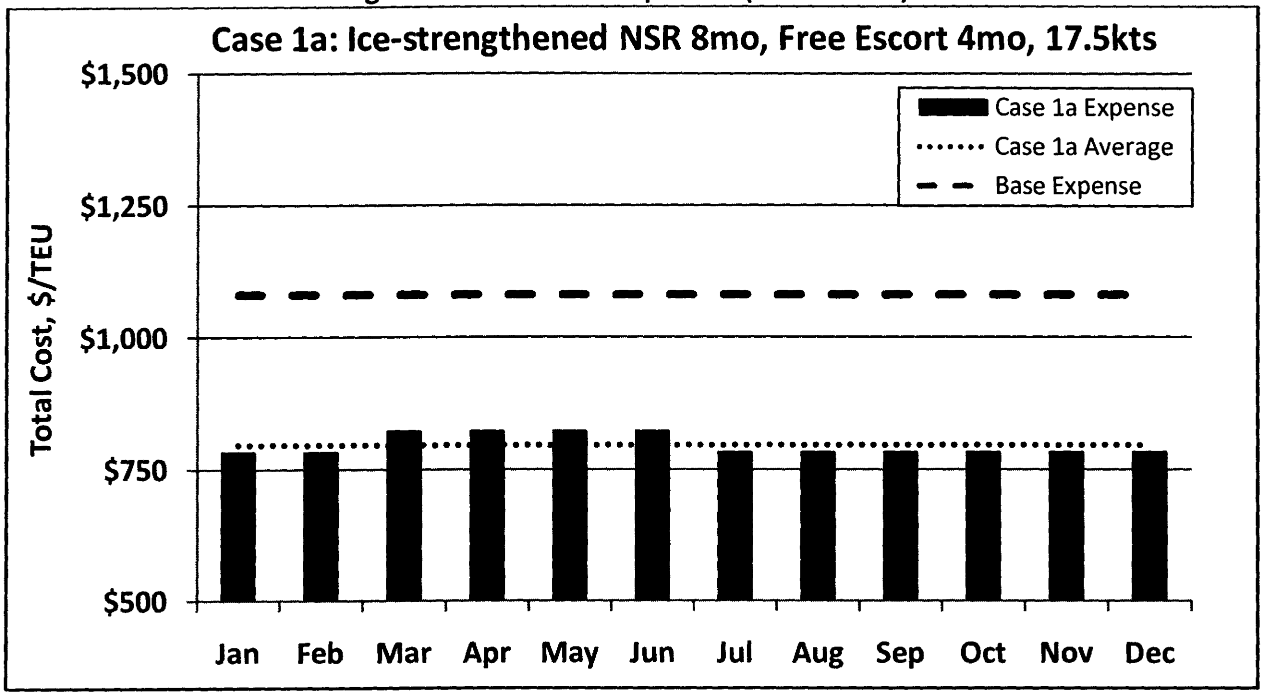
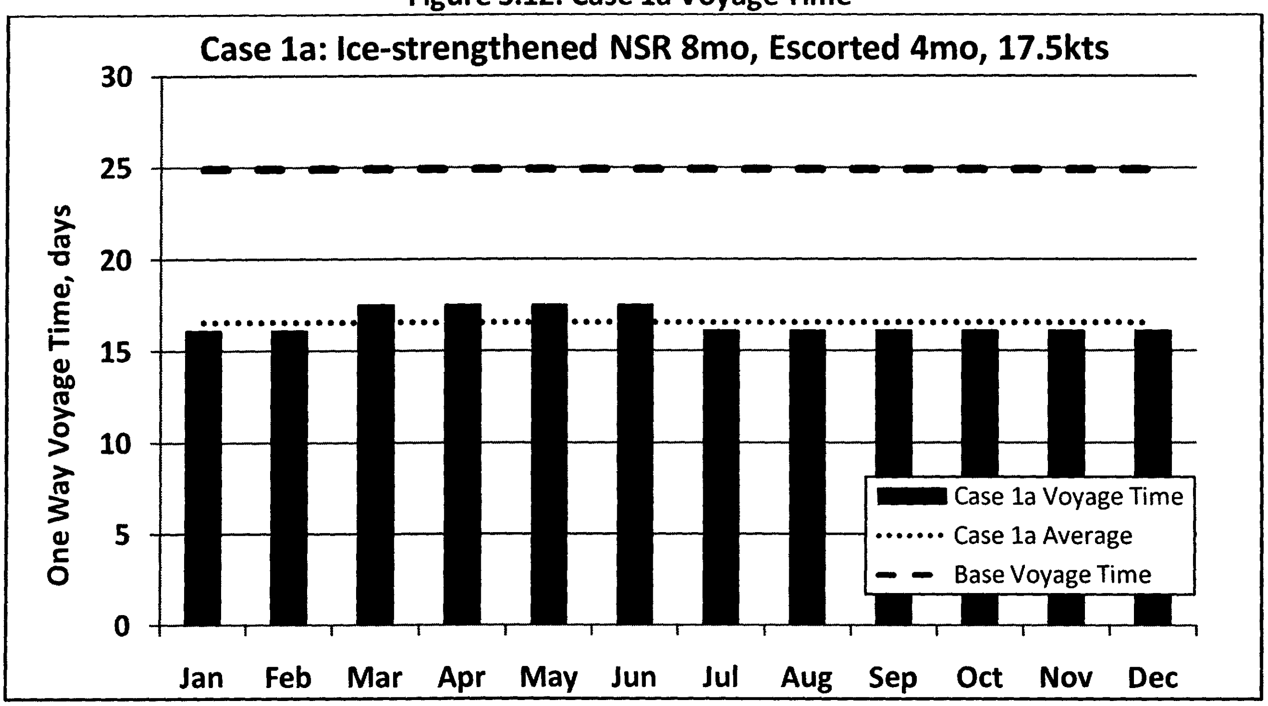


Figure 5.12: Case 1a Voyage Time



5.2.6 Case 1b: Ice-strengthened, 8mo Unescorted 22.2kts, 4mo Escorted 10kts

The speed of an icebreaker escort is not always dictated by its maximum capabilities. According to Dr. Lawson Brigham, former Deputy Director of the U.S. Arctic Research

Commission, a typical escort convoy will not exceed 10kts to avoid damage to the escorted ships from high-speed collisions with broken ice left in the trail of the icebreaker. Case 1b simulates NSR ice conditions that allow for an average of 10kts transit speed.

Despite a 7.5kts decrease in NSR transit speed from Case 1a, even the voyage time in the winter is still 2.5 days shorter than the Suez Canal route. However, 6.5 day variability between ice and ice-free voyage times would present difficulties in establishing a regular service (Figure 5.15). Over the course of a year, Figure 5.13 shows that Case 1b yields a $100/TEU lower expense per TEU than the base case even with an escort fee. If the escort fee is removed the Case 1b voyage expense decreases to $238/TEU less than the base case (Figure 5.14). While the average voyage expense is lower than that of the base case, the high variability in voyage time, nearly one week, makes this case an unattractive alternative.

Figure 5.13: Case 1b Expenses (Paid Escort)

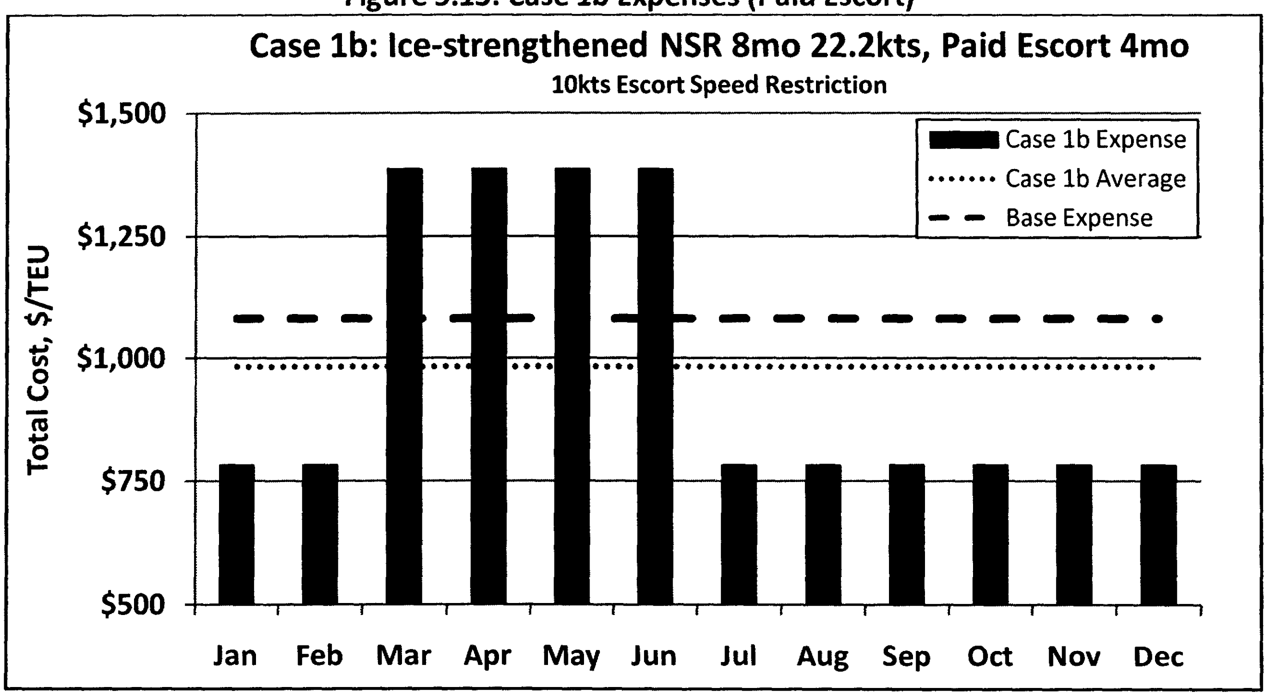


Figure 5.14: Case 1b Expenses (Free Escort)

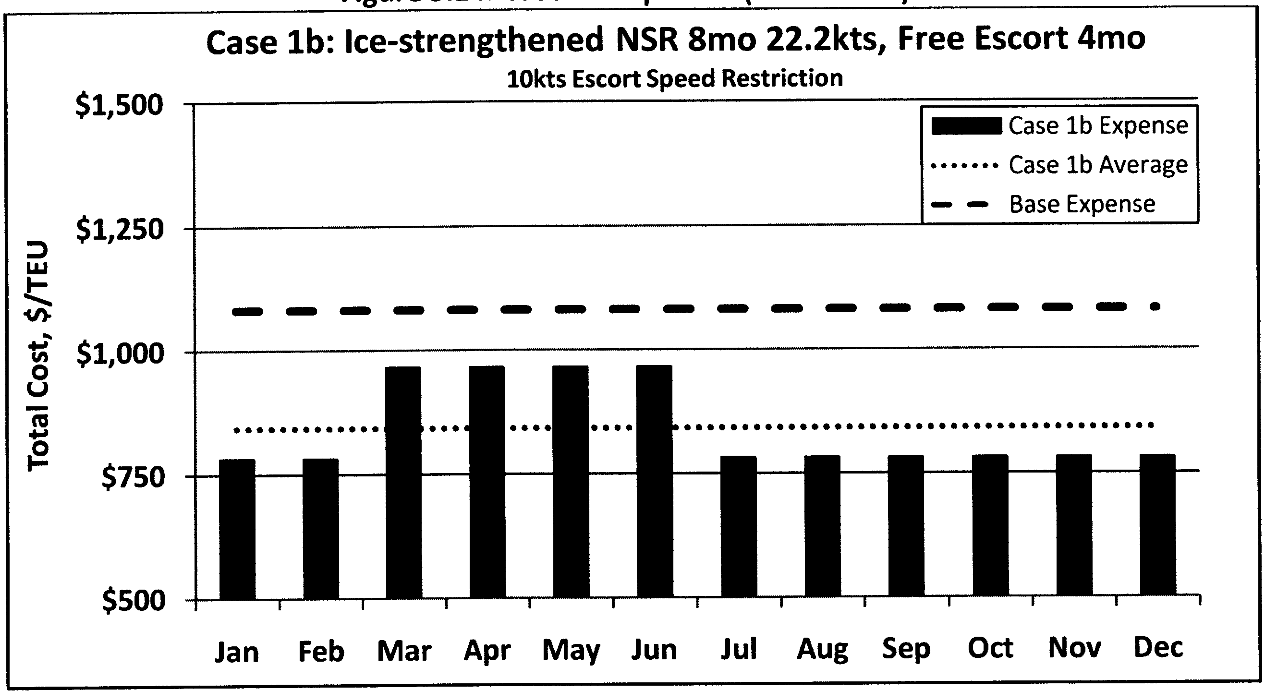
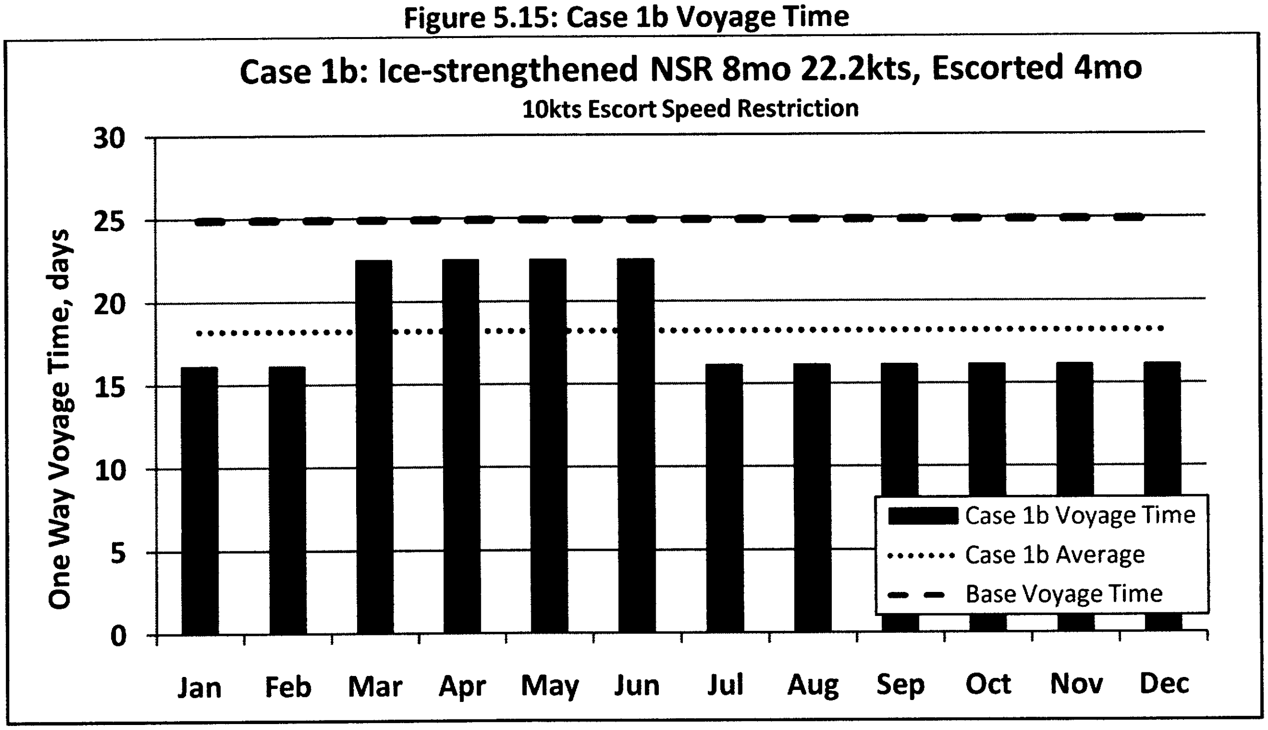


Figure 5.15: Case 1b Voyage Time



5.2.7 Case 1c: Ice-strengthened, 8mo Unescorted 22.2kts, 4mo Escorted 5.5kts

Case 1c uses an escort speed of 5.5kts from March to June and, like Cases 1a and 1b, assumes an open water speed of 22.2kts for the remaining months. The present-day average speed through the Arctic from March to June is 5.0kts. The Aker Arctic speed data, which uses present-day ice conditions to predict transit speeds, drops as low as 4kts for portions of the NSR, resulting in the long voyage times seen in Figure 5.18. Again, the seasonal variability in voyage times would make it difficult to establish a regular container service in conditions like this. The long NSR transit times greatly raise the voyage expense March through June (Figure 5.16), as this study assigns the icebreaker escort fee on a daily basis. If there were no escort fee, Figure 5.17 shows that even with the long ice transit times, the average voyage expense per container is $140 cheaper in Case 1c than for the Suez Canal route.

Figure 5.16: Case 1c Expenses (Paid Escort)

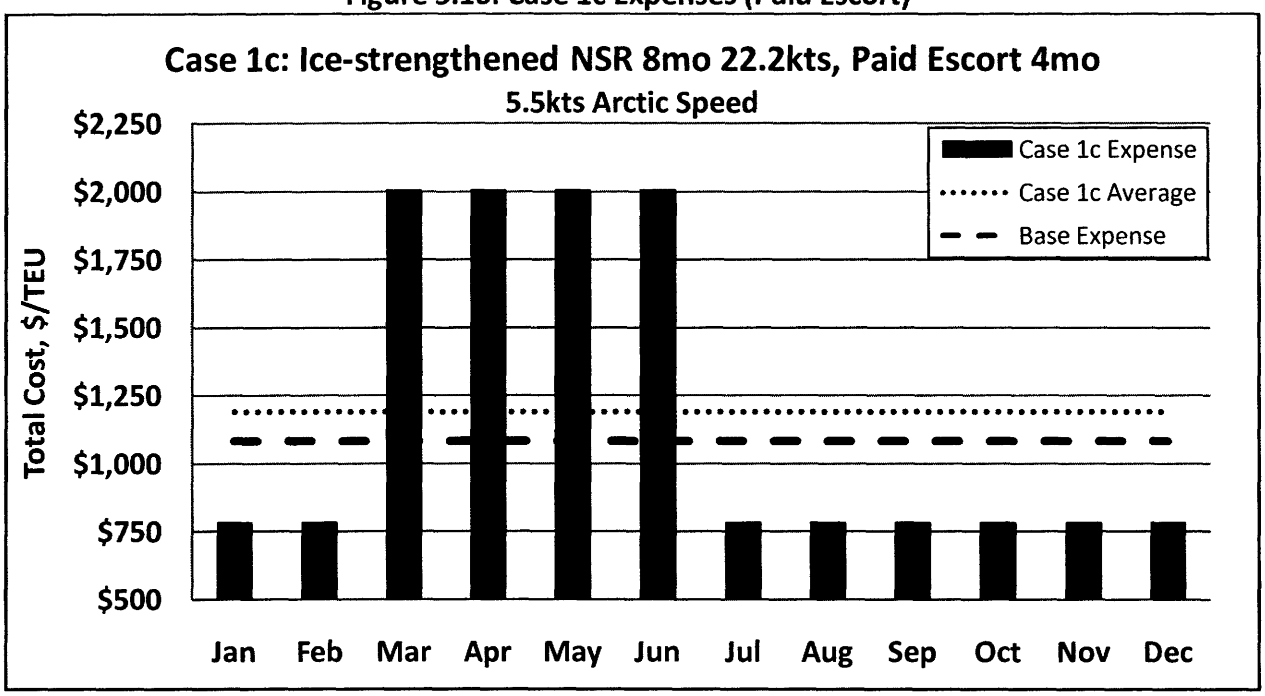


Figure 5.17: Case 1c Expenses (Free Escort)

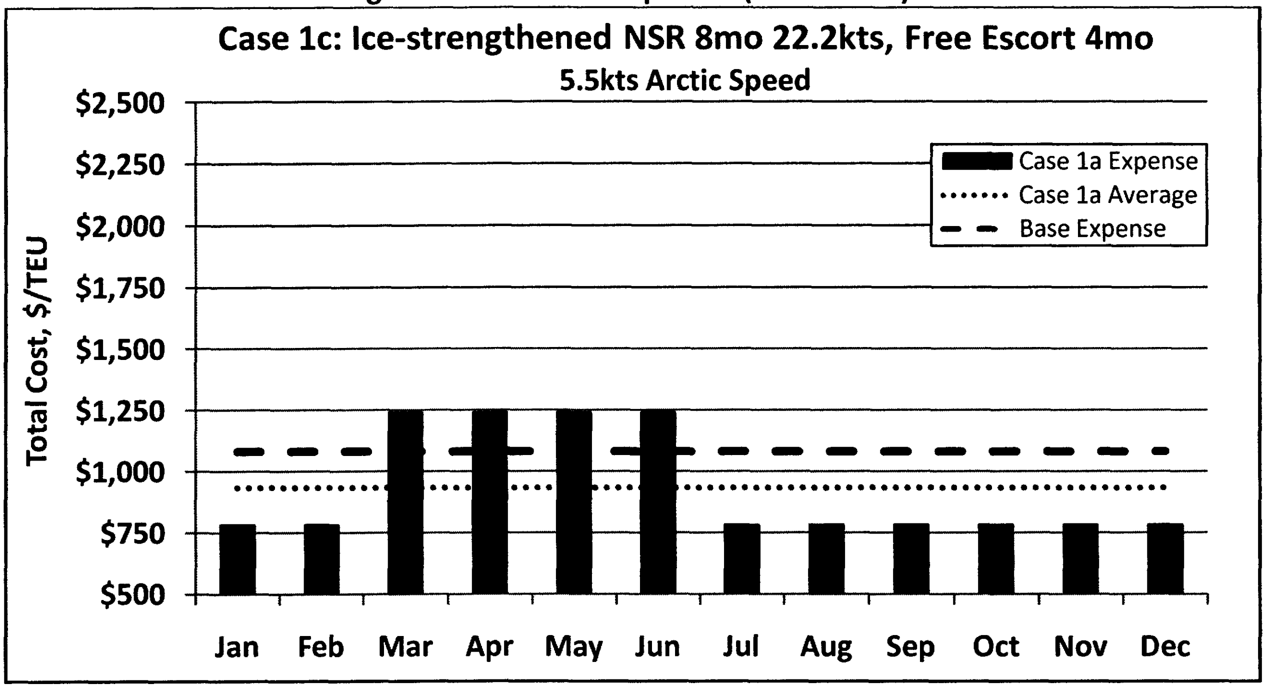
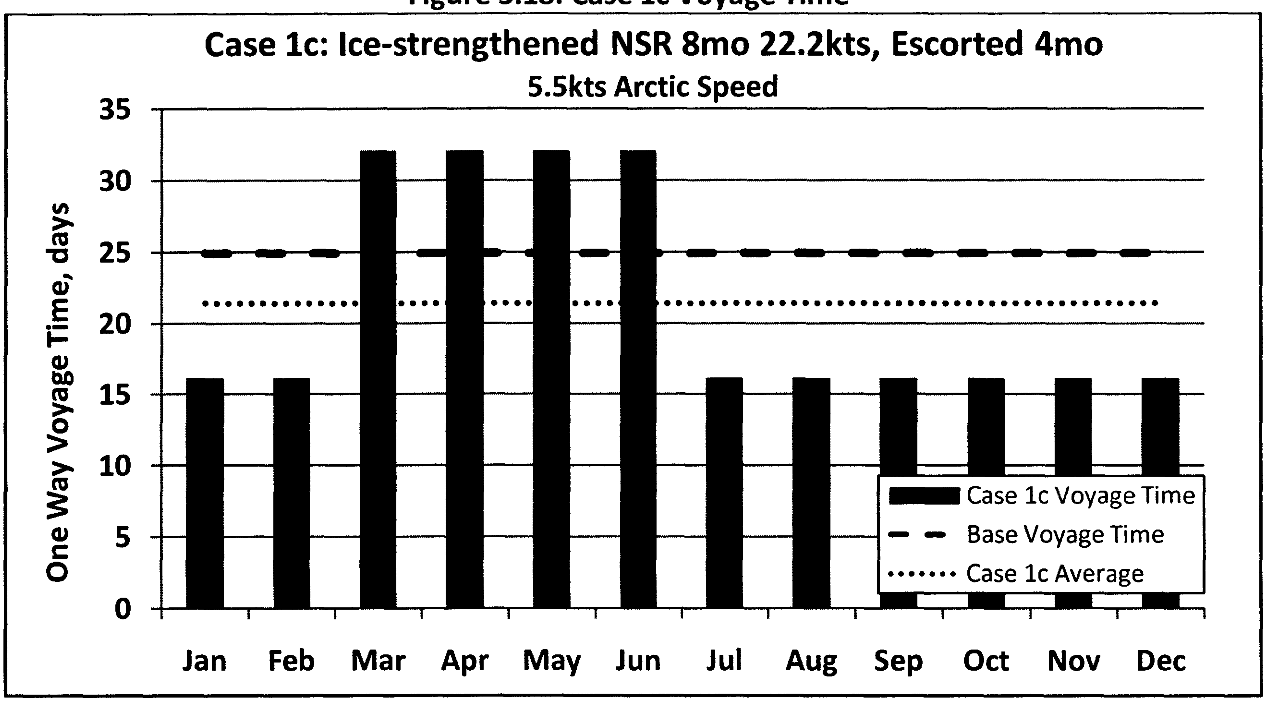


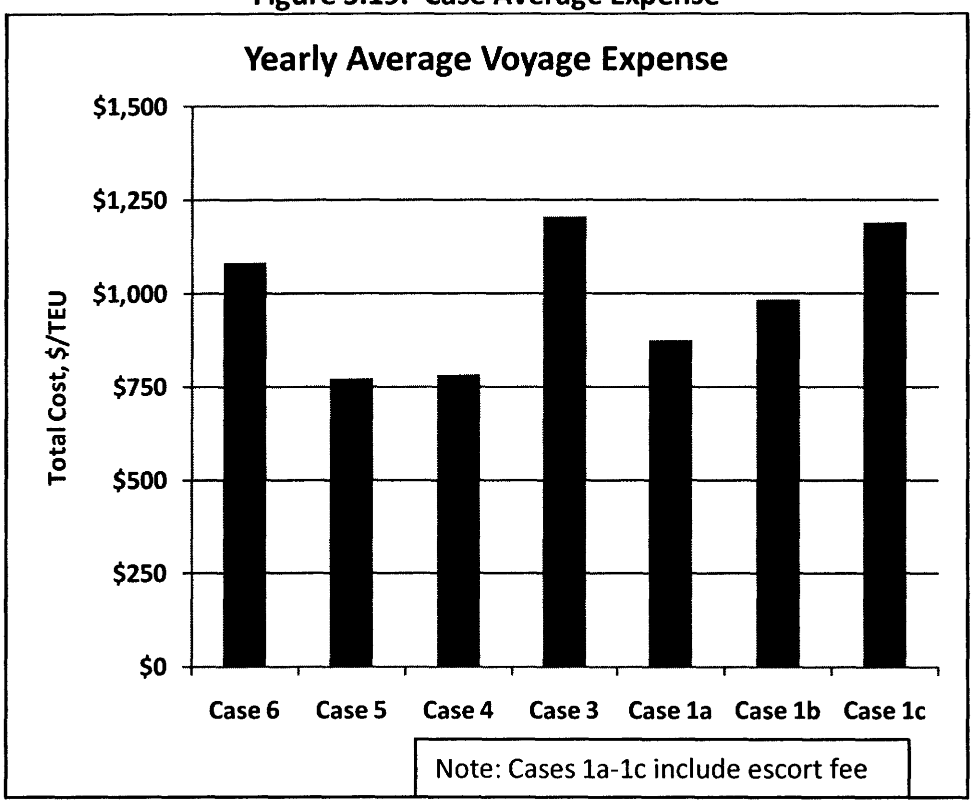
Figure 5.18: Case 1c Voyage Time



5.2.8 Case to Case Comparison

While it is useful to examine the cases on an individual basis, it is difficult to see their merits and disadvantages compared to one another using that method. From Figure 5.19, one can see that, based solely on expense, transshipment (Case 3) is not an attractive alternative to the existing Suez Canal Route (Case 6). The variations of Case 1 show the effect of speed through the NSR on the voyage expense. Even if it were possible to travel through the NSR at the containership's service speed (22.2kts) for 8 months of the year, it would be necessary to average at least 10kts through the NSR for the remaining 4 months (Case 1b) in order to realize a significant advantage over the existing route. However, if Arctic conditions were to allow an ice-free NSR in the future, Cases 5 and 4 show that voyage expenses could be reduced by as much as 25% compared to the existing route (Case 6).

Figure 5.19: Case Average Expense



5.3 Requirements for Commercially Viable Liner Service Through NSR

Current conditions make regular liner service through the Arctic infeasible. As the NSR has the least severe conditions of the Arctic routes, it is likely to be the first to see regular use in the future. In order for that to happen, the total voyage expense of an NSR route must be lower than a corresponding existing route, and the total voyage time must be consistent and shorter than that of an existing route.

Case 1b uses an ice-strengthened containership travelling at 22.2kts for 8 months and at 10kts with an icebreaker escort for 4 months. When Arctic conditions allow for transit similar to that described in Case 1b, the voyage expense and time are both less than those of the existing Suez Canal route. However, there is a 6.4 day difference between the ice and ice-free voyage times. To achieve consistent times, the ice-free voyage times were increased to the icebreaker escort voyage times, as shown in Figure 5.20. While the average time savings is reduced from 6.7 days to 2.4 days, the average expense is $180/TEU less than the Suez Canal route (Figure 5.21).

Figure 5.20: Case 1b, Constant Voyage Times

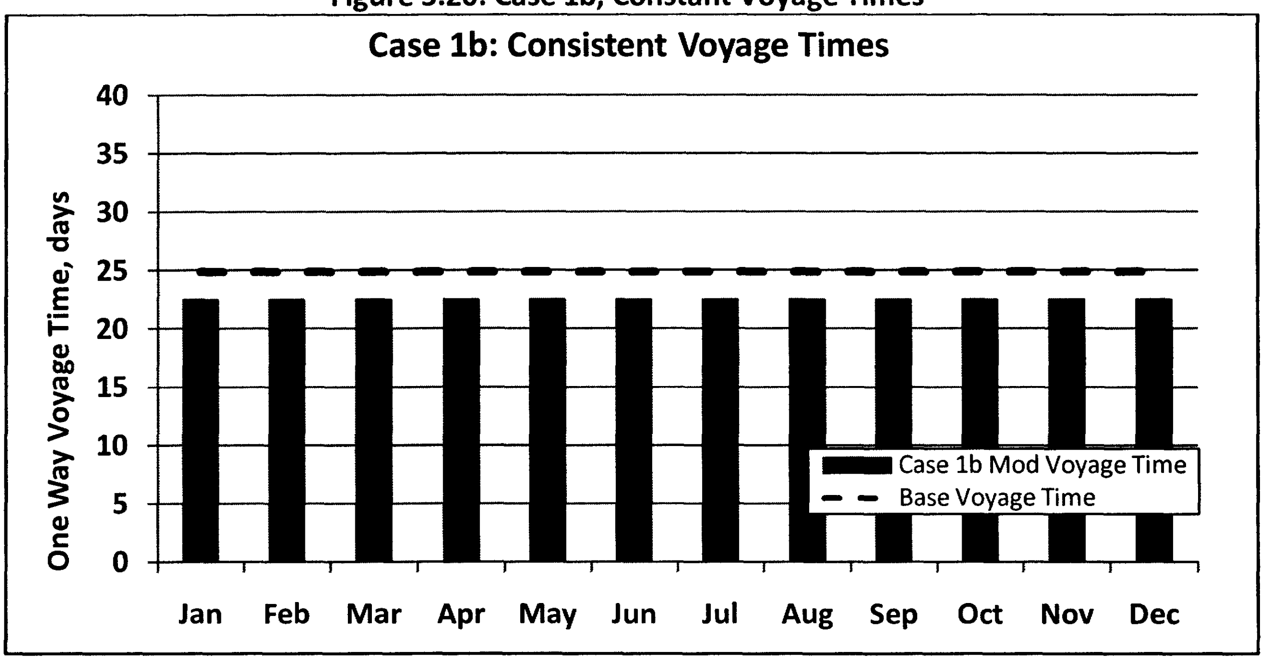
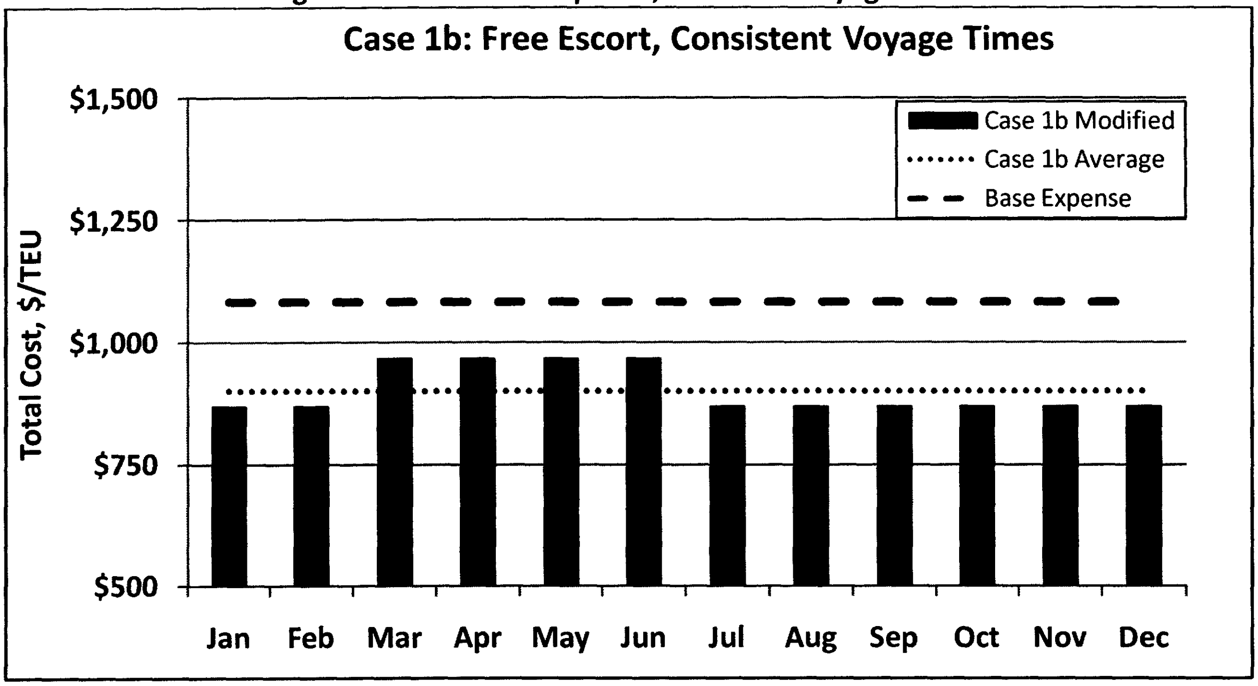


Figure 5.21: Case 1b Expense, Constant Voyage Times



To investigate the effect of fuel price on the voyage expense savings, fuel prices of $250/t and $1000/t were analyzed. As the price of fuel increases, the potential savings from Arctic transit increases due to burning less fuel due to a shorter voyage than the existing route. These numbers reflect the ship at anchor for 6.4 days during the 8 month ice-free period. Other alternatives include travelling at slower speeds or including an extra port stop during the 8 months.

Until it is possible to average at least 10kts through the NSR at any given time of the year, liner service through the Arctic will not be an attractive possibility. In fact, containership operators would want to be able to reliably travel at 10kts every trip, not just on average. Presently, it is not possible to average 10kts or more from February to June [4]. For those 5 months, the average speed through the NSR is 5.8kts, signifying that favorable conditions for year-round Arctic transit will not come in the near future.

6.0 Conclusions

6.1 Considerations in Real World

6.1.1 Vessel Limitations

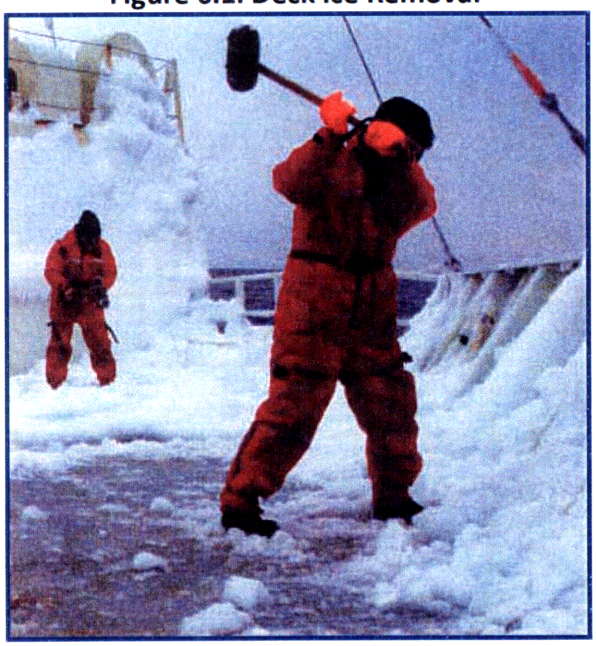
While Norilsk Nickel currently operates a fleet of five 750 TEU icebreaking containerships between Dudinka and Murmansk, Russia, approximately a 1300nm voyage through Arctic waters, the Aker Arctic 5000 TEU Icebreaking Containership is a concept that has yet to be built. While Norilsk Nickel's nickel-carrying containerships give real-world credibility to the 5000 TEU concept and its icebreaking capabilities have been estimated in Aker Arctic's ice model basin, its true capabilities remain to be seen.

Use of an ice-strengthened containership, escorted as necessary appears to be the most commercially viable option for Arctic transit. However, the beam of a 5000 TEU containership (32m minimum) is wider than the 28m beam of the *50 Let Pobedy*, the world's largest icebreaker. Innovative alternatives to conventional icebreaking will be needed to avoid the use of two escorts for containerships. Aker Arctic has developed a concept known as the oblique icebreaker that makes a wider channel through the ice by moving sideways rather than straight. If larger icebreakers are not built in the future and no alternatives come into being, two escorts will be required or very small containerships, like the *Norilsk Nickel* would have to be used. Both of these options would incur significantly higher voyage expenses.

6.1.2 Navigational and Operational Issues

The Arctic environment presents many challenges that must be met for successful commercial operations. Training facilities and standards will need to be created in order to educate the merchant mariners that will crew Arctic commercial vessels. Crews will also have to deal with the threat of icing, as shown in Figure 6.1. A sailor with an ice hammer has yet to be replaced with a more effective method. Containerships travelling through the Arctic will be especially vulnerable to icing due to the large surface area of container stacks. Thorough underwater surveys need to be undertaken to produce accurate navigational charts to prevent groundings. Emergency plans need to be made for Arctic towing, salvage, spills, and rescue, to name a few. Nighttime ice navigation, essential for commercial vessels, presents many challenges due to reduced visibility. Figure 6.2 shows how even light snow can severely restrict visibility, which is essential to navigating through heavy ice.

Figure 6.1: Deck Ice Removal



Source: U.S. Naval Postgraduate School

Figure 6.2: Nighttime Visibility

Source: Unknown Source

6.1.3 Governmental Policy

In addition to technical and logistical challenges, governmental policies currently under development will heavily influence the role of shipping in the Arctic. Russia and Canada are developing new rules governing use of the NWP and NSR. The structure and amount of passage transit fees is currently unknown and an important topic to continue watching. Also of importance to future Arctic container services are environmental and safety regulations unique to the Arctic. Regulations and usage fees are necessary to avoid environmental damage in the region and fund support infrastructure but an excess of either will inhibit growth of Arctic activity. It is possible that governments may provide subsidies to make Arctic passages attractive to commercial shipping by offsetting the cost of establishing capital-intensive infrastructure, such as transshipment terminals and support facilities.

6.2 Future of Arctic Shipping

Shorter liner routes are only one possible advantage from the maritime industry's use of the Arctic. Oil exploration and production in the Arctic will continue to be the main driver of commercial activity. The *Sevmorput*, a Russian nuclear-powered LASH ship, (Figure 6.3) is currently undergoing a refit to become the world's first nuclear drillship [10]. As more drilling and production rigs go into service in the Arctic, ice capable supply vessels, tugs, and other support vessels will be increasingly needed. More ice-classed LNG carriers and shuttle tankers will likely be built. Liner companies will watch these vessels' ice performance when considering Arctic container routes.

Figure 6.3: *Sevmorput*

Source: Unknown Source

Oil industry activity will lead to the development of specific crew training programs for Arctic waters and address the challenges discussed in Section 6.1.2. Russia and Canada have indicated they will have completed policies regarding use of the NSR and NWP, respectively, in the near future. Ice cover in the Arctic routes will need to continually decrease to a level that allows the establishment of regular liner service in order for the routes to be attractive to shipping containers. Current studies give predictions of Arctic conditions allowing for transit similar to what is described in Case 1b ranging from 2013 to later than 2100 [11]. Given the wide range of predictions and non-committal phrases such as "largely ice-free," it would currently be nothing more than a gamble to specify when conditions will allow constant transit times through the Arctic. However, containership owners and operators can be certain that shipping containers through the Arctic becomes increasingly viable with each year of decreasing ice cover. When an icebreaker can escort a minimally ice-strengthened containership through the Arctic reliably at a speed of at least 10kts, serious consideration should be given to Arctic routes for liner services.

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Appendix A: Model User Manual

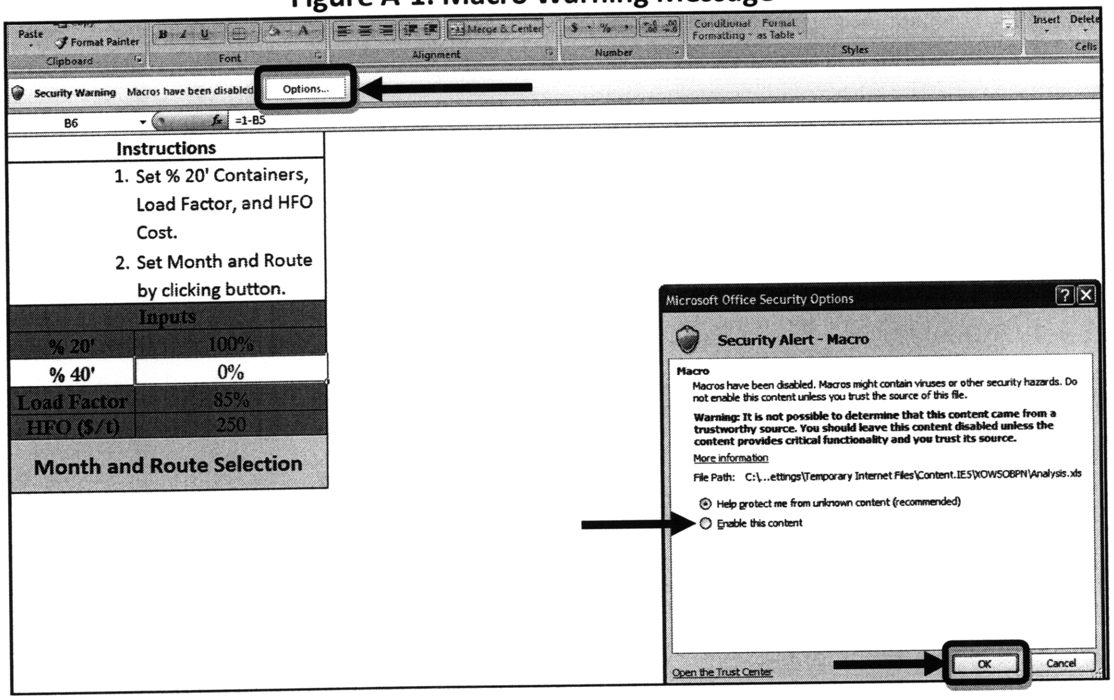
The following provides instructions for use of the model as well as a detailed description of each spreadsheet tab.

A.1 Opening the Model

The model was created using Microsoft Excel. To preserve the original model file, open the model and save a copy named "Original Model" or another name that identifies the original copy. An electronic copy of the model is provided with the final report to ensure an original copy is preserved. Each time the model is run, opt to "Save As" under a different name, such as "Model (Jan 31)," to identify changes made to the model.

Macros in the sheet may cause the user's Excel to display a warning message. To ensure proper functionality of the model, macros must be enabled. Figure A-1 displays a screenshot of the warning message in Excel 2007. Select the "Options" button in the warning message. After the "Security Alert – Macro" window appears, select "Enable Macros" and "OK." Enabling macros will allow the model to function correctly.

Figure A-1: Macro Warning Message



A.2 Entering General Inputs

The tab labeled General is used to change the month of operation, trade route, and fuel price. The price of Fuel Oil (FO) may be changed by entering a new price, in dollars per metric ton, in the cell labeled "FO." A cargo profile may be entered by changing the %20' and the load factor cells. The 20'/40' split sets the percentages of 20' and 40' containers. It is only necessary to enter the percentage of 20' containers, as the percentage of 40' containers is automatically calculated. After setting the blue inputs to the desired values, select the "Month and Route Selection" button to pick the origin-destination ports and month of operation. The month of operation determines the icebreaking speed through the NSR. Colder months will correspond to slower speeds due to thicker ice. After the trade route and month are selected, select the "Calculate" button. The 5000 TEU Summary tab will be displayed. Select the '750 TEU Summary' tab for the corresponding results. To generate Yokohama-Rotterdam expense and time results for the entire year, do not click the "Month and Route Selection" button. Press

Ctrl+G after entering the desired input values in blue. The 'Comparison' tab will be displayed and the first two matrices will contain expense and time data of each scenario for every month. Results for the Seattle-Rotterdam route may not be viewed in this manner.

A.3 Viewing Model Results

The 5000 TEU and 750 TEU Summary tabs show the results of the analysis calculations. A summary of the voyage is given for each scenario, including ports visited, number of containers loaded, and route distances. Please note that some shipping costs, such as passage transit fees charged by countries, icebreaker escort fees, and ice pilot fees, are not currently included in the model. The total voyage costs, time, and cost per TEU are given at the bottom of each scenario.

A.4 Viewing Vessel Information

The Vessels tab contains general characteristics of each vessel and daily expenses, such as fuel, operating, and capital expenses, incurred over the voyage. Data in the Vessels tab are not intended to be modified by the user. User changes to the Vessels tab may cause the model to display invalid results.

A.5 Viewing Port Information

The "Ports" tab contains container handling information, including the handling rate (hourly capacity) of the cranes. Port fees and container handling fees are also given. Total time spent in port is calculated from the maneuvering times and loading/unloading time. As with the "Vessels" tab, changing values in the "Ports" tab may introduce errors into the model.

A.6 Viewing Route Information

The "Routes" tab calculates the sea time for a given route and time of year. Distances and vessel speeds through the NSR were taken from the Aker study to calculate the transit time of the icebreaking vessels. Transit times for the canal routes were also calculated, including wait times at the canals. Estimates of canal fees are listed by the canal transit times.

Appendix B: Selected Model Sheets

Unless otherwise indicated, all values shown reflect inputs shown in Figure B-1.

Figure B-1: General Inputs

Instructions	
1. Set % 20' Containers, Load Factor, and FO Cost. 2. Set Month and Route by clicking button.	
Inputs	
% 20'	20%
% 40'	80%
Load Factor	85%
FO ($/t)	500

Figure B-2: 5000 TEU Summary Layout

Month	FO ($/ton)	Vessel Capacity (TEU)	Service
December	$500	5000	Yokohama-Rotterdam

		Scenario 1 Ice-strengthened Containership, Escorted	Scenario 2 Icebreaking Containership	Scenario 3 Standard-->Icebreaking Containership	Scenario 4 Ice-strengthened Containership, Arctic Route, Unescorted	Scenario 5 Standard Containership, Arctic Route, Unescorted	Scenario 6 Standard Containership, Canal Route
	Start Port	Yokohama	Yokohama	Yokohama	Yokohama	Yokohama	Yokohama
Containers, TEU Loaded		4250	4250	4250	4250	4250	4250
Port Expenses		$763,750	$763,750	$763,750	$763,750	$763,750	$763,750
	Leg 1	Yokohama - Bering St	Yokohama - Rotterdam NSR	Yokohama - Adak	Yokohama - Adak	Yokohama - Rotterdam NSR	Yokohama - Rotterdam SCR
Vessel		Ice-strengthened	Icebreaking	Standard	Ice-strengthened	Standard	Standard
Distance, nm		2452	7090	2237	7090	7090	11070
Transit Cost		$565,611	$2,940,613	$503,563	$1,635,475	$1,596,004	$2,651,842
	Transshipment Point			Adak			
Containers, TEU Unloaded				4250			
Loaded				4250			
Port Expenses				$870,000			
	Leg 2	Bering St - North Sea		Adak - Murmansk			
Vessels		Ice-strengthened, Icebreaker Escort		Icebreaking			
Distance, nm		2788		3755			
Transit Cost		$2,464,949		$1,722,070			
	Transshipment Point			Murmansk			
Containers, TEU Unloaded				4250			
Loaded				4250			
Port Expenses				$870,000			
	Leg 3	North Sea - Rotterdam		Murmansk - Rotterdam			
Vessel		Ice-strengthened		Standard			
Distance, nm		1850		1627			
Transit Cost		$426,746		$366,248			
Canal Fees							$262,004
	End Port	Rotterdam	Rotterdam	Rotterdam	Rotterdam	Rotterdam	Rotterdam
Containers, TEU Unloaded		4250	4250	4250	4250	4250	4250
Port Expenses		$763,750	$763,750	$763,750	$763,750	$763,750	$763,750
Scenario Summary							
Vessels Used							
Icebreaking Containership			Icebreaking Containership	Icebreaking Containership			
Ice-Strengthened Containership		Ice-Strengthened Containership			Ice-Strengthened Containership		
Standard Containership				Standard Containership		Standard Containership	Standard Containership
Icebreaker Escort		Icebreaker Escort					
Total Cargo/Operating Cost		$5,145,243	$4,709,340	$6,714,250	$3,323,412	$3,279,241	$4,597,084
Total Time (days)		19.8	22.0	26.2	16.1	16.1	24.9
Cost per TEU Moved		$1,211	$1,108	$1,580	$782	$772	$1,082

Figure B-3: 750 TEU Summary Layout

Month	FO ($/ton)	Vessel Capacity (TEU)	Service
December	$500	750	Yokohama-Rotterdam

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Ice-strengthened Containership, Escorted	Icebreaking Containership	Standard-->Icebreaking Containership	Ice-strengthened Containership, Arctic Route, Unescorted	Standard Containership, Arctic Route, Unescorted	Standard Containership, Canal Route
Start Port	Yokohama	Yokohama	Yokohama	Yokohama	Yokohama	Yokohama
Containers, TEU						
Loaded	638	638	638	638	638	638
Port Expenses	$131,425	$131,425	$131,425	$131,425	$131,425	$131,425
Leg 1	Yokohama - Bering St	Yokohama - Rotterdam NSR	Yokohama - Adak	Yokohama - Rotterdam NSR	Yokohama - Rotterdam NSR	Yokohama - Rotterdam SCR
Vessel	Ice-strengthened	Icebreaking	Standard	Ice-strengthened	Standard	Standard
Distance, nm	2452	7090	2237	7090	7090	11070
Transit Cost	$314,329	$1,782,259	$279,580	$908,887	$886,108	$954,097
Transshipment Point			Adak			
Containers, TEU						
Unloaded			638			
Loaded			638			
Port Expenses			$140,975			
Leg 2	Bering St - North Sea		Adak - Murmansk			
Vessels	Ice-strengthened, Icebreaker Escort		Icebreaking			
Distance, nm	2788		3755			
Transit Cost	$1,835,248		$1,195,181			
Transshipment Point			Murmansk			
Containers, TEU						
Unloaded			638			
Loaded			638			
Port Expenses			$140,975			
Leg 3	North Sea - Rotterdam		Murmansk - Rotterdam			
Vessel	Ice-strengthened		Standard			
Distance, nm	1850		1627			
Transit Cost	$237,157		$203,342			
Canal Fees						$83,770
End Port	Rotterdam	Rotterdam	Rotterdam	Rotterdam	Rotterdam	Rotterdam
Containers, TEU						
Unloaded	638	638	638	638	638	638
Port Expenses	$131,425	$131,425	$131,425	$131,425	$131,425	$131,425
Scenario Summary						
Vessels Used						
Icebreaking Containership		Icebreaking Containership	Icebreaking Containership			
Ice-Strengthened Containership	Ice-Strengthened Containership			Ice-Strengthened Containership		
Standard Containership			Standard Containership			Standard Containership
Icebreaker Escort	Icebreaker Escort					
Total Cargo/Operating Cost	$2,687,167	$2,103,196	$2,417,503	$1,209,321	$1,185,464	$1,337,223
Total Time (days)	20.7	27.0	29.7	18.6	18.6	19.9
Cost per TEU Moved	$4,215	$3,299	$3,792	$1,897	$1,860	$2,098

Figure B-4: Vessel Data

	5000 TEU Icebreaking Containership	750 TEU Icebreaking Containership	5000 TEU Standard Containership
Capacity, TEU	5000	750	5000
LOA, m	281	169	294
LBP, m	269	160	283
Breadth, m	34.6	23.1	32.2
Depth, m	21.3	14.2	21.8
Design Draft, m	13.5	9.0	13.5
Holds	8	3	
OW Speed, kts			
Maximum	19	17	25.1
Service	17.5	15.5	22.2
Shaft Power, kW	36000	13000	51390
Service Speed Fuel Consumption, t/day	134.1	41	128.3
Generator Power, kW	5747	3000	5747
Aux. Generator Fuel Consumption, t/day	24.8	13.0	24.8
Daily Expenses			
Fuel			
Propulsion	$ 67,050	$ 20,500	$ 64,150
Auxilliary	$ 12,414	$ 6,480	$ 12,414
OPEX	$ 17,250	$ 12,938	$ 15,000
Building Cost	$ 195,000,000	$ 100,000,000	$ 97,500,000
Owner Equity	$ -	$ -	$ -
Amount Financed	$ 195,000,000	$ 100,000,000	$ 97,500,000
Interest Rate	8%	8%	8%
Number of Years	20	20	20
Yearly Payment	$ 19,861,181	$ 10,185,221	$ 9,930,590
Daily Capital Cost	$ 56,746	$ 29,101	$ 28,373
Sum of Daily Exp. and Daily Cap. Cost	**$ 153,460**	**$ 69,018**	**$ 119,937**

Figure B-4: Vessel Data, Continued

	750 TEU Standard Containership	5000 TEU Ice-strengthened containership	750 TEU Ice-strengthened containership
Capacity, TEU	750	5000	750
LOA, m	145	294	145
LBP, m	134	283	134
Breadth, m	22.7	32.2	23
Depth, m	11	21.8	11
Design Draft, m	8.2	13.5	8
Holds			
OW Speed, kts			
Maximum	19	25.1	19
Service	17	22.2	17
Shaft Power, kW	10860	51390	10860
Service Speed Fuel Consumption, t/day	41	128.3	41
Generator Power, kW	2172	5747	2172
Aux. Generator Fuel Consumption, t/day	9.38	24.8	9
Daily Expenses			
Fuel			
Propulsion	$ 20,500	$ 65,433	$ 20,910
Auxilliary	$ 4,692	$ 12,662	$ 4,785
OPEX	$ 11,250	$ 15,300	$ 11,475
Building Cost	$ 50,000,000	$ 101,400,000	$ 52,000,000
Owner Equity	$ -	$ -	$ -
Amount Financed	$ 50,000,000	$ 101,400,000	$ 52,000,000
Interest Rate	8%	8%	8%
Number of Years	20	20	20
Yearly Payment	$ 5,092,610	$ 10,327,814	$ 5,296,315
Daily Capital Cost	$ 14,550	$ 29,508	$ 15,132
Sum of Daily Exp. and Daily Cap. Cost	$ 50,992	$ 122,903	$ 52,303

Figure B-5: Yokohama-Rotterdam Route Data

Yokohama - Rotterdam NSR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Distance (nm)							7090					
5000 TEU Icebreaking Containership												
Avg Speed (kt)	13.9	11.4	9.3	8.9	9.1	9.6	15.8	17.2	17.5	17.5	16.9	15.4
Time (hr)	510	621	764	794	780	739	448	412	405	405	420	460
Time (day)	21.2	25.9	31.8	33.1	32.5	30.8	18.7	17.2	16.9	16.9	17.5	19.2
750 TEU Icebreaking Containership												
Avg Speed (kt)	9.3	8.4	8.0	8.0	8.0	8.0	11.1	15.0	15.5	15.5	14.5	11.4
Time (hr)	763	846	885	891	889	883	639	471	457	457	488	620
Time (day)	31.8	35.3	36.9	37.1	37.1	36.8	26.6	19.6	19.1	19.1	20.3	25.8
Escorted Time (day)	7.4	14.7	23.1	23.1	23.1	20.1	7.4	0	0	0	0	0
5000 TEU Ice-strengthened												
Leg							Yokohama - Bering St					
Distance							2452					
Avg Speed (kt)							22					
Time (day)							4.6					
Leg							Bering St - North Sea, Escorted					
Distance							2788					
Avg Speed (kt)	10.6	7.4	5.4	5.1	5.2	5.7	13.8	16.8	17.5	17.5	16.0	13.0
Time (day)	11.0	15.6	21.6	22.8	22.3	20.5	8.4	6.9	6.6	6.6	7.3	8.9
Leg							North Sea - Rotterdam					
Distance							1850					
Avg Speed (kt)							22					
Time (day)							3.5					
750 TEU Ice-strengthened												
Leg							Yokohama - Bering St					
Distance							2452					
Avg Speed (kt)							17					
Time (day)							6.0					
Leg							Bering St - North Sea					
Distance							2788					
Avg Speed (kt)	10.6	7.4	5.4	5.1	5.2	5.7	13.8	16.8	17.0	17.0	16.0	13.0
Time (day)	11.0	15.6	21.6	22.8	22.3	20.5	8.4	6.9	6.8	6.8	7.3	8.9
Leg							North Sea - Rotterdam					
Distance							1850					
Avg Speed (kt)							17					
Time (day)							4.5					

Figure B-6: Case Values

Yokohama - Rotterdam (FO=$500/t)

Case 6 — **Standard Containership, Suez Canal Route**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**AVG**	Difference
Cost ($/TEU)	$1,082	$1,082	$1,082	$1,082	$1,082	$1,082	$1,082	$1,082	$1,082	$1,082	$1,082	$1,082	**$1,082**	$0
O-D Time (day)	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	**24.9**	0.0

Case 5 — **Standard Containership, Northern Sea Route, Unescorted**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**AVG**	
Cost ($/TEU)	$772	$772	$772	$772	$772	$772	$772	$772	$772	$772	$772	$772	**$772**	$310
O-D Time (day)	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	**16.1**	8.8

Case 4 — **Ice-strengthened Containership, Northern Sea Route, Unescorted**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**AVG**	
Cost ($/TEU)	$782	$782	$782	$782	$782	$782	$782	$782	$782	$782	$782	$782	**$782**	$300
O-D Time (day)	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	**16.1**	8.8

Case 3 — **Ice-strengthened Containership, Northern Sea Route, 8mo Unescorted, 22.2kts** — **4mo Transshipment through Arctic at Aker data speeds**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**AVG**	
Cost ($/TEU)	$782	$782	$2,050	$2,050	$2,050	$2,050	$782	$782	$782	$782	$782	$782	**$1,205**	$123
O-D Time (day)	16.1	16.1	39.1	39.1	39.1	39.1	16.1	16.1	16.1	16.1	16.1	16.1	**23.8**	1.1

Case 1a — **Ice-strengthened Containership, Northern Sea Route, 8mo Unescorted, 22.2kts** — **4mo Escorted through Arctic at 17.5kts**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**AVG**	
Cost ($/TEU)	$782	$782	$1,062	$1,062	$1,062	$1,062	$782	$782	$782	$782	$782	$782	**$875**	$206
O-D Time (day)	16.1	16.1	17.5	17.5	17.5	17.5	16.1	16.1	16.1	16.1	16.1	16.1	**16.6**	8.3

Case 1a (Free) — **Ice-strengthened Containership, Northern Sea Route, 8mo Unescorted, 22.2kts** — **4mo Escorted through Arctic at 17.5kts, Free Escort**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**AVG**	
Cost ($/TEU)	$782	$782	$823	$823	$823	$823	$782	$782	$782	$782	$782	$782	**$796**	$286
O-D Time (day)	16.1	16.1	17.5	17.5	17.5	17.5	16.1	16.1	16.1	16.1	16.1	16.1	**16.6**	8.3

Case 1b — **Ice-strengthened Containership, Northern Sea Route, 8mo Unescorted, 22.2kts** — **4mo Escorted through Arctic at 10kts**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**AVG**	
Cost ($/TEU)	$782	$782	$1,386	$1,386	$1,386	$1,386	$782	$782	$782	$782	$782	$782	**$983**	$98
O-D Time (day)	16.1	16.1	22.5	22.5	22.5	22.5	16.1	16.1	16.1	16.1	16.1	16.1	**18.2**	6.7

Case 1b (Free) — **Ice-strengthened Containership, Northern Sea Route, 8mo Unescorted, 22.2kts** — **4mo Escorted through Arctic at 10ktS, Free Escort**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**AVG**	
Cost ($/TEU)	$782	$782	$967	$967	$967	$967	$782	$782	$782	$782	$782	$782	**$844**	$238
O-D Time (day)	16.1	16.1	22.5	22.5	22.5	22.5	16.1	16.1	16.1	16.1	16.1	16.1	**18.2**	6.7

Figure B-6: Case Values, Continued

Case 1c	Ice-strengthened Containership, Northern Sea Route, 8mo Unescorted, 22.2kts						4mo Escorted through Arctic at 5.5kts						
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG	Difference
Cost ($/TEU)	$782	$782	$2,004	$2,004	$2,004	$2,004	$782	$782	$782	$782	$782	$782	**$1,189**	$108
O-D Time (day)	16.1	16.1	32.0	32.0	32.0	32.0	16.1	16.1	16.1	16.1	16.1	16.1	**21.4**	3.5

Case 1c (Free)	Ice-strengthened Containership, Northern Sea Route, 8mo Unescorted, 22.2kts						4mo Escorted through Arctic at 5.5kts, Free Escort							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG	
Cost ($/TEU)	$782	$782	$1,241	$1,241	$1,241	$1,241	$782	$782	$782	$782	$782	$782	**$935**	$147
O-D Time (day)	16.1	16.1	32.0	32.0	32.0	32.0	16.1	16.1	16.1	16.1	16.1	16.1	**21.4**	3.5

Case 1b (Modified)	Ice-strengthened Containership, Northern Sea Route, 8mo Unescorted, 22.2kts, 6.5 days idle							4mo Escorted through Arctic at 10ktS, Free Escort						
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG	
Original Cost ($/TEU)	$869	$869	$967	$967	$967	$967	$869	$869	$869	$869	$869	$869	**$901**	$180
Original Time (day)	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	**22.5**	2.4

(FO=$1000/t)

Case 6 (Base)	**Standard Containership, Suez Canal Route**													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG	Difference
Cost ($/TEU)	$1,488	$1,488	$1,488	$1,488	$1,488	$1,488	$1,488	$1,488	$1,488	$1,488	$1,488	$1,488	**$1,488**	$0

Case 1b (Free)	**Ice-strengthened Containership, Northern Sea Route, 8mo Unescorted, 22.2kts**						**4mo Escorted through Arctic at 10ktS, Free Escort**							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG	
Cost ($/TEU)	$1,019	$1,019	$1,337	$1,337	$1,337	$1,337	$1,019	$1,019	$1,019	$1,019	$1,019	$1,019	**$1,125**	$363

(FO=$250/t)

Case 6 (Base)	**Standard Containership, Suez Canal Route**													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG	Difference
Cost ($/TEU)	$878	$878	$878	$878	$878	$878	$878	$878	$878	$878	$878	$878	**$878**	$0

Case 1b (Free)	**Ice-strengthened Containership, Northern Sea Route, 8mo Unescorted, 22.2kts**						**4mo Escorted through Arctic at 10ktS, Free Escort**							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG	
Cost ($/TEU)	$656	$656	$782	$782	$782	$782	$656	$656	$656	$656	$656	$656	**$698**	$181

Note: Differences from base show that voyage expense savings increase with cost of fuel for escorted ice-strengthened containership.

Figure B-7: 5000 TEU Icebreaking Containership Speeds by Region (Aker)

Yokohama-Rotterdam	Length [nm]	Length [km]		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
				Avg. Speed [kn]											
Yokohama-Aleutians	1900	3519		17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Bering Sea	552	1023		17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Bering St	356	659		16.2	15.4	14.6	13.9	13.7	14.5	17.5	17.5	17.5	17.5	17.5	17.3
Chukchi	370	685		9.7	7.3	3.2	3.4	3.5	3.8	16.4	17.5	17.5	17.5	15.9	12.9
E Siberia	622	1152		7.3	4.1	3.4	3	2.9	3.1	9.6	15	17.5	17.5	15.3	11.8
Laptev	577	1069		13.5	11.6	9.9	7.6	7.8	9.2	14	17.2	17.5	17.5	15	11.3
Kara E	238	442		9.6	5.5	3.2	3.5	4.5	4.5	14.3	17.5	17.5	17.5	15.9	13.1
Kara N	283	523		10.6	8.9	7.7	7.8	8	9.4	16.2	17.5	17.5	17.5	16.6	13.8
Pechora N	342	633		14.1	13.9	13.3	13	13.1	13.8	17.5	17.5	17.5	17.5	17.3	15.3
NS-Rotterdam	1850	3426		17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Total	**7090**	**13131**		**13.9**	**11.4**	**9.28**	**8.93**	**9.09**	**9.60**	**15.8**	**17.2**	**17.5**	**17.5**	**16.9**	**15.4**
				Time [h]											
Yokohama-Aleutians				109	109	109	109	109	109	109	109	109	109	109	109
Bering Sea				32	32	32	32	32	32	32	32	32	32	32	32
Bering St				22	23	24	26	26	25	20	20	20	20	20	21
Chukchi				38	51	116	109	106	97	23	21	21	21	23	29
E Siberia				85	152	183	207	214	201	65	41	36	36	41	53
Laptev				43	50	58	76	74	63	41	34	33	33	38	51
Kara E				25	43	74	68	53	53	17	14	14	14	15	18
Kara N				27	32	37	36	35	30	17	16	16	16	17	21
Pechora N				24	25	26	26	26	25	20	20	20	20	20	22
NS-Rotterdam				106	106	106	106	106	106	106	106	106	106	106	106
			Total	**510**	**621**	**764**	**794**	**780**	**739**	**448**	**412**	**405**	**405**	**420**	**460**

Figure B-8: 5000 TEU Containership Escorted Speeds by Region (Aker)

ARCTIC LEGS (Escort)	Length [nm]	Length [km]		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
				Avg. Speed [kn]											
Bering St	356	659		16.2	15.4	14.6	13.9	13.7	14.5	17.5	17.5	17.5	17.5	17.5	17.3
Chukchi	370	685		9.7	7.3	3.2	3.4	3.5	3.8	16.4	17.5	17.5	17.5	15.9	12.9
E Siberia	622	1152		7.3	4.1	3.4	3	2.9	3.1	9.6	15	17.5	17.5	15.3	11.8
Laptev	577	1069		13.5	11.6	9.9	7.6	7.8	9.2	14	17.2	17.5	17.5	15	11.3
Kara E	238	442		9.6	5.5	3.2	3.5	4.5	4.5	14.3	17.5	17.5	17.5	15.9	13.1
Kara N	283	523		10.6	8.9	7.7	7.8	8	9.4	16.2	17.5	17.5	17.5	16.6	13.8
Pechora N	342	633		14.1	13.9	13.3	13	13.1	13.8	17.5	17.5	17.5	17.5	17.3	15.3
Total	2788	5163		**10.6**	**7.4**	**5.4**	**5.1**	**5.2**	**5.7**	**13.8**	**16.8**	**17.5**	**17.5**	**16.0**	**13.0**
				Time [h]											
Bering St				22	23	24	26	26	25	20	20	20	20	20	21
Chukchi				38	51	116	109	106	97	23	21	21	21	23	29
E Siberia				85	152	183	207	214	201	65	41	36	36	41	53
Laptev				43	50	58	76	74	63	41	34	33	33	38	51
Kara E				25	43	74	68	53	53	17	14	14	14	15	18
Kara N				27	32	37	36	35	30	17	16	16	16	17	21
Pechora N				24	25	26	26	26	25	20	20	20	20	20	22
			Total	**264**	**375**	**518**	**548**	**535**	**493**	**203**	**166**	**159**	**159**	**175**	**214**

Figure B-9: 5000 TEU Transshipment Speeds by Region (Aker)

ARCTIC TRANSSHIPMENT	Length [nm]	Length [km]		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
				Avg. Speed [kn]											
Adak-Bering St	547	1013		17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Bering St	356	659		16.2	15.4	14.6	13.9	13.7	14.5	17.5	17.5	17.5	17.5	17.5	17.3
Chukchi	370	685		9.7	7.3	3.2	3.4	3.5	3.8	16.4	17.5	17.5	17.5	15.9	12.9
E Siberia	622	1152		7.3	4.1	3.4	3	2.9	3.1	9.6	15	17.5	17.5	15.3	11.8
Laptev	577	1069		13.5	11.6	9.9	7.6	7.8	9.2	14	17.2	17.5	17.5	15	11.3
Kara E	238	442		9.6	5.5	3.2	3.5	4.5	4.5	14.3	17.5	17.5	17.5	15.9	13.1
Kara N	283	523		10.6	8.9	7.7	7.8	8	9.4	16.2	17.5	17.5	17.5	16.6	13.8
Pechora N	342	633		14.1	13.9	13.3	13	13.1	13.8	17.5	17.5	17.5	17.5	17.3	15.3
Pechora N - Murmansk	420	778		17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Total	**3755**	**6954**		**11.8**	**8.7**	**6.5**	**6.2**	**6.4**	**6.8**	**14.6**	**17.0**	**17.5**	**17.5**	**16.3**	**13.9**
				Time [h]											
Adak-Bering St				31	31	31	31	31	31	31	31	31	31	31	31
Bering St				22	23	24	26	26	25	20	20	20	20	20	21
Chukchi				38	51	116	109	106	97	23	21	21	21	23	29
E Siberia				85	152	183	207	214	201	65	41	36	36	41	53
Laptev				43	50	58	76	74	63	41	34	33	33	38	51
Kara E				25	43	74	68	53	53	17	14	14	14	15	18
Kara N				27	32	37	36	35	30	17	16	16	16	17	21
Pechora N				24	25	26	26	26	25	20	20	20	20	20	22
Pechora N - Murmansk				24	24	24	24	24	24	24	24	24	24	24	24
			Total	**319**	**430**	**573**	**604**	**590**	**548**	**258**	**221**	**215**	**215**	**230**	**269**

Figure B-10: 750 TEU Icebreaking Containership Speeds by Region (Aker)

Yokohama-Rotterdam	Length [nm]	Length [km]		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
				Avg. Speed [kn]											
Yokohama-Aleutians	1900	3519		15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Bering Sea	552	1023		15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Bering St	356	659		13.8	12.2	11.3	10.1	9.9	10.8	15.5	15.5	15.5	15.5	15.5	15.4
Chukchi	370	685		4.3	4	4	4	4	4	13.5	15.5	15.5	15.5	13.6	8.6
E Siberia	711	1152		4	4	4	4	4	4	4	12	15.5	15.5	12.4	6.6
Sannikova St	91	169		4.6	4	4	4	4	4	10	15.6	15.5	15.5	13.3	8.7
Laptev	523	1069		9.1	4.8	4	4	4	4	9.7	15.1	15.5	15.5	11.9	6
Kara E	238	442		4.5	4	4	4	4	4	6	15.5	15.5	15.5	12.6	9
Kara N	283	523		6.1	4.7	4	4	4	4.1	13.4	15.5	15.5	15.5	14.5	10.3
Pechora N	342	633		10.3	10.4	9.1	8.6	9.1	9.6	16	15.5	15.5	15.5	15.4	12.3
NS-Rotterdam	1850	3426		15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Total	**7216**	**13300**		**9.3**	**8.4**	**8.0**	**8.0**	**8.0**	**8.0**	**11.1**	**15.0**	**15.5**	**15.5**	**14.5**	**11.4**
				Note: Yellow cells indicate escort assistance.											
				Time [h]											
Yokohama-Aleutians				123	123	123	123	123	123	123	123	123	123	123	123
Bering Sea				36	36	36	36	36	36	36	36	36	36	36	36
Bering St				26	29	32	35	36	33	23	23	23	23	23	23
Chukchi				86	93	93	93	93	93	27	24	24	24	27	43
E Siberia				178	178	178	178	178	178	178	59	46	46	57	108
Sannikova St				20	23	23	23	23	23	9	6	6	6	7	10
Laptev				57	109	131	131	131	131	54	35	34	34	44	87
Kara E				53	60	60	60	60	60	40	15	15	15	19	26
Kara N				46	60	71	71	71	69	21	18	18	18	20	27
Pechora N				33	33	38	40	38	36	21	22	22	22	22	28
NS-Rotterdam				119	119	119	119	119	119	119	119	119	119	119	119
			Total	**777**	**861**	**901**	**907**	**905**	**898**	**651**	**480**	**466**	**466**	**496**	**631**
			Escorted	178	353	554	554	554	483	178	0	0	0	0	0

Figure B-11: 750 TEU Transshipment Speeds by Region (Aker)

ARCTIC TRANSSHIPMENT	Length [nm]	Length [km]		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
				Avg. Speed [kn]											
Adak-Bering St	547	1013		15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Bering St	356	659		13.8	12.2	11.3	10.1	9.9	10.8	15.5	15.5	15.5	15.5	15.5	15.4
Chukchi	370	685		4.3	4	4	4	4	4	13.5	15.5	15.5	15.5	13.6	8.6
E Siberia	711	1152		4	4	4	4	4	4	4	12	15.5	15.5	12.4	6.6
Sannikova St	91	169		4.6	4	4	4	4	4	10	15.6	15.5	15.5	13.3	8.7
Laptev	523	1069		9.1	4.8	4	4	4	4	9.7	15.1	15.5	15.5	11.9	6
Kara E	238	442		4.5	4	4	4	4	4	6	15.5	15.5	15.5	12.6	9
Kara N	283	523		6.1	4.7	4	4	4	4.1	13.4	15.5	15.5	15.5	14.5	10.3
Pechora N	342	633		10.3	10.4	9.1	8.6	9.1	9.6	16	15.5	15.5	15.5	15.4	12.3
Pechora N - Murmansk	420	778		15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Total	**3881**	**7123**		**6.9**	**6.0**	**5.7**	**5.6**	**5.6**	**5.7**	**8.9**	**14.7**	**15.5**	**15.5**	**13.8**	**9.3**
				Time [h]											
Adak-Bering St				35	35	35	35	35	35	35	35	35	35	35	35
Bering St				26	29	32	35	36	33	23	23	23	23	23	23
Chukchi				86	93	93	93	93	93	27	24	24	24	27	43
E Siberia				178	178	178	178	178	178	178	59	46	46	57	108
Sannikova St				20	23	23	23	23	23	9	6	6	6	7	10
Laptev				57	109	131	131	131	131	54	35	34	34	44	87
Kara E				53	60	60	60	60	60	40	15	15	15	19	26
Kara N				46	60	71	71	71	69	21	18	18	18	20	27
Pechora N				33	33	38	40	38	36	21	22	22	22	22	28
Pechora N - Murmansk				27	27	27	27	27	27	27	27	27	27	27	27
			Total	**562**	**646**	**685**	**691**	**690**	**683**	**436**	**265**	**250**	**250**	**281**	**416**
			Escorted	178	353	554	554	554	483	178	0	0	0	0	0

Appendix C: Favorable Assumptions

- Fully allocated costs are calculated as if all vessels and infrastructure (terminals) utilized in the study are used year-round.

- NSR fees, including ice pilot and escort fees, are approximated by using the daily expense of owning and operating a 5000 TEU icebreaking containership.

- Cases in the analysis used an origin/destination port pair that gave the largest distance savings possible between the Arctic and existing routes.

- Cases used constant speeds through the Arctic for 4 and 8 month periods.

- Ports used for transshipment in study currently have no transshipment terminals. While Murmansk is currently building a new container terminal, facilities at Adak were abandoned when the Adak Naval Air Station was closed in 1997.

- The 5000 TEU ice-strengthened containership is escorted by a single icebreaker. Currently there are no icebreakers that are always capable of single-handedly breaking a wide enough channel to escort a containership of this size.

- The financial impact of likely environmental regulations and requirements was not estimated.

- The issue of spray ice building up on container stacks was not evaluated. De-icing procedures could increase the cost of Arctic transit.

Appendix D: Vessel Characteristics

Figure D-1: 5000 TEU Icebreaking Containership General Arrangement

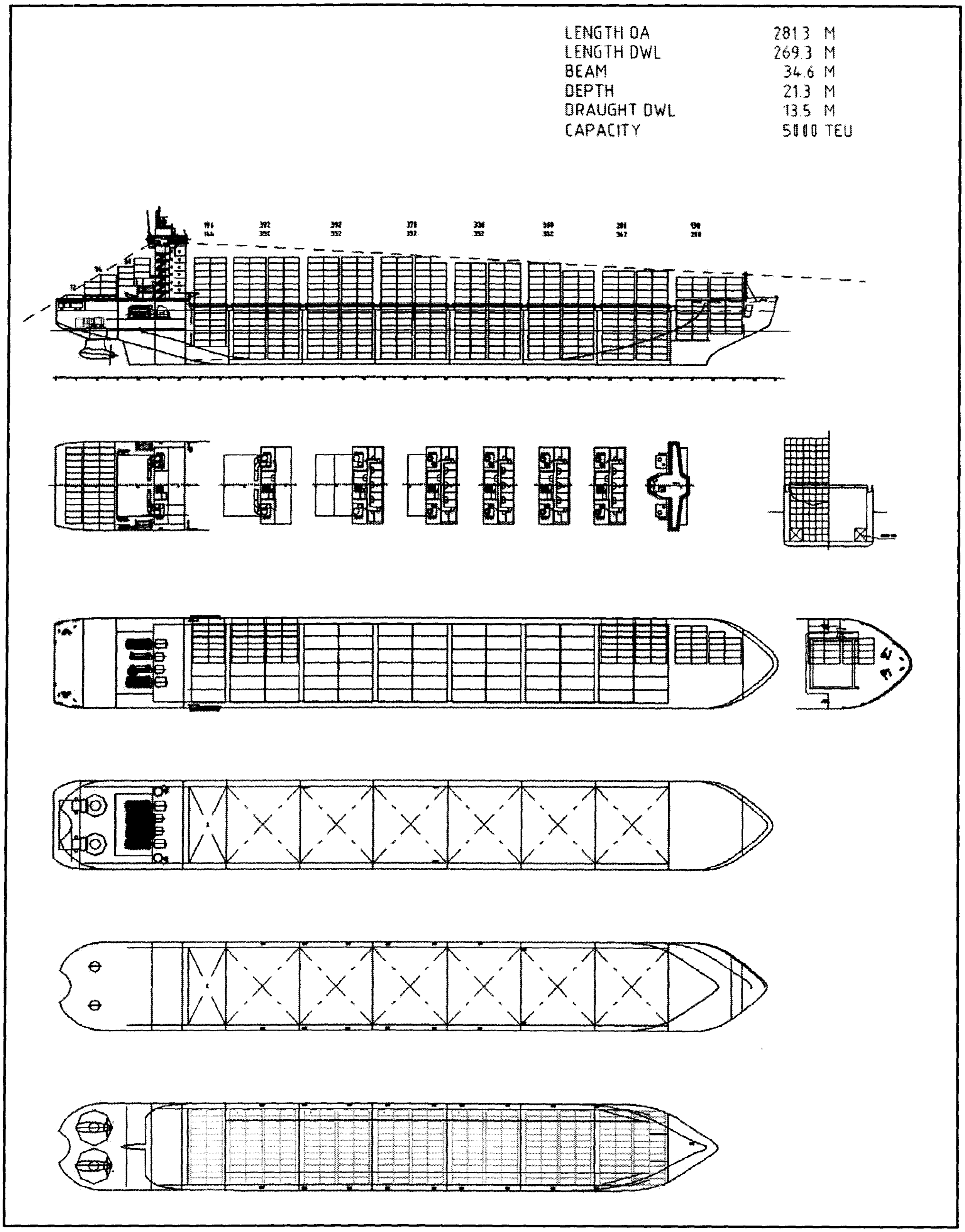


Figure D-2: 5000 TEU Icebreaking Containership Lines Plan

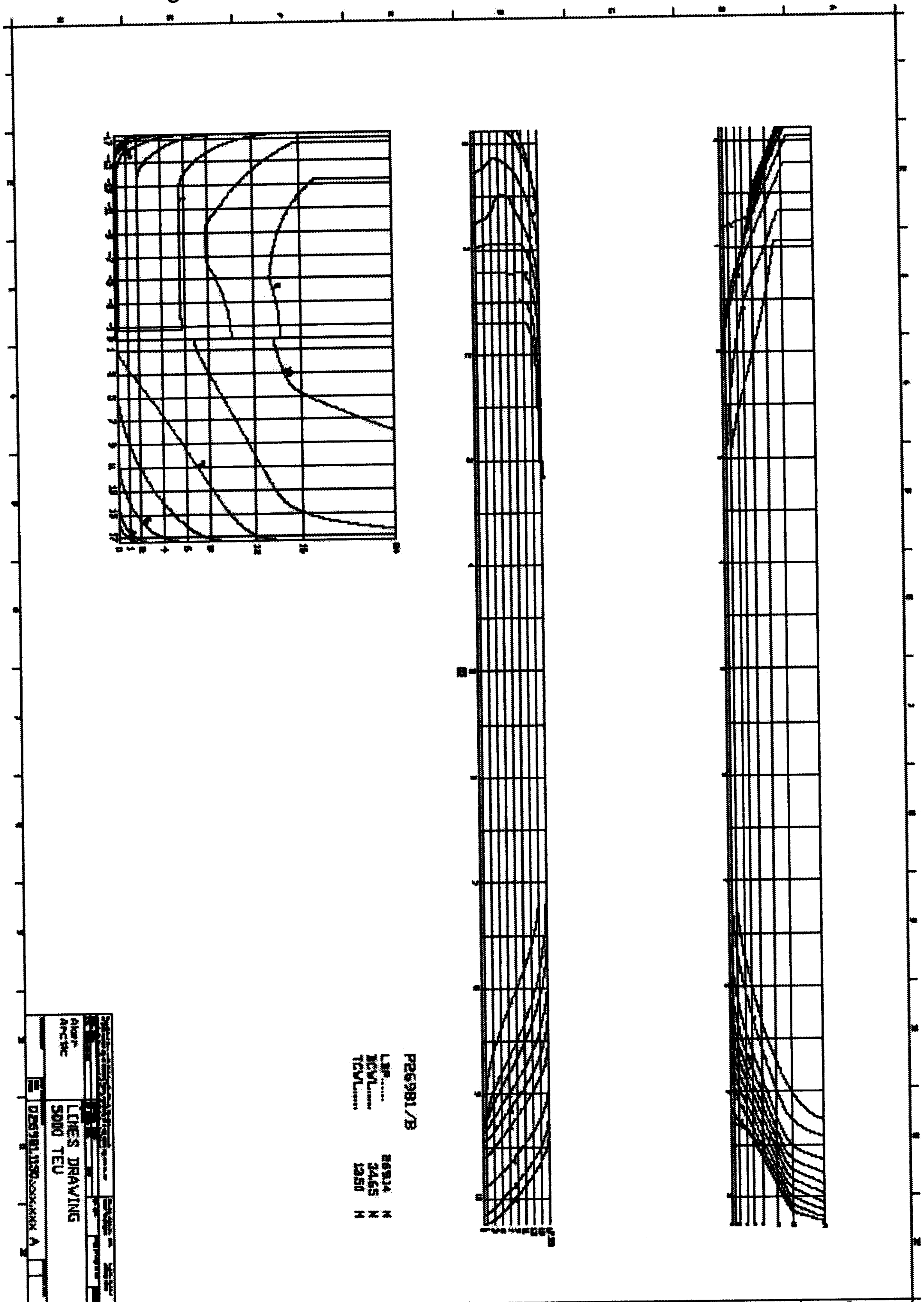


Figure D-3: 750 TEU Icebreaking Containership General Arrangement

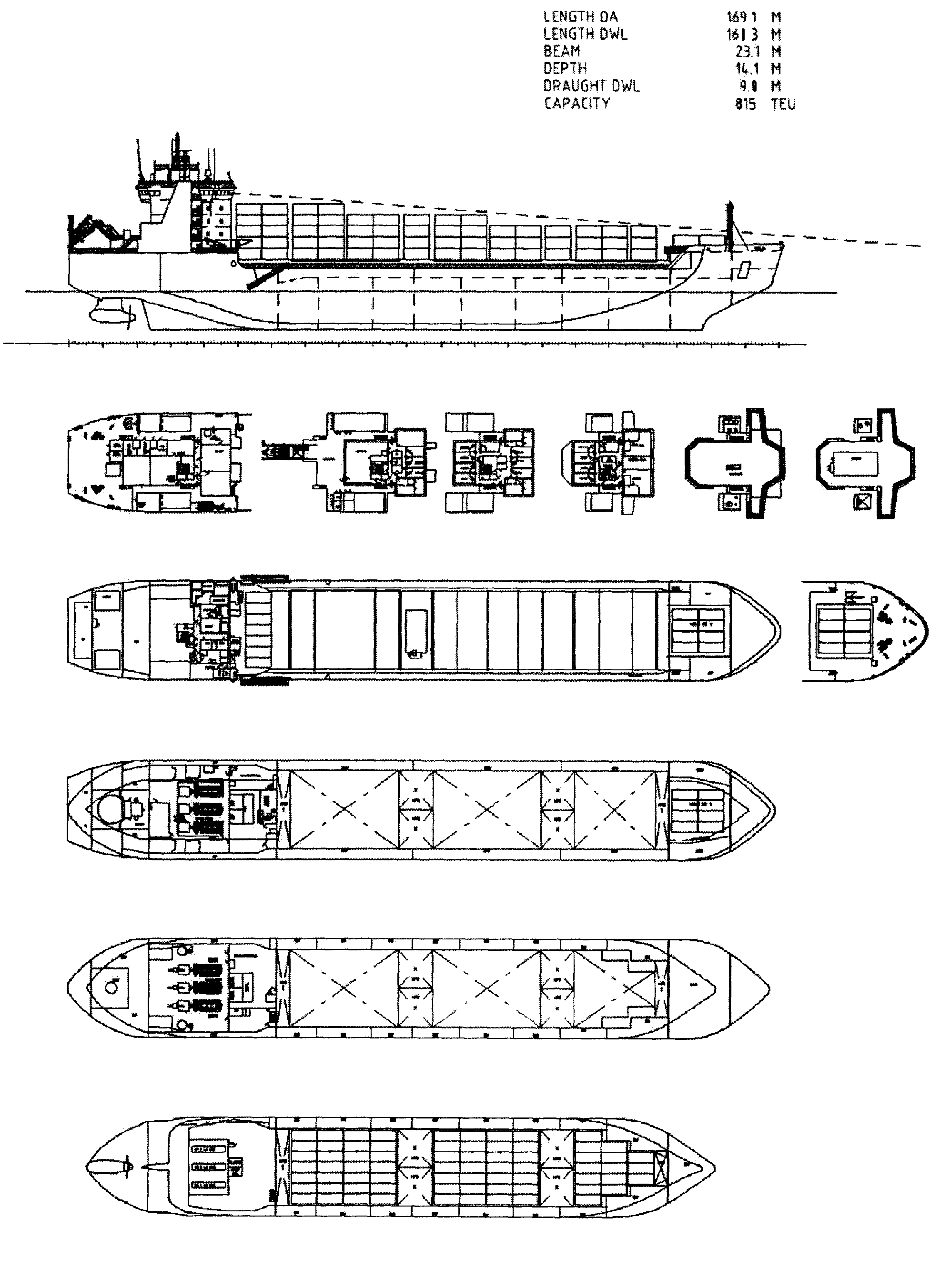


Figure D-4: 750 TEU Icebreaking Containership Lines Plan