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Development and Results of a Northern Sea Route Transit Model

Nathan D. Mulherin, Duane T. Eppler, Tatiana O. Proshutinsky, Andrey Yu. Proshutinsky, L. Dennis Farmer and Orson P. Smith

May 1996

Abstract
For a Corps of Engineers reconnaissance study, we developed a numerical model to estimate the time needed for various ship types to transit the Russian Northern Sea Route. We simulated liquid bulk, dry bulk, and container ship transits during the months of April, June, August, and October. In the model, probability distributions for various ice, ocean and atmospheric inputs are exercised by a Monte Carlo algorithm to generate combinations of conditions that affect ship speed. The speed, dependent on the established environment during each time and distance segment, is read from empirically derived lookup tables. Daily ship rates and Russian passage fees were applied to calculate the relative total costs for moving the various cargoes over the route. The model's development, limiting assumptions, simulation logic, data inputs, and resulting output are discussed.

Cover: Canadian Coast Guard icebreaker Louis St.-Laurent *follows in the wake of the U.S. Coast Guard icebreaker* Polar Sea *during their historic North Pole crossing in August 1994 (photo by Anthony Gow).*

For conversion of SI units to non-SI units of measurement consult ASTM Standard E380-93, *Standard Practice for Use of the International System of Units,* published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

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US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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Prepared for
U.S. ARMY ENGINEER DISTRICT, ALASKA

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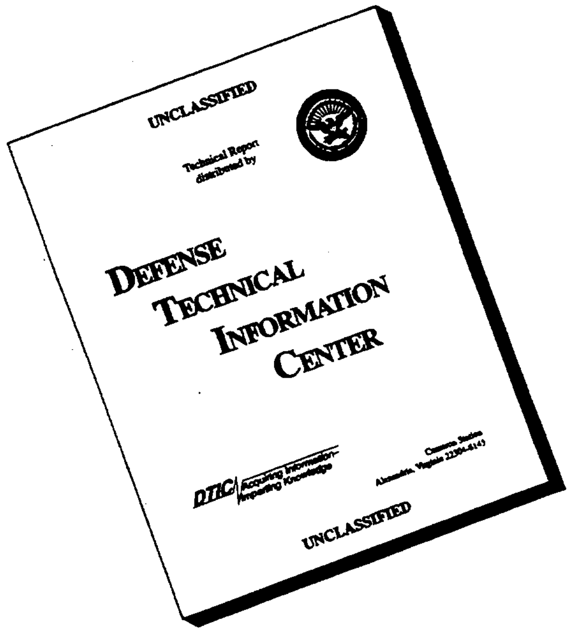

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PREFACE

This report was written by Nathan D. Mulherin, Research Physical Scientist, Snow and Ice Division, Research and Engineering Directorate, of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL); Duane T. Eppler and L. Dennis Farmer, research consultants and co-owners of Bronson Hills Associates; Tatiana O. Proshutinsky and Andrey Yu. Proshutinsky, visiting Russian scientists at the Institute of Marine Science, University of Alaska Fairbanks; and Orson P. Smith, Coastal Engineer/Oceanographer of the U.S. Army Engineer District, Alaska. This report represents one of several investigations supporting a U.S. Army Corps of Engineers reconnaissance study of the Northern Sea Route. These supporting investigations were funded by the U.S. Army Engineer District, Alaska, under contract no. E86954003 with oversight provided by Orson P. Smith, Reconnaissance Study Manager.

The authors are indebted to Capt. Lawson Brigham, former commanding officer of the U.S. Coast Guard icebreaker *Polar Sea*, for advice, valuable background material, and technical review of the manuscript; Mark Maliavko, Director of HydroCon Ltd., St. Petersburg, Russia, for obtaining and translating Russian material that was crucial for this work, and his associate, Finn Fjellheim at HydroCon in Norway for facilitating communications; Walter Tucker III, Chief of CRREL's Snow and Ice Division, for encouragement, timely advice, and technical manuscript review; and Dr. William Full of Wichita State University's Department of Geology for expert assistance in the finer points of FORTRAN coding. The following individuals are recognized for significant contributions of information: Trond Ramsland of Norway's Foundation for Research in Economics and Business Administration (he also provided technical review); Tor Wergeland of the Norwegian School of Economics and Business Administration; Devinder Sodhi of CRREL's Ice Engineering Research Division; Leonid Tunik of Backbone Publishing Company in New York; and Alfred Tunik of the American Bureau of Shipping in New York.

The dedicated work of the following individuals at CRREL in producing this report is gratefully acknowledged: Maria Bergstad and Edmund Wright for editorial review; William Bates and Edward Perkins for figure preparation; Stephen Flanders and Anatoly Fish for spur-of-the-moment translations of Russian information; and Sandra Smith for production assistance.

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ABBREVIATIONS AND ACRONYMS

deg	degrees
diam.	diameter
hp	horsepower
nm	nautical miles
mt	million tons
PDF	probability distribution function
shp	shaft horsepower
dwt	deadweight tons
loa	length overall
kn	knots
s	seconds
SD	standard deviation
t	metric tons
TEU	twenty-foot equivalent unit

AARI	Arctic and Antarctic Research Institute
ANSR	Administration of the Northern Sea Route
BHA	Bronson Hills Associates
CNIIMF	Central Marine Research and Design Institute
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
FESCO	Far Eastern Shipping Company
GEC	Gulf Engineers and Consultants, Inc.
INSROP	International Northern Sea Route Programme
IWR	Institute of Water Resources
MSC	Murmansk Shipping Company
NIC	U.S. Navy/NOAA National Ice Center
NSR	Northern Sea Route
RSMOT	Russian State Ministry of Transport
UAF	University of Alaska Fairbanks
USAED	U.S. Army Engineer District, Alaska

Development and Results of a Northern Sea Route Transit Model

NATHAN D. MULHERIN, DUANE T. EPPLER, TATIANA O. PROSHUTINSKY, ANDREY YU. PROSHUTINSKY, L. DENNIS FARMER, AND ORSON P. SMITH

INTRODUCTION

About this report

This report details the development and results of a Monte Carlo-based transit model constructed for a Northern Sea Route reconnaissance study. The model was commissioned by the Alaska District of the Corps of Engineers to estimate transit time and cost of potential marine shipments via the Russian Northern Sea Route (NSR). In this final report, we include a description of our assumptions, the model's input parameters and its output formats, a description of our sensitivity analyses, and the results of our many simulations to arrive at meaningful transit times and costs.

Purpose of the reconnaissance study

A series of meetings between State officials in Alaska and the U.S. Army Corps of Engineers led to a formal request from the State to have the Corps investigate the need for infrastructural improvements that would facilitate Alaskan shipping by way of the Northern Sea Route. As the first step in evaluating need, Congress allocated $300,000 in FY94 and an equal amount in FY95 to fund a reconnaissance study. This was a preliminary study to provide a general assessment of the route's potential benefit to the State of Alaska and the nation. It will be referred to hereinafter as the NSR Reconnaissance Study. The study was to determine whether more detailed feasibility studies for specific improvement projects were warranted. In the way of definition, a *reconnaissance study* provides a preliminary identification of promising projects, if they exist. A follow-on *feasibility study* is then done to calculate the actual costs and benefits of potential Corps improvement projects. Projects such as harbor construction or sea lane improvement, identified by feasibility studies as having a net benefit, could then be recommended for Congressional approval and funding.

Reconnaissance study participants and products

The U.S. Army Corps of Engineers, Alaska District (USAED), was named as the lead agency to conduct the reconnaissance study. USAED assembled a team from several agencies to bring various backgrounds of expertise to the process. The primary team members consisted of USAED, the U.S. Army's Cold Regions Research and Engineering Laboratory (CRREL), the University of Alaska Fairbanks (UAF), and Gulf Engineers & Consultants, Inc. (GEC). These primary team members were responsible for specific portions of the overall study and, in some cases, subcontracted for additional expertise from various other organizations and marine consultants. The names, addresses, and reporting responsibilities of the primary team members are listed in Table 1.

The overall NSR reconnaissance study was completed in June 1995 and published in three volumes (USAED 1995):

- Volume I:
  Main report and summary findings
  Appendix A: *History and Present Status of Operations*
  Nathan D.Mulherin, U.S. Army Cold Regions Research and Engineering Laboratory
- Volume II:
  Appendix B: *Climatology of Environmental Conditions Affecting Commercial Navigation Along the Northern Sea Route*
  Andrey Proshutinsky, Tatiana Proshutinsky, and Tom Weingartner, University of Alaska Fairbanks, Institute of Marine Science

Appendix C: *Summary of Icebreaking Technology and Inventory of Polar Ships*
Devinder S. Sodhi, U.S. Army Cold Regions Research and Engineering Laboratory
Appendix D: *Russian Institutions, Monitoring and Forecasting Capabilities and Sources of Data for the Northern Sea Route*
Andrey and Tatiana Proshutinsky, University of Alaska Fairbanks, Institute of Marine Science

- Volume III:
Appendix E: *Summary of Findings from the International Northern Sea Route Programme (INSROP) and Other International Initiatives Related to the Northern Sea Route*
W.M. Sackinger, University of Alaska Fairbanks, Geophysical Institute
Appendix F: *Forecast of Commodity Flows*
Gulf Engineers & Consultants, Inc.
Appendix G: *Transit Model Development and Results* (Draft)
Nathan D. Mulherin et al., U.S. Army Cold Regions Research and Engineering Laboratory
Appendix H: *Correspondence and Public Involvement*

Some general conclusions and recommendations of the reconnaissance study include:

- The potential exists for increased shipping between the Atlantic and the Pacific basins via the NSR due to the presence of a complex support infrastructure, potential cargoes, and emerging international interest.
- Environmental conditions that affect NSR shipping are highly variable from place to place and from season to season.
- Russian administration of the NSR, including passage regulations, the tariff structure, and ship charter rates, are in a state of flux, reflecting the rapid social and political changes now occurring.
- The ice-strengthened ships using the NSR have less than 25% of the cargo capacity of ships using the conventional warm-water routes, due to draft limitations in key straits and ports.
- Pacific Northwest U.S. and Alaskan ports will be affected by increased NSR throughput, and further study is warranted for potential channel improvements at the Alaskan port of Dutch Harbor.
- The U.S. will have increased responsibility for international vessels en route to and from the NSR, and efforts should be made to improve our nautical charts, navigation aids, and communications in that region.

Table 1. Reconnaissance study team members.

Agency	*Unit, Point of Contact, and Study Task*
U.S. Army Corps of Engineers, Alaska District (USAED) ATTN: CENPA-EN-CW-PF P.O. Box 898 Anchorage, AK 99506-0898	Dr. Orson P. Smith, *Study Manager*
U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) 72 Lyme Road Hanover, NH 03755-1290	Ice Engineering Research Division Dr. Devinder S. Sodhi, *Icebreaking Ship Technology* Snow and Ice Division Nathan D. Mulherin, *History and Current Status*
University of Alaska Fairbanks (UAF) Fairbanks, AK 99775-1080	Institute of Marine Science Dr. Thomas Weingartner, *Oceanography* Dr. Tatiana O. Proshutinsky, *Climatology* Dr. Andrey Yu. Proshutinsky, *Russian Institutions* Geophysical Institute Dr. William M. Sackinger, *International Initiatives*
Gulf Engineers & Consultants, Inc. (GEC) P.O. Box 84010 9357 Interline Avenue Baton Rouge, LA 70884-4010	Donald W. Ator, Jr., *Commodity Flows Forecasting* Daniel S. Maher, *Commodity Flows Forecasting*

The need for a transit model

The various reports from each of the primary team members were delivered to the Alaska District in the fall of 1994. It was the task of the Alaska District, in the second year, to assimilate the information from these reports into overall reconnaissance recommendations. Due to the complexity of the data accumulated in that first year, the Study Manager further identified a need for a transit model that would help to compare the NSR with the conventional southerly routes. That is, the NSR's shipping costs would be compared with those of the Panama and Suez Canal routes.

The USAED Study Manager then selected UAF and CRREL to combine their respective environmental and operational databases to produce a computer model that would estimate NSR transit times and costs. The Study Manager guided the modeling investigation and provided the conventional cargo ship cost data that were the basis for estimating similar costs of the ice-strengthened vessels that are needed for NSR shipping. USAED provided the rationale to adjust these warm-water ship costs upward to reflect added construction and operational costs for ice-going vessels.

UAF assembled the model's climatological input, which portrays the meteorological and oceanographic conditions of the route. The data were available to predict the probability of occurrence of winds, wave heights, ocean currents, ice conditions, and visibility factors (such as fog, snowstorms, atmospheric icing, and darkness). Each of these were simulated as functions of time and location.

The fact that much of the environmental data were available in the form of probability distributions was the major reason we chose to use a Monte Carlo modeling technique. This method derives its name from the city on the French Riviera where games of chance and gambling are popular. In the fashion of gambling, Monte Carlo simulation "rolls a die" (randomly selects) for the existence or magnitude of variables from their respective probability density functions at each trip node. The voyage is repeated a large number of times (100–500) to allow the time and cost calculations to reflect all probable conditions to be encountered on a typical voyage. In other words, the model produces Gaussian distributions of voyage time and cost parameters.

CRREL, having recently completed studies of the history and current administration of the NSR (Mulherin et al. in prep.), provided input on ship operational capabilities and NSR cost factors for foreign passage. CRREL was also assigned to oversee the coding for the model, perform the simulations, and report the results. CRREL subcontracted the actual work of writing the computer code to Bronson Hills Associates (BHA) of Fairlee, Vermont. In addition to being skilled computer programmers, the BHA principals were two veteran Arctic researchers for the U.S. Navy and were experienced in sea-ice processes and navigation.

All participants worked closely at all stages of the model's development, from defining its purpose through flow-chart conception to final execution. Direction and decision-making was accomplished through constant communication that included telephone, facsimile, and electronic mail. During the course of the modeling work, the participants gathered at two workshops. The first was held at the beginning of the project, and the second occurred approximately midway through its development.

On-site workshops

Two 3-day workshops were held at CRREL in Hanover, New Hampshire. The first took place in December 1994, during which the USAED's needs were fully explored in light of the collective capabilities and the data available. We defined the various legs of the northern route to be modeled and established a set of ship routing *decision nodes*, where two or more alternative route choices exist. The NSR is not a unique shipping channel but rather is generally regarded as any and all possible routes from the Atlantic to the Pacific Ocean through the passages, open seas, and island groups north of the Eurasian land mass. We agreed on the types of ships to model and the class of Russian icebreaker to serve as the cargo ship's escort when needed. We agreed to consider cargo transits in three different seasons to simulate best-case, worst-case, and intermediate transit scenarios. We established a timetable, discussed the sources and suitability of data, constructed a preliminary flow chart, and agreed on the task assignments noted in the previous subsection.

The second workshop was held in February 1995, during which a preliminary version of the model was tested and modified. The model prototype provided feedback on data suitability, the program algorithms, and indicated where refinement was needed. At this time, we incorporated in-ice ship performance criteria that we formulated from 1) consultation with Lawson W. Brigham, USCG, an experienced captain of a U.S. Coast Guard *Polar*-class icebreaker and noted expert on Russian icebreaking technology, and 2) Russian sources in the open literature. After introducing ship performance criteria into the model, we were ready to generate preliminary travel times. We compared these values with those derived from the open literature and then adjusted the performance criteria to more closely calculate the known transit times.

We added several other program modules to simulate environmental factors that we believed would have an important effect on ship passage. For example, we incorporated a speed reduction algorithm for ice pressure and a seasonally dependent darkness algorithm, and devised a maneuvering algorithm depending on the ice concentration. We decided not to use Russian historical data on the probability of needing icebreaker escort, in favor of letting the probability-generated ice conditions determine when escort was needed. The February workshop produced our final flow chart and a final list of individual tasks for completing the modeling work.

Scope of this report

This report is a detailed description and discussion of our Monte Carlo-based transit model that was formulated in support of the Northern Sea Route Reconnaissance Study. The model's output was used to estimate the time and cost of several scenarios of commercial ship transits in order to compare the efficacy of the NSR with the conventional Suez and Panama Canal routes. The model represents one phase of a larger investigation conducted by the Alaska District of the U.S. Army Corps of Engineers (USAED 1995).

This report discusses the development of the computer model, our assumptions, the model input variables and output capabilities, our simulations and sensitivity studies, and the model results. A section describes how to run the model and what user options are available. The appendixes include a program flow chart (App. A), the formats for and examples of input data files (App. B), and examples of the various output printing options (App. C).

What is the Northern Sea Route?

The Northern Sea Route, or NSR, is the modern-day designation for the Arctic marine route that extends from the Russian islands of Novaya Zemlya to the Bering Strait, which separates the State of Alaska from Russia. It extends a distance of between 2200 and 2900 nautical miles (nm) along Russia's northern coastline, where ecounters with bitter cold temperatures, ice-choked seas, shallow straits, blinding fog, and isolation are routine. The route extends across or into four seas of the Arctic Basin: the Kara, the Laptev, the East Siberian, and the Chukchi. It is the most challenging segment of the historic Northeast Passage from Europe to the Far East, offering a shorter distance between seaports in the North Atlantic and the North Pacific relative to the Suez and Panama Canal routes that are currently used. Transit distances between North Pacific and European ports are 35–60% less than the traditional southerly routes.

For approximately 50 years before 1991, the Soviet Union devoted significant energy and resources to developing a vast marine transportation system to help bring the abundant natural resources of Russia's isolated northern frontier to its more populated manufacturing centers. An intricate system of seaports, navigation aids, communications systems, icebreaking ships, ice forecasting, and piloting expertise was developed despite the considerable physical challenges of the Arctic regions. Today, open-ocean cargo transportation routinely occurs four months of the year along the entire Eurasian Arctic coastline. Shipping traffic, both local and transit, plies the entire route from the beginning of July to the end of October. On the western end of the NSR, regular service from Murmansk across the Barents and Kara Seas and up the Yenisey River to Dudinka has been operating virtually year-round since about 1980.

Numerous routes are possible (Fig. 1), depending mainly on transient ice conditions. The first is the most southerly and conventional coastal route. A second is a midroute from Cape Zhelaniya (the northern tip of Novaya Zemlya) to Dikson and from Novaya Sibir' Island to the port of Pevek. A third route, which is shorter for through traffic, stays to the north of Cape Zhelaniya, Cape Arkticheski (the northern tip of Severnaya Zemlya), and the Novosibirskiy Islands. A fourth route, 700 nm shorter than the coastal route, is the great circle route by way of the geographic North Pole. This fourth course is not economically feasible at the present time, but it may become viable in the future with improved transportation technology.

International interest

Using their highly advanced fleet of icebreaking ships, the Russians have the experience and technological capability to move ships virtually anywhere in the Arctic during the summer months, a fact that has been demonstrated by many trips to the North Pole by Russian nuclear-powered ice-

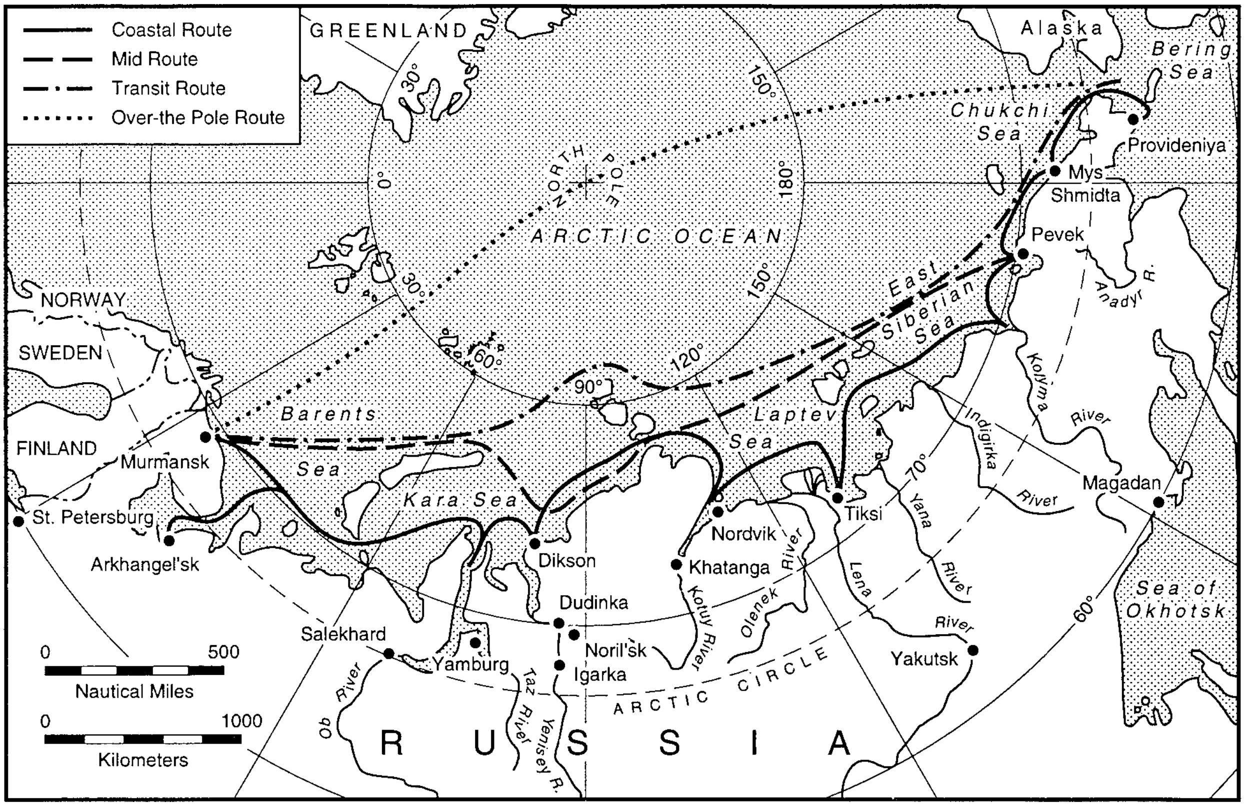


Figure 1. The various Northern Sea Route options.

breakers since 1977. Year-round maintenance of the entire route is currently being promoted by the Russians as a way of bringing hard currency into the country. The shorter shipping route might serve to open the entire northern region to increased economic development, foreign trade, and tourism.

The shift from socialism to a privatized, market-driven economy in the Soviet Union that began around 1985 resulted in economic and social disruption. The problems were compounded in 1991 with the transformation of the Soviet Union into the Commonwealth of Independent States (CIS). One way to address these problems may lie in the Commonwealth's ability to stimulate domestic growth and attract foreign trade. Although it was fortunate that authority over the entire NSR transferred intact to the new Russian Federation, inexperience with free enterprise and reduced state subsidies have resulted in unemployment and excess capacity in all sectors of the economy, including the Arctic marine transportation system.

Historically, the USSR claimed that crucial sections of the Northern Sea Route passed through its sovereign waters and they guarded these carefully from incursion by foreign vessels, effectively eliminating all foreign traffic. Before 1991, the last transit of the NSR by a foreign ship was in 1940. However, in October of 1987, then-General Secretary Mikhail Gorbachev announced a new spirit of cooperation in Arctic regions. As one item on the agenda, he proposed opening the Northern Sea Route, with certain restrictions, to all foreign vessels for peaceful and commercial purposes. This landmark change of policy was the first step in the privatization of Russia's Arctic fleet. Important assets, the NSR and the northern fleet continue to be promoted for bringing foreign currency into the country by "selling" premiere Russian ice navigation capabilities to the world. The Russians have proposed the following ways of employing their Arctic fleet to raise foreign capital:

- Escorting foreign ships along the route with Russian icebreakers,
- Transporting foreign goods aboard Russian ice-strengthened cargo ships,
- Encouraging the export and coastal movement of Russian goods in foreign ships,
- Employing idle Russian icebreakers and cargo vessels in the U.S. and Canadian Arctic,
- Promoting Arctic tourism.

The world's northern-tier nations and territories have become increasingly attracted to the idea of a trade route that will open new markets to their exports as well as generate income for their own economies acting as ports of call along the route.

Further development needed

The challenge of the physical environment of the Northern Sea Route requires the development and exploitation of technologies pertaining to ship design as well as to ship operations. Public policy alternatives will need to be investigated, some of which pose difficult trade-offs between economic development and other considerations, such as social well-being and environmental protection.

Establishing a viable year-round cargo transportation system will require advances in several areas, including:

- Further development of markets for cargoes,
- Development of more powerful and economical icebreaking ships,
- Improvement in the navigation infrastructure,
- Consideration of the rights and well-being of the region's indigenous peoples,
- Reduced risk to vessels, cargoes, and the environment, leading to more affordable insurance rates.

All these improvements should serve to make the NSR alternative more competitive with other routes and hence more attractive to international shipping.

THE TRANSIT MODEL

Simulation software successfully mimics real-world phenomena only to the extent that two conditions are met. First, data sets that describe variables on which predictions are based must accurately reflect real-world conditions. Second, the method chosen to model possible outcomes must be appropriate to the data. The algorithms that underlie our model have been constructed to ensure that both conditions are satisfied to the greatest extent possible within constraints governed by the data that are available.

Northern Sea Route data such as ice conditions, sea state, conditions that degrade visibility, and meteorology come primarily from Soviet and Russian observations acquired over long time periods. The nature of these data allow probability density functions to be constructed that reflect the probability of encountering specific environments, given that future conditions do not depart significantly from those observed in the past. Monte Carlo simulation techniques, which we applied, are well matched to this type of data because they select random samples of different combinations of conditions based on their probability of occurrence within the data set.

Other data, such as market-related variables that describe historic fluctuations in exchange rates, fuel and insurance costs, tariffs, and transit fees, are less well known or more poorly behaved and thus less likely to be indicative of future trends. Accurate simulation of such variables using Monte Carlo methods is unlikely to be reliable because a single probability density function (derived from past observations) cannot be used to describe both past and future patterns of variability. In other words, past events do not necessarily predict future events. Data such as these can be handled in several ways. Either a single fixed estimate can be established for all simulations, random samples can be selected from a range of discrete values with equal probability of occurrence, or a series of simulations can be run to produce estimates of transit cost at each of several discrete values.

Monte Carlo simulation

We selected values for most parameters in the model using a Monte Carlo (MC) approach. MC methods make random drawings from pools of possible values. We weighted each drawing by a priori knowledge of the frequency with which each value occurs in the real world. For instance, if we wish to make a simplistic simulation of New York City's April weather, we need to know how many April days in past years were rainy and how many were sunny. After searching weather observations recorded at nearby LaGuardia Airport for the past 40 years, we find that, over the long term, four April days in ten were rainy and the remaining six were sunny. Our simulation must reflect this frequency distribution so we bias the random drawings such that, on average, 40% of the time it's raining and 60% it's sunny. We do this by constraining the range of random numbers that are generated such that they fall between one and ten inclusive. If one, two, three, or four is drawn, it's raining; five through ten mean it's sunny. Since, by definition, a random drawing means that all values are equally likely to occur on any given selection, over the long run it will rain 40 times in 100 and the sun will shine the remaining 60 times. Our model thus simulates the ratio of rainy to sunny days observed at LaGuardia Airport.

In principle, the NSRSIM01 (Northern Sea Route Simulator—Version 01) model works in this manner. The likelihood that a particular variable will assume a given value is described by a probability density function (PDF) that is based in most cases on observational data acquired over long time periods. A variable is initialized by making a random drawing, weighted by the PDF, from the range of possible values the variable can assume. Take, for example, a hypothetical case in which ice thickness observations at some point along the NSR produce the PDF shown in Figure 2. MC sampling of this distribution as implemented in the NSRSIM01 algorithm involves first converting this raw PDF to a cumulative probability distribution (Fig. 2), generating a random number R drawn from a uniform distribution such that $0.0 \leq R \leq 1.0$, and then selecting an ice thickness value on the basis of the value of R taken with respect to the cumulative probability distribution. Figure 2 shows ice thickness selections based on two values of R: for $R = 0.30$, ice thickness is in the 0 to 120 cm category, and for $R = 0.60$, thickness is in the 120 to 240 cm category. Using this same logic, randomly selected values of 0.10 and 0.90 would fall in the ice-free and >240 cm categories, respectively.

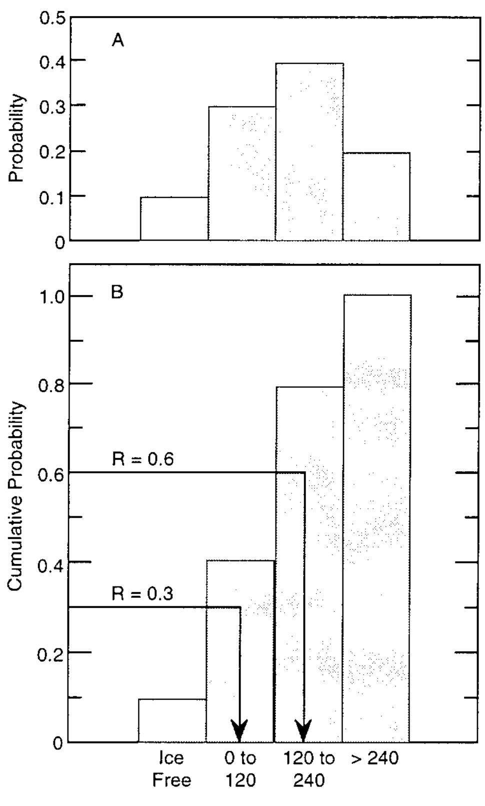


Figure 2. Selection of ice thickness values from a hypothetical probability density function (PDF) using Monte Carlo methods.

Inasmuch as R is drawn from a uniform distribution, all values within the range that R can assume are equally likely to be selected. On average, 10% of the time R will fall between 0.0 and 0.1, meaning that the ice-free category, which has a probability of occurrence of 0.1, will be chosen once in every ten selections. The 0 to 120 cm category, with a probability of 0.3, will be selected three times in ten, or when R is between 0.1 and 0.4. Over the long term, an ice thickness distribution produced through many iterations of this algorithm would replicate the PDF in Figure 2. Thus, to the extent that raw PDFs reflect environmental parameters accurately, the MC method simulates the frequency with which real-world conditions occur.

Our transit model uses the MC technique for calculating an average time and cost for shipping between Murmansk, Russia, and the Bering Strait, using the NSR. We selected the MC method as a practical approach for addressing the many random parameters that affect the cost of shipping. Instead of relying on fixed input parameters, the MC technique makes full use of the probability density functions of input variables to calculate a probable distribution of transit times and costs. In this case, many of the environmental (atmospheric, ice, and sea) conditions along the route are sufficiently known at various times of the year to yield distributions of their likelihood of occurrence. The environmental conditions that are encountered on a voyage affect the time needed for transit, which in turn affects the cost of transit. For example, we have sufficient data to say that near Cape Zhelaniya (the northern tip of Novaya Zemlya) in August, the wind direction and wind speed have ranges of known probabilities (see Table 2). When the ship reaches that location, the model randomly selects a weighted wind direction from the table (column 2). Once the direction is set, the model then randomly selects a weighted wind speed associated with that direction (e.g., from row 3 for a 90–135° wind direction).

For some conditions, such as fog, snowstorm, and icing, we have the probabilities of existence but not the additional knowledge of their magnitudes. So, for example, if there is a 20% historical probability of fog occurring, then the random selection for fog is weighted 80% in favor of clear weather.

Table 2. Percent probability of wind speed and direction for mesh point 2A (Cape Zhelaniya) in August.

Direction (degrees)	*Prob. (%)*	*Max. (m/s)*	*Min. (m/s)*	*Wind speed (m/s)* 0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	>50
000–045	15.6	19.3	6.6	5.2	8.4	1.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
045–090	14.1	20.8	7.2	4.4	6.3	2.6	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0
090–135	10.8	15.4	5.9	4.5	5.3	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
135–180	12.4	17.4	6.1	5.4	5.6	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
180–225	12.3	18.5	6.3	4.7	6.2	1.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
225–270	10.5	16.1	6.0	3.8	5.9	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
270–315	13.0	19.3	6.1	5.2	6.1	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
315–360	11.3	20.2	6.1	5.2	4.9	0.8	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0

General description and assumptions

We wrote our transit model in the FORTRAN77 programming language. We assembled and stored our data in companion files and lookup tables. The main program is approximately 1000 lines long and utilizes 21 subroutines. The user can choose any number between 1 and 500 repeating voyages from which to generate the summary statistics for transit time and total cost. We used a DOS-based platform running on a 33-MHz 486-SX desktop computer. With a math coprocessor, the model performs 500 repetitions of one set of voyage parameters in approximately 2 minutes if the short output format is selected. The various output formats are discussed below, under *Running the Model*. The following assumptions concerning icebreaker escort, transit routes between Murmansk and the Bering Sea, and the degree to which simulated conditions reflect real-world conditions underlie the model.

Icebreaker escort. In practice, icebreaker escort is mandated by Russian authority in some NSR locations where navigation is usually difficult. We did not program any voyage segments to always require escort. We triggered the need for escort only when the MC-selected conditions reach certain combinations of severity. Second, we assumed that escort is instantaneously available when needed. In actual practice, delay in a voyage may occur while waiting for an icebreaker to arrive or to form up convoys of ships. Third, our "escorted" ship speeds are those of a single ship under escort; i.e., convoys are not considered. Convoys that are slower than a single-ship escort might be able to transport cargo at a lower cost, but to analyze this possibility, more complex ship performance tables would have to be incorporated. Fourth, our model progresses in 8-hr time segments with ice conditions being reexamined during each segment. This can result in required escort for isolated 8-hr segments of the transit rather than for consecutive days, which is probably more realistic. In the cost calculation, however, we round the number of escort hours to the next greater whole day.

Transit routes. The transit routes that we selected for simulation are designed to cover the range of paths that might be followed if the NSR were to become heavily traveled. We recognize that some of our transit legs are rarely used at present. Our objective was to evaluate the full range of costs possible if demand were sufficient to warrant opening new routes that now see little or no traffic. We also assume that transit from Murmansk to the Bering Strait is non-stop; that is, the model does not currently allow for intermediate ports of call to pick up or discharge cargo. The model is designed, however, so that intermediate stops at Siberian ports could easily be accommodated. Finally, the calculation of ship's heading needed to sail from one data node to the next is performed only at the node embarked from. It is not updated between nodes to correct for route deviations caused by wind, waves, and currents. Transit distances are calculated along great circle routes, one consequence of which is the fact that, except for due north–south and due east–west travel, compass headings change continuously en route. We assume that the effect of these factors on ship motion is minor and not important to our overall results.

Simulated conditions. An artifact of the MC method that is inherent in our model is that, to the extent that underlying PDFs permit, conditions set in two consecutive time steps are independent of each other. It is thus conceivable that one 8-hr transit segment with clear skies, no ice, unlimited visibility, and light winds might be followed by the next having 2.5-m-thick ice at 100% concentration, with a foggy gale wind causing topside icing. Sequences of events generated in a few segments of a few voyages may not necessarily reflect real-world conditions accurately. However, in the more global sense, when a multivoyage transit is considered, we assume that the range of simulated conditions and their frequency of occurrence will reflect the real world quite well. Our objective in building the model was to estimate a range of costs that an operator might incur using the Northern Sea Route. Simulation of a large number of voyages for each transit will capture the maximum and minimum costs as well as the variance that is likely over the long term.

Random number generator

Monte Carlo simulations depend on selections drawn from number sequences that are truly random. Careful choice of algorithms that are used to produce random numbers is critical if model results are to be reliable. Press et al. (1992) note that the logic underlying many "canned" random number generators supplied with compilers or operating systems is flawed, either in terms of the manner in which generators provide for initialization or seeding, or, in worse cases, specifics of algorithms used to generate random numbers. One of the most common weaknesses concerns the relatively small period over which the number sequence that is generated repeats itself. No generator will produce an infinitely long sequence of random numbers; if an algorithm is run over and over again, eventually the number sequence will repeat itself exactly.* The period of recurrence is predictable if the random number algorithm is known, so it is important to use code that provides, for all practical purposes, no chance of repeating the same sequence over the number of selections that must be made. For applications that require only a few numbers to be generated, simple canned generators may suffice. But algorithms that utilize MC simulations can require that thousands of numbers be generated during each run. As Press et al. (1992, p. 276) indicate, using a generator with a period that is too short, "... can be disastrous in many circumstances: for an MC integration, you might well want to evaluate 106 different points, but actually be evaluating the same 32767 points 30 times each...." Although the outcome of such an exercise may appear reassuringly robust to the unsuspecting, the results may not adequately represent the processes the routine is intended to simulate.

To ensure that the results of our simulation are sound, NSRSIM01 uses the long-period RAN2 routine presented by Press et al. (1992, p. 280). RAN2 is based on the algorithm of L'Ecuyer (1988), which combines two generators with different periods to produce a long-period generator with a repeat period that is the least common multiple of the two shorter-component periods. RAN2's period exceeds 2 × 1018, which should be adequate for any implementation of NSRSIM01. RAN2 also uses the Bays–Durham shuffling algorithm (Knuth 1981) to guard against serial correlations in random number series in which the occurrence of particular values, although random in their own right, always are followed or preceded by numbers of the same general magnitude or value.

The seed used to initialize RAN2 is derived from the date and time read from the system clock when NSRSIM01 begins executing. NSRSIM01 constructs a signed 4-byte integer variable from the current month, day, hour, minute, second, and hundredth of a second (Fig. 3). Hundredths of a second are converted to tenths of a second and a bias is added so that the sign bit (bit 32) is set to 1 in half the seeds that are generated. This ensures that the full range of positive and negative values afforded by the signed 4-byte seed are available. Note that the same seed can occur more than once, but only if

* Random number sequences commonly include sections where digits repeat (e.g., 92173888940999995132 or 65749749749128361), but this is not the concern addressed here. Rather, at issue is the natural period unique to each random-number-generating algorithm that defines the length of the sequence of numbers that the algorithm is capable of producing. If allowed to iterate beyond this period, the generator will replicate the same sequence of numbers with an exactitude perversely characteristic of the machines on which we increasingly rely.

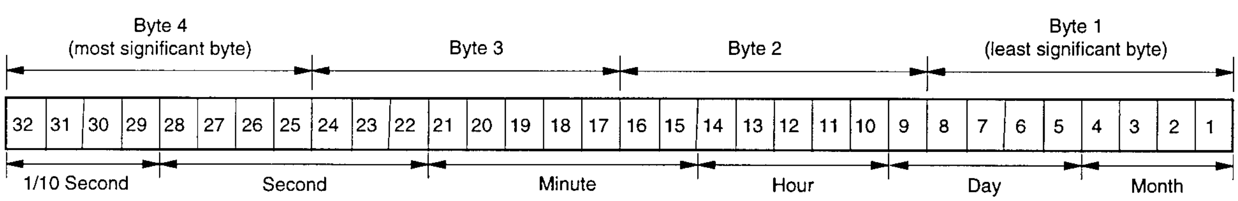


Figure 3. Bit-by-bit map of the signed 4-byte integer seed used to initialize RAN2. Date and time data retrieved from the system clock are combined to create a variable that, within acceptable limits, will produce a unique sequence of random numbers each time NSRSIM01 is run.

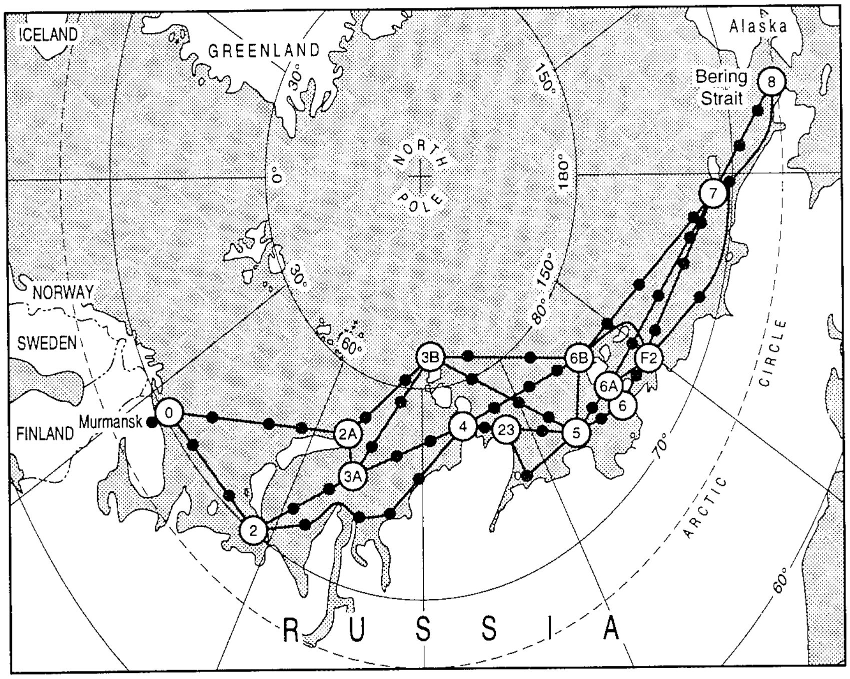


Figure 4. NSR overlain with meshing scheme.

execution of NSRSIM01 begins during the same tenth of a second in two different years.

Mesh description

Figure 4 offers a map of the Russian Arctic, showing the set of route alternatives programmed into the model. We segmented the various route choices with a mesh of data nodes, which are generally spaced 250 nm apart. These nodes are mesh points where the navigation conditions are set for an upcoming trip segment and are associated with the major climatological regions (Table 3) along the NSR (Treshnikov 1985, The Soviet Arctic 1970, RSMOT in prep., Proshutinsky et al. 1994).

Decision nodes, shown as circled numbers in Figure 4, are similar to data nodes in that we update the environmental conditions of the voyage, but they have the additional feature of marking where two or more route choices exist. That is, where the choice is made to follow the coastal route or a more northerly variant. For example, from decision node 0 at the mouth of the Kolskiy Gulf (43 nm seaward from Murmansk), we can choose to skirt Novaya Zemlya either to the south (to node 2) or to the north (to node 2A). We will refer to voyage segments between consecutive decision nodes as *legs* (leg 0–2 and leg 0–2A in this example).

Route options are selected using MC methods. Nodes files(NDESEW**.DAT and NDESWE**.DAT, App. B) give probabilities that particular legs will be followed, based on NSR historical data supplied by RSMOT (in prep.). In the absence of historical data, we assumed that each leg leading away from a decision node has an equal probability of being selected. A more detailed view of the entire mesh pattern, identifying all data nodes, appears as Figure 5. Not all routes are used during all months; in some cases the probability assigned to a given leg is zero. Appendix D gives the specific routing diagrams used for each of the four months simulated and shows which legs may or may not be active. A complete listing of nodal points is given in Table 4.

Table 3. Regional subdivisions of the NSR.

Region	*Description of the region*
1	Ice edge—Franz Josef Land
2	Ice edge—Cape Zhelanya
3	Ice edge—Karskiy Vorota Strait
4	Karskiy Vorota Strait—Cape Kharasavey
5	Cape Kharasavey—Belyi Island—Dikson
6	Mouth of the river Ob'
7	Mouth of the river Yenisey
8	Cape Zhelaniya—Dikson
9	Dikson—Cape Cheluskin
10	Dikson—Sedova Island
11	Cape Arkticheskii—Vil'kitskogo Strait—Khatanga River—Tiksi Bay
12	Tiksi Bay—Novosibirskiye Straits
13	Novosibirskiye Straits
14	Laptev Strait—Indigirka River—Kolyma River
15	Kolyma River mouth
16	Kolyma mouth—Cape Shelagskiy
17	Cape Shelagskiy—De Long Strait
18	De Long Strait—Bering Strait
19	Wrangel Island—Bering Strait
20	Bering Strait

Table 4. Listing of transit model nodes.

Node type	Transit segment	Geographic location	Latitude (deg min)	Longitude (deg min)
Data node 1	1–0	Murmansk	69 24	34 26
Decision node 0		Mouth of Kolskiy Gulf	69 57	35 43
Data node 1A	0–2A		72 30	40 00
Data node 2	0–2A		74 13	50 57
Data node 5	0–2A		75 55	56 30
Decision node 2A		Cape Zhelaniya	77 39	71 46
Data node 6	2A–3B		78 04	73 02
Data node 7	2A–3B		80 27	87 07
Decision node 3B		Cape Arkticheskiy	82 06	95 19
Data node 18	3B–6B		81 08	113 37
Data node 19	3B–6B		78 30	130 00
Decision node 6B		Zemlya Bunge	76 46	140 54
Data node 27	6B–7		75 36	150 20
Data node 28	6B–7		74 44	161 37
Data node 29	6B–7		71 36	172 48
Decision node 7		Longa Strait	70 11	177 03
Data node 37	7–8		68 36	182 36
Data node 38	7–8		67 32	187 44
Decision node 8		Bering Strait	66 41	189 03
Data node 3	0–2		70 30	40 00
Data node 4	0–2		71 10	50 43
Decision node 2		Kara Gate & Yugorskiy Shar	70 13	56 09
Data node 15	2–4		71 40	65 52
Data node 16	2–4		73 12	76 32
Data node 3	2–4	Dikson	73 21	81 21
Data node 11	2–4		75 47	90 43
Decision node 4		Vil'kitskiy & Shokal'skogo Straits	77 42	103 26
Data node 13	4–23		77 39	108 38
Decision node 23		Taymyr Peninsula	76 10	117 29
Data node 24	23–5		75 22	122 09
Decision node 5		Tiksi	74 00	130 00
Data node 26	5–6		72 56	135 03
Decision node 6		Dmitriya Lapteva	72 39	141 38
Data node 33	6–7		73 52	146 12
Data node 34	6–7		72 32	153 38
Data node 35	6–7		72 06	165 55
Data node 36	6–7		71 14	171 46
Data node 14	2–3A		71 37	62 23
Data node 17	2–3A		73 37	71 16
Decision node 3A		Mid Kara Sea	74 11	74 42
Data node 8	3A–3B		78 36	77 53
Data node 9	3A–3B		79 44	86 59
Data node 20	3B–5		80 02	112 29
Data node 21	3B–5		77 20	120 55
Data node 22	3B–5		75 58	125 55
Data node 25	5–6A		73 26	135 12
Decision node 6A		Sannikova Strait	74 13	140 58
Data node 30	6A–7		73 23	151 10
Data node 31	6A–7		73 12	160 23
Data node 32	6A–7		71 34	170 37
Data node 10	3A–4		76 12	86 28
Data node 12	3A–4		77 06	94 28
Data node 39	4–6B		77 54	122 53
Data node 40	4–6B		77 29	127 43
Data node 41	4–6B		76 59	132 13
Data node F1	23–5		74 00	114 00
Decision node F2		Indigirka River	73 00	148 00
Data node F3	F2–8		71 00	162 00
Data node F4	F2–8		69 30	178 00

Transit directionality

The model can simulate shipping in either an easterly or westerly direction. East-bearing voyages (except for April transits) make use of data files having course probabilities associated with each decision node. At these nodes, the model makes a weighted selection to decide on which leg to continue forward. These data were also obtained from RSMOT (in prep.). We did not have similar data for the month of April and, therefore, course selections were made on an equal probability bases. For example, we have assigned an equal likelihood of selecting either the 5–6, 5–6A, or 5–6B leg in April, whereas for August, the historical data shows 50% probabilities for the 5–6A and 5–6B legs and zero probability for the 5–6 leg. West-bearing voyages for all months use equal probability for all course choices because we had no historical data to do otherwise.

Months selected for simulation

We have constructed the model and assembled the necessary companion data files to allow transit simulations for April, June, August, or October voyages. April represents the worst-case scenario when the weather, ice conditions, and visibility are most difficult to overcome. August transits simulate the best case, that is, the easiest conditions through which to navigate. The months of June and August represent intermediate navigation conditions. We simulated the intermediate and extreme conditions, as requested by USAED, to enable their projection of U.S. port throughput based on 60-day, 120-day, and year-round NSR shipping.

Ships selected for simulation

We simulated three different ice-strengthened ship types: a *Noril'sk*-class multipurpose cargo ship, a *Lunni*-class tanker, and a *Strekalovsky*-class dry bulk freighter. These are the most ice-capable ships that currently use the route for moving liquid and dry bulk and specialized cargoes. For that reason, we assumed that they adequately represent what is most efficient, available, and therefore necessary for NSR passage. Icebreaking support in our model is provided by a Russian *Arktika*-class nuclear icebreaker whenever the ice conditions warrant escort. These icebreakers are currently the most powerful in the world and are used extensively for the most challenging sections of the route. These ship types are further described below.

The *Noril'sk*-class multipurpose cargo ship, also known as the SA-15, is the newest and most capable cargo vessel in use on the NSR today (Fig. 6). It is a multipurpose icebreaking vessel of 19,950 dwt and is designed to carry up to 15,650 t of a variety of cargoes including containers, trailers,

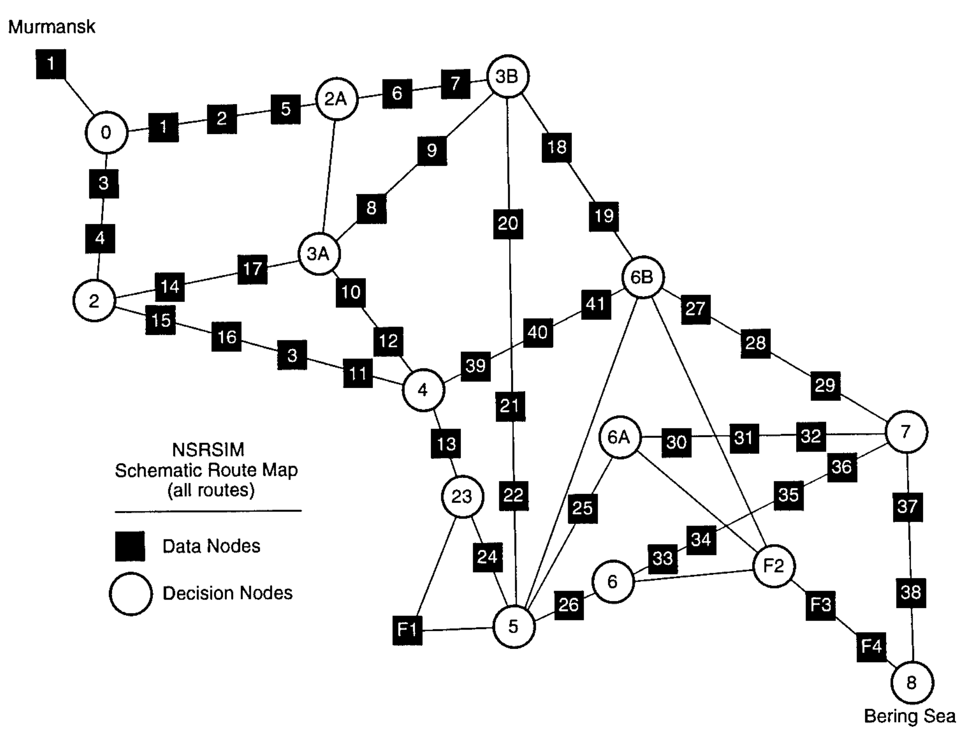
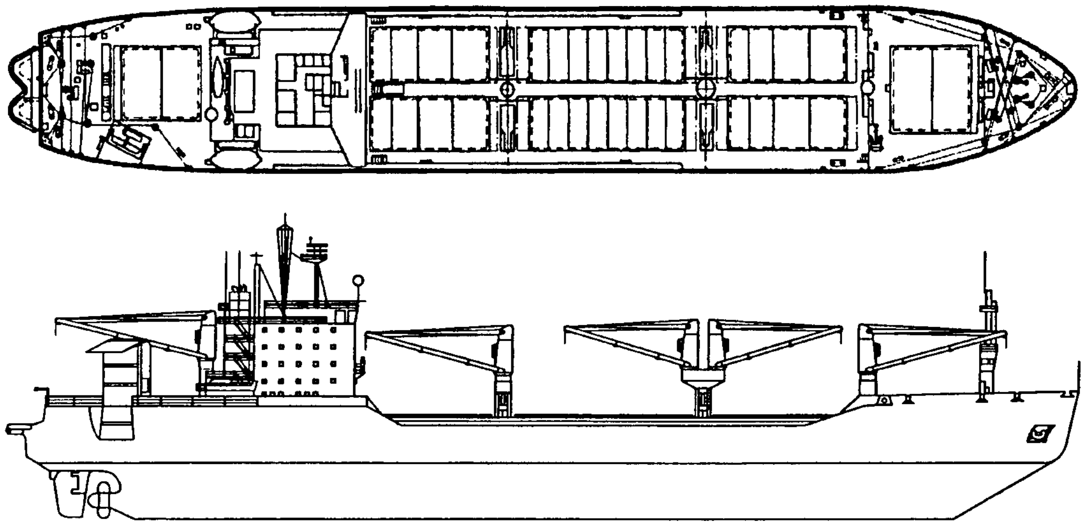


Figure 5. Detail of route meshing scheme showing all possible routes.



Ship stores					
Description		Mass, t	Daily consumption, t/day		
			Underway	In port	
				cargo operation	no cargo operation
Fuel	diesel oil	783	2.0	2.0	1.0
	high viscosity fuel	3,743	76	7.0	3.0
Lubricating oil		185	0.6	0.1	0.1
Boiler water		44.4	—	—	—
Fresh water		457	13.2	13.2	10.0
Fuel heating			provided		
Water ballast heating			provided		

Deck cranes		
Type	Outreach, m	Number and capacity
electro-hydraulic	22	3×20
electro-hydraulic	20	2×40

Ventilation	
Cargo spaces	naturally and mechanically
Service spaces	naturally and mechanically
Accommodation spaces	provided with air conditioner

Main machinery		
Two geared diesel engine of 14ZV 40/48 Wärtsilä-Sulzer type		
Built in Finland, 1982		
output	$\times$ kW (b.h.p)	$2 \times 7{,}700$ $2 \times 10{,}500$
Recommended fuel	$cSt_{50°C}$	180
	$secR1_{100°F}$	1,500
Type, number and diameter of propellers	unit $\times$ m	VPP 1×5.6

Supplementary data
1. The ship is provided with a corner ramp 18 m long and 5.0 m wide.

Figure 6. Russian Noril'sk*-class SA-15 multipurpose icebreaking cargo ship. (Courtesy of Murmansk Shipping Company.)*

Built at the Shipbuilding Yard Wörtsilö, Turku, Finland, 1982	Ship's type The single-screw, double-deck motorship with long forecastle, long poop, intermediate engine room and house, corner ramp, icebreaker bow and transom stern

General				Main particulars			
Classification KM ⊛ Y Λ A $\boxed{2}$ A2				Length o.a.		m	173.5
Register tonnage	gross	g.r.t.	17,910	Length b.p.		m	159.6
	net	n.r.t.	9,484	Breadth moulded		m	24.0
Service speed	full-loaded	knots	17.0	Depth moulded		m	15.2
	in ballast	knots	17.6	Summer load-line draft		m	10.5
Navigating range		miles	16,000	Loaded displacement		t	30,758
Crew		pers.	39	Deadweight		t	19,942
Height of mast above the baseline		m	51.0	Loading capacity		t	15,648
Capacity	bale	m^3	25,300	Light draft	forward	m	1.10
	grain	m^3	31,185		aft	m	7.45
	containers	TEU	576	Loading capacity per 1 cm draft		tpcm	
	packed timber	m^3	—	Type of hatch covers	Upper deck end-rolling	Tweendecks hinged to ends	

Description, dimensions and capacities of cargo spaces

	Holds						Tweendecks				Deep-tanks	Cargo hatches	
	Dimensions, m			Capacity, m^3			Dimensions, m		Capacity, m^3		Capacity, m^3	Dimensions, m	
Space no.	Length	Breadth	Height	grain	bale	containers, TEU	Length	Height	bale grain	containers, TEU	grain	Length	Breadth
1	12.25	20.5	4.50	978	800	4	19.0	5.0	3,100 2,799	40	900	12.8	13.0
2	27.0	18.0	8.50	3,657	2,900	96	27.0	5.0	2,900 3,793	48	2	19.2	2 × 8.0
3	33.25	18.0	8.50	4,257	3,900	144	33.25	5.0	3,800 4,760	64	2	25.6	8.0
4	23.75	18.0	8.50	3,255	2,300	108	23.75	5.0	2,200 3,431	44	2	19.2	
5	11.0	23.0	3.25	902	500	4	21.25	5.25	2,000 2,746	24	—	12.8	11.0
6	—	—	—	—	—	—	—	—	— 607	—	—		
	Total			13,049	10,400	356	Total		14,000 18,136	220	900		

Figure 6 (cont'd). Russian Noril'sk-*class SA-15 multipurpose icebreaking cargo ship. (Courtesy of Murmansk Shipping Company.)*

refrigerated cargo, and dry bulk material (such as ore, grain, or coal). It is fitted with a stern ramp and 40-ton-capacity cranes (operable in –40°C ambient temperatures) that allow cargo exchange where there are no pier facilities. These ships are 174 m long, have a maximum draft of 10.5 m, an operating range of 16,000 nm, and are manned with a crew of 39. The 20,600-hp diesel powerplant delivers 19,000 hp at the shaft to enable it to travel at 17 kn in open water when fully loaded. It is ice-classed as ULA, the highest freighter rating in the Russian Registry, and it is able to operate independently and continuously at 2 kn in 1-m-thick ice. Special ice navigation features include a low-friction hull coating and air-bubbling and water-jetting systems to enable easier passage. The two Finnish yards of Wartsila and Valmet produced the first 14 of these ships; the first, the *Noril'sk*, was completed in 1982. Five more were built between 1985 and 1987. As of July 1994, 16 were owned by the Murmansk, Far Eastern, and Sakhalin shipping companies and operated along the NSR. The remaining three are owned by North Bulk Shipping, fly the flag of Cyprus, and their home is the Cypriot port of Limassol.

The *Lunni*-class liquid bulk carrier is a Finnish-built vessel (Fig. 7) that is currently being used by Arctic Shipping Services, a jointly-owned Finnish and Russian venture, to transport petroleum products along Russia's northern coastline. The diesel propulsion system generates a total of 15,400 hp, which can move the ship through open water at 14.5 kn. According to A. Tunik,* it is ice-classified as 1A Super under the Det norske Veritas system, which translates to UL classification† under the Russian Register. It is listed by L. Tunik (1994) as capable of breaking 1-m-thick ice at a constant speed of 2 kn. Its dimensions are 164.5 m loa, 22.3 m beam, 9.5 m draft, and 16,000 dwt. There are four ships in the series. They were built in 1976 and fitted with air bubbling systems to enable easier passage through ice and snow. Two are owned by Nemarc Shipping and two by Neste Oy. Their homeport is Naantali, Finland, and they are currently in use in the Baltic Sea, Greenland, and the Russian Arctic. A sister ship, *Uikku*, was modified in 1993 to accomodate a 16,000 hp, azimuthing diesel-electric propulsion system, capable of generating 15,300 hp at the shaft. Its deadweight was also increased to 16,500 t.

The *Mikhail Strekalovsky* dry bulk cargo ship was German-built. It was launched in 1981, and the class was expanded to a total of 14 ships in the three years following. It is a single-screw, single-deck vessel (Fig. 8); it carries a crew of 36 and a cargo that is mainly ore, ore concentrates, apatites, and grain. It is fitted with five 12.5-ton cranes and one with 25-ton capacity. Its 11,050-hp diesel powerplant produces 9,960 hp at the shaft, which moves the vessel at 15.2 kn when fully loaded and provides an operating range of 11,000 nm. Its dimensions are 162.1 m loa, 22.9 m beam, 9.9 m draft, and 19,252 dwt. It is a UL-class vessel with an icebreaker bow and is capable of operating in broken ice of some thickness and concentration. However, an actual icebreaking capacity is not listed. Half of these ships are now Cypriot-owned (North Bulk Shipping). Of the remaining seven, five are owned by MSC and two by FESCO, and they continue to operate along the NSR.

The *Arktika*-class icebreaker is a series of five Russian nuclear-powered vessels that were built by the Admiralty Ship Yard. These are the largest and most powerful icebreaking ships ever built and are the major reason for the year-round maritime activity that occurs in the Russian Arctic (Fig. 9). With 75,000 total shp and a nearly limitless operating range (4 years between fuel rod changes), they are capable of operating nearly anywhere in the Arctic Basin, at least in summer. They are called on to perform the most difficult year-round duties, as they are officially rated (L. Tunik 1994) for 2.25-m-thick ice at about 2 kn continuously. Informational literature (Headland 1994) carried aboard the *Arktika*-class *Yamal* (App. E) claims a rating of 3-m ice at 3 kn. It also states that the maximum thickness of ice through which it can maintain continuous headway is 5 m, and that individual ice ridges estimated at 9 m thick have been penetrated. Data published by A. Tunik (1994) following the *Rossiya*'s 1990 voyage to the North Pole gives a continuous mean speed of 11.4 kn through 1.8-m-thick summer ice.

The *Arktika*, first in the series, entered service in 1974, and three years later it was the first surface ship to reach the North Pole. In 1978, the one-year-old *Sibir'* completed the first "high-latitude transit" of the NSR, navigating to the north of the ma-

* A. Tunik, American Bureau of Shipping, New York, personal communication, 1995.

† One technical reviewer for this report disagrees. Trond Ramsland of Norway's Foundation for Research in Economics and Business Administration states that the *Lunni* should be considered ULA-class. The effect that this has on the final results is addressed under Transit Costs, in the Results of Simulations section.

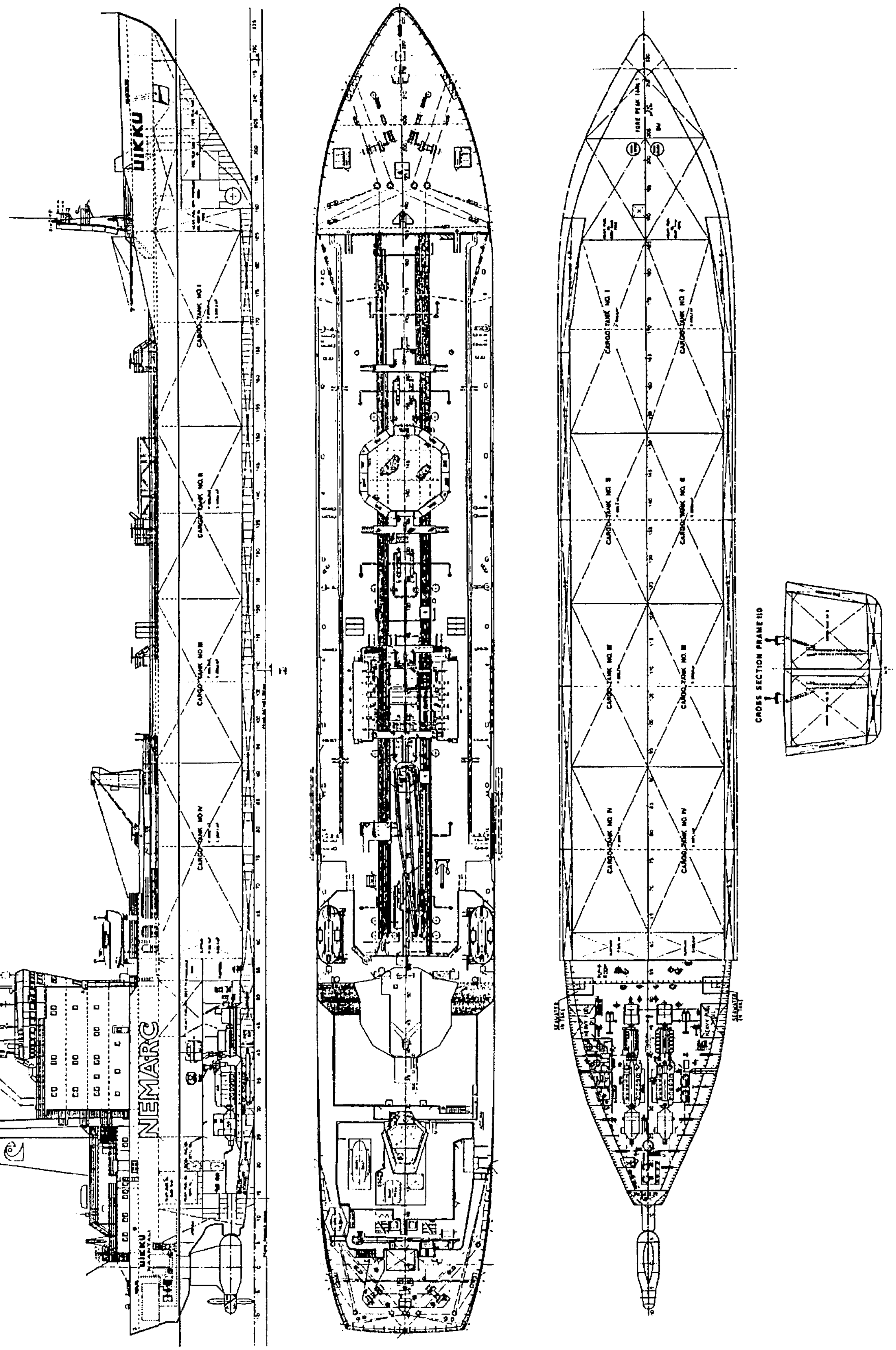


Figure 7. Finnish Lunni-*class liquid bulk carrier. (Courtesy of Neste Shipping.)*

MOTOR TANKER UIKKU

General description
The vessel is a double hull ice breaking motor tanker with eight coated cargo tanks and two slop tanks

Main particulars

Length O.A.	164.4 m
Length B.P.	150.0 m
Breadth moulded	22.2 m
Depth moulded	12.0 m
Draught on summer freeboard	9.5 m
Corresponding deadweight	15 748 tons
Distance keel top antenna	39.0 m

Registered tonnage	Gross	Net
International	10936.3 t	5140.3 t
Panama	11751.6 t	7240.1 t
Suez	11749.7 t	9061.8 t

Classification
Det Norske Veritas +1 A 1 Tanker for Oil,
Ice 1 A Super, MV, EO, F, Inert
Azipod-unit DNV Ice 10

Certificates
Solas 1974
Finnish Board of Navigation Regulations
St.Lawrence Seaway Approved

Builders
Werft Nobiskrug Gmbh, Rendsburg, built 1977
Kvaerner Masa-Yards Inc.,
Helsinki New Shipyard rebuilt
Azipod conversion 1993

Signal letters
OIHQ

Speed and consumption
Service speed 14.5 knots on maximum draught at 50 % MCR
consumption: Abt. 23 t/24 hours IFO max 380 cSt for main diesel generators

Propulsion machinery
Two WV 12 V 32/ABB diesel generators, output 4.8 MW, one WV 12 V 22 HF/AEG diesel generator, output 1.9 MW, one MaK 282 M 12/AEG diesel generator, output 2.3 MW and *auxiliary machinery:* two MTU/AEG diesel generators, output 2x520 kW, two blowers 2x13700 m³/h, air bubble system for navigation in ice

Bow thruster
One bow thruster, type Kamewa, 730 kW

Nautical equipment
S-band radar, X-band radar, Anticollision device/ARPA, Two gyrocompasses with autopilot, Satellite navigator, Decca navigator, Radiodirection finder, Echo sounder, Speed log, Vector navigation computer

Fuel oil/Diesel oil/Ballast water capacities

– Fuel oil	1350 t
– Diesel oil	83 t
– Ballast water	5990 t

Cargo control and monitoring
Onboard NAPA loading computer

Cargo equipment
- Eight epoxy coated cargo tanks
- Tank pairs are totally segregated and have own cargo lines
- Each of the cargo tanks is fitted with a hydraulically operated Frank Mohn deepwell pump, capacity 420 m³–10 bar
- Total discharge capacity is 3300 m³/h
- Each of the cargo tanks is fitted with deck mounted steam heat exchanger – capacity to maintain cargo temperature at +70°C with –30°C air temperature
- Moss inert gas generator, capacity 3500 m³/h
- Each of the cargo tanks is fitted with two fixed tank cleaning units (Gunclean)
- Closed loading system

Cargo tanks
Tank capacities
Volume m³ (98 %)

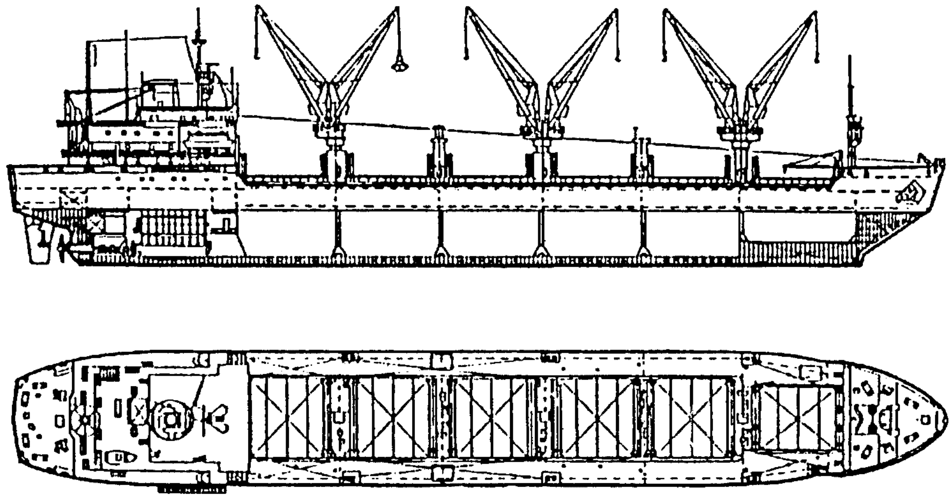
Cargo tank 1 P	2092.0	Common deck line
Cargo tank 1 SB	2096.2	and crossover
Cargo tank 2 P	1999.4	Common deck line
Cargo tank 2 SB	2003.4	and crossover
Cargo tankt 3 P	2003.3	Common deck line
Cargo tank 3 SB	2006.6	and crossover
Cargo tank 4 P	2006.7	Common deck line
Cargo tank 4 SB	2007.1	and crossover
Total of cargo tanks	16214.7	
Slop tank P	325.1	
Slop tank SB	325.8	
Grand total	16865.6	

Cargo manifold position

– Distance from bow to manifold	81.4 m
– Distance from stern to manifold	83.0 m
– Distance from ship's rail to manifold	5.9 m
– Height of manifold above deck	1.6 m
– Cargo manifold 10 inch ANSI 150	

Reducers onboard
12 inch–10 inch
10 inch– 8 inch
10 inch– 6 inch
One hose handling crane, capacity 10 tons at max radius 18.0 m

Figure 7 (cont'd).



Built at the Shipbuilding Yard "Warnowerft" Warnemünde, GDR, 1981	Ship's type The single-screw, single-deck motor ship with surplus freebord, short forecastle, long poop aft engine room and superstructure, ice-breaker bow and transom stern

General			
Classification KM ⊛Y ∧ A ② A2			
Register tonnage	gross	g.r.t.	13,520
	net	n.r.t.	6,936
Service speed	full-loaded	knots	15.2
	in ballast	knots	15.51
Navigating range		miles	11,000
Crew		pers.	31
Height of mast above the base-line		m	41
Capacity	grain	m^3	
	containers	TEU	422

Main particulars			
Length o.a.		m	162.1
Length b.p.		m	154.81
Breadth moulded		m	22.86
Depth moulded		m	13.5
Summer load-line draft		m	9.88
Loaded displacement		t	27,340
Deadweight		t	19,252
Loading capacity		t	17,204
Light draft	forward	m	0.22
	aft	m	6.07
Loading capacity per 1 cm draft		tpcm	31
Type of hatch covers	hydraulic, end rolling		

Cargo Space & Capacity Information

Cargo hold	Grain capacity (ca. metres)	Container capacity (TEU)	Hold dimensions (metres)			Hatch dimensions (metres)	
			Length	Breadth	Hight	Length	Breadth
No. 1	2,185	32	17.50	10.80	8.90	12.80	10.80
No. 2	4,451	50	15.80	16.60	11.60	12.80	13.50
No. 3	3,162	50	16.00	13.50	11.60	12.80	13.50
No. 4	4,625	50	16.80	18.00	11.60	12.80	13.50
No. 5	4,750	50	16.00	18.00	11.60	12.80	13.50
No. 6	3,075	50	15.20	13.50	11.60	12.80	13.50
Total cargo	22.448	282					

Hatch covers can accomodate loads of up to 1.75 tons per square metre.

Figure 8. Russian Mikhail Strekalovsky*-class dry bulk carrier. (Courtesy of Murmansk Shipping Company.)*

Ship stores					
Description		Mass, t	Daily consumption, t/day		
			Under way	in port: cargo operation	in port: no cargo operation
Fuel	diesel oil	329	5.0	2.5	2.5
Fuel	high viscosity fuel	1,348	43.1	7.3	7.3
Lubricating oil		52	0.3	–	–
Boiler water		134	2.9	5.8	5.8
Fresh water		136	4.0	4.0	4.0
Fuel heating			provided		
Water ballast heating			provided		

Deck cranes .		
Type	Outreach, m	Number and capacity
electric	22	6 x 12.5
(in tandem operation can lift up to 25 tons)		

Ventilation	
Cargo spaces	naturally
Service spaces	naturally and mechanically
Accommodation	14 x 1 berth officer's cabins. 17 x 1 berth crew's cabins. 1 x 2 berth pilot cabins. 5 x 1 berth passenger cabins. 2 x 2 berth passenger cabins. Airconditioning

Main machinery		
One diesesl engine of K8Z 70/120 E MAN type		
Built in GDR, 1980		
output	kW b.h.p	8,240 11,200
Recommended fuel	$cSt_{50° C}$	111
	$secR1_{100° F}$	1,000
Type, number and diameter of propellers	unit x m	d-b.f.p. 1 x 5.15

Supplementary data
The ship is intended for carrying bulk cargoes various ores, ore concentrates (non-flammable), apatites, grain and ISO type containers.

Figure 8 (cont'd).

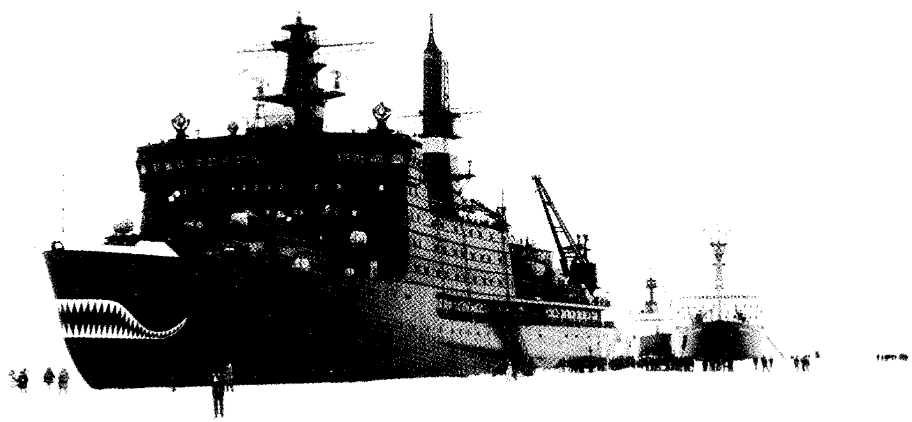


Figure 9. Russian Arktika-*class icebreaker upon meeting the USCGS* Polar Sea *and the CCGS* Louis St.-Laurent *near the North Pole in August of 1994. See Appendix F for ship specifications. (Photo: Anthony Gow.)*

jor island groups while leading a cargo ship. It too reached the Pole in 1987, becoming the second surface vessel ever to do so. During the summer of 1990, the *Rossiya*, built in 1985, accomplished the first commercial cruise to the North Pole, with 88 tourists from 12 countries aboard. In 1991, the 2-year-old *Sovietskiy Soyuz* repeated the commercial cruise with 80 more tourists from 15 countries on board. The very next year, this same ship became the first to reach the Pole twice in one summer, as this type of commercial venturing grew in popularity. The *Yamal*, built in 1992, had reached the Pole six times by August of 1994.* A sixth ship, the *Ural*, was scheduled to be commissioned in 1995 but was delayed due to economic conditions. All six ships list their home port as Murmansk.

These ships are uniquely equipped for escort duty through ice conditions that thwart any other icebreaker. The *Arktika*-class icebreaker has three 5.7-m-diameter screws that can power the ship at 22 kn through open water. Special ice navigation features include a low-friction hull coating, water- and air-jetting systems, and heeling tanks. The outer hull is 4.8 cm thick where it meets ice and 2.5 cm elsewhere. At its strongest point, the steel prow is 50 cm thick. The ship can break ice in both forward and reverse directions. Its dimensions are 150 m loa, 30 m beam, 11.1 m draft, and 23,460 t displacement. It is a multipurpose icebreaker with some cargo capacity and four deck cranes, two of which have a 16-t lift capacity. It does require a large crew of 145, and articles have appeared recently mentioning its high cost to maintain and operate.

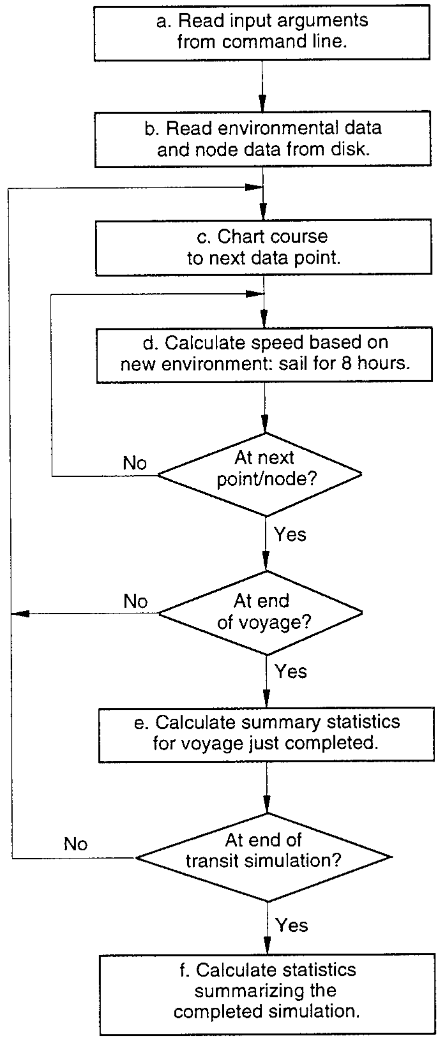


Figure 10. Simplified flowchart of entire model.

Logic summary

The flowchart shown in Figure 10 summarizes the logic used in the model. The program first reads the user-supplied command line arguments that inputs the parameters of ship class, transit direction, month of transit, level of detail desired in the printed output, and number of voyages the simulated transit is based on (step a). Next, the data files containing the required probability density functions are loaded into the program's working arrays (step b). The program then initializes the ship's position at the origin and selects the first leg of the voyage (step c). Using the MC method, the environmental conditions are established for determining the ship's speed for the next 8 hours or until the next data node is reached (step d). Based on ship speed and sailing time, the ship's position is updated along the transit path and checked to determine whether the next data point has been reached. At the end of that time or distance segment, the voyage statistics are updated. If the voyage is complete, the summary statistics are compiled (step e) and either another voyage is begun (back to step c) or the final statistics are compiled for that transit simulation (step f).

* Capt. L.W. Brigham of the U.S. Coast Guard commanded the first U.S. surface ship, the *Polar Sea*, and accompanied the first Canadian ship, the *Louis St.-Laurent*, in reaching the North Pole on 22 August 1994. By chance, the *Yamal* had arrived there two days earlier, and the three ships held an impromptu rendezvous on the 23rd, approximately 20 nm from the Pole. An unprecedented social engagement ensued during which the crews exchanged tours of their respective ships (Brigham 1995).

Table 5 Summary of environmental variables. Shaded blocks indicate variables used in NSRSIM01.

		Apr	Jun	Aug	Oct
Sea Ice	Concentration				
	Thickness				
	Pressure				
	Salinity	2	2	2	2
	Strength	2	2	2	2
Ridges	Distribution	1	1	1	1
	Spacing	1	1	1	1
Fog					
Icing		1	1		
Snowstorms			1, 4	1, 4	
Currents	Permanent Ocean				
	Wind induced				
Waves	Height				
	Frequency	1	1	1	1
Winds					
Temperature		2	2	2	2
Tides	Diurnal	4	4	4	4
	Storm surge	2, 4	2, 4	2, 4	2, 4
Darkness			3		

Notes: 1. Insufficient data.
2. Impact accounted for by other factors.
3. 24 hours of daylight assumed for June.
4. Not a significant factor at most data points.

Input variables: Meteorological

Table 5 shows the environmental parameters that were considered when we designed NSRSIM01. Shaded cells indicate those variables that are currently used, and the notes explain why others were not used.

Three major meteorological phenomena that can impede commercial navigation are addressed in the model. These are wind (both speed and direction), vessel topside icing (due to the combined influences of cold air and water temperatures, direction and speed of the wind, direction and speed of the ship, and state of the sea), and horizontal visibility (as affected by fog, rain, snowstorm, and duration of daylight).

Wind

The available wind regime information was not adequate to make a statistical description of the wind speed and direction. We therefore used a geostrophic wind model (Gill 1982) to simulate the wind regime over the Arctic Ocean with a space resolution of about 50 km. Simulations of wind were initialized and started from rest on 1 January 1946, and run for 43 years until 31 December 1988, using daily surface atmospheric pressure data from the National Center for Atmospheric Research (NCAR 1990). The results of the calculations were used for statistically estimating the probability of wind direction and wind speed at each point on our grid. We compared these simulated wind statistics with observed data at meteorological stations located along the Northern Sea Route, and found reasonable agreement between observed and simulated data.

The model reads the tables of wind speed and direction observations from WINDS**.DAT files (Tables B.10 and B.11) using subroutine GETDAT.

Icing

Strong winds, cold air, and water contribute to accumulations of topside ice on vessels. Icing along the Northern Sea Route is not a serious problem for large cargo ships, but along some routes (e.g., Murmansk to Igarka) icing can be very dangerous, especially at the end of autumn, when air temperatures are below zero and there is no ice cover on the sea surface. In the Arctic seas, icing of vessels may occur throughout the year from either atmospheric (rime icing, freezing rain, and the like) or marine sources (freezing sea spray). From December through June, only atmospheric icing is possible due to the sea-ice cover. From July through October marine icing accounts for 50% of all cases of icing, mixed icing for 45%, and atmospheric icing for 5%.

Duration of an icing event is 12 hours in 74% of cases, and the maximum duration is 7 days. In September, slow icing occurs 20–40% of the time in the coastal areas, and 50–70% of the time in the central parts of the Arctic seas. Slow icing, for a 300- to 500-t displacement ship, is defined by RSMOT (in prep.) as less than 1.5 t/hr mass rate of accumulation or less than 1 cm/hr thickness rate of accumulation. The occurrence of fast icing, defined as a 1.5 to 4 t/hr (or 1–3 cm) rate of accumulation, ranges from 1–5% of time in the southern parts to up to 10% of time in the northern regions of the Arctic seas. These values increase by about 10% in October. In the Barents Sea, the frequency of marine icing varies from the beginning of January to mid-March, and the maximum frequency of occurrence of 78% is observed in February. Atmospheric icing is possible in the Arctic seas throughout the year because negative air temperatures are possible at any time. Atmospheric icing has been observed 30–50 times per year in the Kara Sea and 80–90 times in the Laptev, East Siberian, and Chukchi Seas (RSMOT, in prep.). To avoid icing, ships must reduce their speed, change course, or seek shelter, thus increasing the time of transit.

The probability values for icing used in the model were obtained from RSMOT (in prep.). The icing data are read from ICEFOG**.DAT files (Table B.4) using subroutine GETDAT.

Snowstorms

Lack of visibility is cause for slowing a vessel when operating in ice concentrations of 30% and greater (Gordienko et al. 1967, Gordienko 1977, Himich 1977). Diminished horizontal visibility is very important, especially in the autumn–winter period when limited visibility due to fog and snowstorms is combined with darkness. In conditions of limited visibility, ships can lose a channel or become icebound in the channel, interrupting convoy motion. Work by icebreakers to free icebound ships and to reorganize the convoy adds to the total transit time and decreases the efficiency of commercial navigation.

We regarded the occurrence of snowstorms along the route as one of three visibility factors to affect the speed of ship transit. Fog, another meteorological factor, and darkness were considered similarly. Since probability of occurrence data were available for snowstorms and fog, and a simple algorithm could simulate the occurrence of darkness, these three slowing factors were integrated into the model. Snowstorms occur only rarely in summer, so for modeling purposes we assumed that they would not occur in the months of June and August.

The snowstorm probability for April and October was digitized from maps presented in Proshutinsky et al. (1994) that were derived from the data of Mozalevskaia and Chukanin (1977), The Soviet Arctic (1970), Polkhova (1980), and Sergeeva (1983). In the model, snowstorm probability is read from ICEFOG**.DAT files (Table C.4) using subroutine GETDAT.

Fog

The frequency data for the occurrence of fog is from Proshutinsky et al. (1994). These data were digitized from maps appearing in The Soviet Arctic (1970) and Brower et al. (1988). The probability of fog occurring at each point is read from ICEFOG**.DAT files (Table B.4) using subroutine GETDAT.

Input variables: Oceanographic

Waves

We assumed that wind-induced waves would have an effect on navigation and that the larger the wave, the greater its influence. While storm waves can be dangerous for a small ship, they also make navigation difficult for large ships. Waves in the Arctic seas are principally affected by wind and ice conditions. Higher winds create larger waves, while greater sea-ice concentration reduces wave magnitude.* Maximum wave heights are generally observed in autumn.

We constructed probabilities of wind wave height based on available information on wind speed probability and maximum waves in April, June, August, and October (The Soviet Arctic 1970, Wind and Waves in Oceans and Seas 1974, Proshutinsky et al. 1994). In retrospect, we now realize that wave heights were used incorrectly in the model. Our wave heights were derived directly from the wind speed data in the following way. At every point of interest, we assumed that a 1–5 m/s wind produces waves of 0–1 m in height, winds of 5–10 m/s generate wave heights of 1–2 m, winds of 10–15 m/s generate wave heights of 2–3 m, winds of 15–20 m/s produce wave heights of 3–5 m, and winds of 20–25 m/s lead to wave heights of 5–7 m. As such, these data were not independent PDFs, but they are treated in the model as if they were. We should have simply assigned the appropriate wave height after selecting the wind speed instead of randomly selecting the wave height. This mistake resulted from a miscommunication between the study participants and has been corrected in case the model is used in the future. As will be made clearer in the *Sensitivity Analyses* section, the resulting error in wave height has a negligible effect on the total time and cost conclusions arrived at in this study.

In the model, wave-height PDFs are read from WAVE**.DAT files (Table B.9) using subroutine GETDAT. Waves are evaluated at each data point and every 8 hours according to the MC algorithm using subroutine WAVES.

* More specifically, wave height is a function of wind speed, duration of the wind, fetch (the distance along open water over which the wind blows), and sea depth.

Currents

Currents are a second oceanographic feature that we assumed have an effect on speed of transit. Summary currents in the Arctic seas are composed of tidal, permanent, and wind-induced currents. In simulating NSR passage, we did not take into account tidal currents, which are semidiurnal and primarily reversing in nature. We assumed instead that their cumulative influence on transit navigation is essentially zero.

The summary current algorithm employed in the model thus considers only permanent and wind-induced currents. Permanent ocean currents are related to general circulation of the Arctic Ocean and the general thermohaline structure of the region under consideration. In general, these currents remain quite constant with regard to both speed and direction throughout the year. Due to our assumption that the permanent currents are invariant, the MC algorithm is not needed to select values. The permanent currents for each data node were obtained from Treshnikov (1985), Proshutinsky (1993), Proshutinsky et al. (1994), and RSMOT (in prep.). These data, shown in Table B.8, are read into the model from the PCURRNT.DAT file by subroutine ADDCCUR.

Wind-induced currents, near the sea surface, are generally in the direction of the wind and equal to 2.5–3.0% of the wind's speed (Zubov 1945). Using this algorithm, the model calculates a wind-induced current based on the wind speed and direction probabilities obtained from the WINDS**.DAT files discussed earlier. Wind-induced current is calculated in subroutine ADDWCUR by multiplying wind speed by a factor of 0.025. The wind speed values used are those derived using subroutine WINDS as described above. The magnitude of the wind-induced current is assumed to be independent of ice conditions. Under ice-free conditions, the wind is assumed to induce a current that moves parallel to the wind direction in the mixed surface layer of the open ocean. For ice-covered seas, the wind is assumed to push the pack in the direction the wind is blowing.

Input variables: Ice conditions

Sea ice greatly affects navigation in the Arctic Ocean, but its presence is highly variable in terms of both space and time. Certain regions and key straits have a very high probability for the presence of difficult ice during the summer season, requiring icebreaker escort. These heavy ice accumulations, sometimes covering hundreds of square kilometers and found in roughly the same locations each summer, are known as ice massifs. Apart from these regional accumulations, the interannual extent of the ice cover is markedly variable. In summer, much of the coastal route may be entirely ice free, although the straits still are more likely to have ice. Other summers have resulted in very little melting such that ships needed nearly continuous escort. Ice concentration, thickness, and ice pressure are the major direct factors influencing ship speed. These three characteristics of the ice cover were included in the database used to simulate transit navigation.

Ice concentration

We used ice concentration data for August and April taken from Romanov (1993). For June and October, we digitized this information from the *Sea Ice Climatic Atlas* of USNOCD (1986a, b) and from *Arctic and Antarctic Sea Ice, 1978–1987* (Gloersen et al. 1992). In the Chukchi Sea region, the ice concentration data were corrected using information from *Alaska Marine Ice Atlas* (LaBelle et al. 1983) and USNOCD (1986a, b). We input the probabilities of ice concentration for April, June, August, and October to the model from CONC**.DAT files (Table B.2) using subroutine GETDAT. Concentration PDFs contain five categories: ice free, 10–30%, 40–60%, 70–80%, and 90–100%. For simplicity, these concentration ranges are converted to discrete concentrations by NSRSIM01: 0%, 20%, 50%, 75%, and 100%. Ice concentration is updated at each data node from the MAIN program, and a new concentration is selected at 8-hr intervals using the MC algorithm via subroutine ICECON.

Ice thickness

We obtained ice thicknesses for April and August from Romanov (1993). We computed our ice thickness data for October using the equation of Zubov (1944):

$$I^2 + 50I - 8R = 0 \quad (1)$$

where I = ice thickness (cm)
R = cumulative freezing degree-days (°C).

The air temperature information required for calculating cumulative freezing degree-days was taken from Proshutinsky et al. (1994).

We interpolated or extrapolated ice thickness for June using April and August observations from coastal and island stations.

Probabilities of ice thickness for April, June, August, and October are read from ICTHCK**.DAT files (Table C.6) using subroutine GETDAT. These PDFs contain five categories: ice free, <120 cm, 120–180 cm, 180–240 cm, and >240 cm. For simplicity, these ranges are converted to discrete thicknesses by NSRSIM01: 0 cm, 60 cm, 150 cm, 210 cm, and 240 cm. Ice thickness PDFs are updated at each data point from the MAIN program, and a new thickness is selected at 8-hr intervals using the MC algorithm via subroutine ICETHICK.

Ice pressure

Ice pressure, or ice compression, is one of the most important factors that can slow ship speed or even stop an icebreaker (Buzuev 1977, Voevodin 1981a, b). We simulated ice compression and its probability along the NSR on the basis of atmospheric pressure for the period from 1946 to 1988. We assumed the divergence of the drift velocity of ice to be proportional to divergence of the wind after Doronin and Kheisin (1977). That is

$$P_i = A_p[\text{div}\,(V_i)] \quad (2)$$

where P_i is ice pressure, div is operator of divergence, V_i is ice velocity, and A_p is a coefficient of ice compression where

$$A_p = 0 \text{ if div } (V_i) < 0$$
$$A_p = 10^7 \text{ if div } (V_i) > 0\,.$$

On the other hand, the ice divergence is inversely related to the divergence of atmospheric pressure:

$$\text{div}\,(V_i) = -K\frac{d}{dt}\left(\frac{d^2P}{dx^2} + \frac{d^2P}{dy^2}\right) \quad (3)$$

where d/dt is a time derivative, d^2/dx^2 and d^2/dy^2 are second-order space derivatives, and P is atmospheric pressure. In general, the coefficient K depends on the compactness of the ice and divergence. In a region of low atmospheric pressure, an increase in compactness (i.e., convergence of ice) takes place, and in a region of high atmospheric pressure, thinning occurs.

For simulation purposes, we categorized ice pressure into four levels of severity: no ice pressure (when div $(V_i) < 0$) and low, medium, and high ice pressure. We thus assigned probabilities of occurrence for each category at each data node on the basis of atmospheric pressure data from NCAR (1990).

The model reads the probability of encountering different levels of ice pack pressure from the ICEPRE**.DAT files (Table B.5) using subroutine GETDAT. Ice pressure falls into one of four categories: none, low, medium, and high. Ice pressure is updated at each data point from the MAIN program at 8-hr intervals using the MC algorithm.

Input variables: Costs

In this section we discuss the rationale used to formulate the cost factors used in the model. The model allows the input of shipping costs in three separate categories: 1) cargo ship operating and ownership costs, 2) Russian icebreaker fees, and 3) miscellaneous passage fees. The cargo ship costs and icebreaker escort fees are both applied as daily rates in the model. In the case of ship costs, the model calculates the total number of hours required for transit, divides that number by 24, and multiplies by the daily rate. Icebreaker fees are applied only as complete days of service. That is, an odd number of escort hours is rounded up to the next whole day. The miscellaneous passage fees, on the other hand, are applied as a fixed cost regardless of how long the transit takes. Each cost component is further described below.

The vessel rates and the fixed passage fee are read from file COST.DAT (Table B.3) using subroutine GETSHIPDAT.

Cargo ship operating and ownership costs

Actual NSR ship ownership and operating costs could not be determined for application in this study. Instead, we adjusted Corps of Engineers estimates for average ship costs (USACE 1995) to reflect higher costs for owning and operating the ice-strengthened cargo ships now available for Arctic service. These estimates are based on empirical long-term trends of the following cost factors for conventional cargo vessels of various service types and cargo capacities:

- Ownership costs, considered as fixed annual amounts at 1995 price levels:
  - Replacement costs (new vessels amortized in 20 years at 7.5%/yr interest)
  - Crew wages, benefits, and subsistence
  - Stores and supplies
  - Maintenance and repair
  - Insurance
  - Other costs
  - Administration
- Variable costs
  - Fuel at sea
  - Fuel in port

The Corps estimates for these factors are consensus values for new cargo ships that operate in ice-free waters. U.S. flag ships are distinguished from foreign-flag ships. Ships are classified as non-double-hull tankers, double-hull tankers, bulk carriers, container ships, and general cargo vessels. Other representative ship characteristics presented with each set of the above factors include: deadweight tonnage, container capacity, length, beam, loaded draft, horsepower, and fuel consumption rates of main and auxiliary power plants at sea and in port.

Current regulations (ANSR 1991) require that ships using the NSR have ice-strengthed hulls and other features so as to be classified by the Russian Registry* as L1, UL, or ULA. We selected three vessel classes from the *Inventory of Icebreaking Ships for Navigation on the Northern Sea Route* (L. Tunik 1994) to represent the more modern of the Russian fleet now in service for dry bulk, liquid bulk, container, and general cargo deliveries via the NSR.

We chose categories from the Corps estimates to match the length, power, and cargo service of each of the three NSR vessel classes. We adjusted the USACE ownership and operating costs to account for the different design and the different service of NSR ships, as tabulated below. The age of the existing fleet of container ships and dry bulk carriers was taken into account by assuming a reduced capital book value by the double-declining balance method of depreciation. This book value was then recovered by the same assumptions of the USACE (1995) estimates for the remaining life of the ships. This discount appears to be in keeping with recent quotes for NSR ship charters and with the overall economic climate in Russia and associated incentives for competitive ship charter rates in these early years of international trade via the NSR. We estimated costs for a new class of NSR tankers with characteristics equivalent to the *Uikku*, a 16,500-dwt double-hulled tanker formerly of the *Lunni* class, which was refitted in 1993 with azimuth drives and other new mechanical equipment.

Tables 6 through 8 show how ownership and operating costs were calculated for each ship type. The vessels presently available will inevitably be replaced with new ships. Designers will presumably apply the full benefit of modern commercial ship design and ship building methods to these

* See Appendix F for ice classification equivalencies.

Table 6. Estimated ownership and operating costs for an NSR container ship or general cargo ship.

From USACE (1995) 20,000 *dwt (1,200 TEU)foreign container ship*		*Estimate for NSR simulations* Noril'sk *(ULA class) NSR multipurpose ship*		
Length	180 m		173.5 m	
Beam	26 m		24 m	
Draft	9.5 m		10.5 m	
Horsepower	19,000 shp		21,000	
Speed	17 kn		17 kn	
Replacement cost		$31,422,000	× 1.2 =	$37,700,000
Double-declining balance book value, year 12 of 20:				10,648,000
Annual capital recovery		3,141,053		1,510,400*
Total fixed annual operating cost		2,290,502		2,712,000
(including insurance)		421,463	× 2.0 =	843,000
Total annual fixed cost		5,431,556		4,222,400
Total daily fixed cost		15,519		12,064
Daily fuel cost at sea		3,508	× 1.25 =	4,385
Daily fuel cost in port		515	× 1.25 =	644
Total daily cost at sea		19,027		16,449
Total hourly cost at sea (24 hr)		793		685

*Allows salvage value 5% of replacement cost, 7.75% interest for 8 years.

Table 7. Estimated ownership and operating costs for an NSR tanker.

From USACE (1995) 20,000 *dwt foreign double-hull tanker*		*Estimate for NSR simulations* *New* Uikku*-class (16,500 dwt) NSR tanker*		
Length	158 m		164.5 m	
Beam	23 m		22.3 m	
Draft	9.0 m		9.5 m	
Horsepower	10,000 shp		15,500	
Speed	14 kn		15 kn	
Replacement cost:		$20,954,000	× 1.2 =	$25,145,000
Annual capital recovery		2,094,701		2,513,500
Total fixed annual operating cost:		2,144,669		2,366,900
(including insurance)		222,215	× 2.0 =	444,430
Total annual fixed cost:		4,239,370		4,880,400
Total daily fixed cost:		12,112		13,944
Daily fuel cost at sea:		2,264	× 1.25 =	2,830
Daily fuel cost in port:		309	× 1.25 =	386
Total daily cost at sea		14,376		16,774
Total hourly cost at sea (24 hrs)		599		690

Table 8. Estimated ownership and operating costs for an NSR dry bulk ship.

	From USACE (1995) *25,000 dwt (34,000 m^3) foreign bulk carrier*		*Estimate for NSR simulations* M. Strekalovsky *(UL class) NSR bulk carrier*
Length	169 m		162 m
Beam	24 m		23 m
Draft	9.9 m		9.9 m
Horsepower	11,000 shp		11,200
Speed	14 kn		15 kn
Replacement cost	$17,512,000	× 1.2 =	$21,014,400
Double-declining balance book value, year 13 of 20:			5,341,600
Annual capital recovery cost	1,750,567		817,120*
Total fixed annual operating cost	1,449,565		1,658,272
(including insurance)	208,707	× 2.0 =	417,414
Total annual fixed cost	3,200,131		2,475,392
Total daily fixed cost	9,143		7,073
Daily fuel cost at sea	2,504	× 1.25 =	3,130
Daily fuel cost in port	412	× 1.25 =	515
Total daily cost at sea	11,647		10,202
Total hourly cost at sea (24 hr)	485		425

* Allows salvage value 5% of replacement cost, 7.75% interest for 7 years.

replacements. The new vessels will almost certainly be more mechanically efficient and have larger cargo capacity. These enhancements will be necessary for the NSR to have a lasting competitive advantage over other routes between the ocean basins.

To summarize, the cargo ship rates we used in our final time and cost simulations are as follows:

Noril'sk-class	$16,450/day
Lunni-class	$16,775/day
Strekalovsky-class	$10,200/day

Icebreaker escort fees

MSC or FESCO, depending on the direction of travel, provides icebreaker escort on the NSR for a fee. Russian escort is officially mandated for perennially difficult sections of the route, and the transitory nature of the Arctic ice makes escort highly probable in other locations.

There have been relatively few NSR voyages to date involving foreign vessels. Financial information from those voyages is very difficult to obtain, since it is not covered in much detail in the open literature.

Wergeland (1993) conducted a cost analysis based on information supplied by MSC. He listed typical costs for a *Noril'sk*-class vessel during the summer season. Line items included the icebreaker fee, pilotage, helmsman, maps, and guidebooks, which amounted to $97,240. The icebreaker fee alone was $92,910. He also stated that the expected transit time was 12 to 14 days. Using his mean voyage duration, we can calculate a daily icebreaker rate of $7,150 (= $92,910/13 days).

Davies (1994) reported on a trial shipment of timber from Finland to Japan. A company spokesperson quoted the figure of $100,000 as an estimated passage fee for a *Noril'sk*-class vessel during the summer season.

We based our icebreaker fees on recent Russian information provided by Ramsland.* Taking his figures from a preliminary schedule of fees issued by the Russian Ministry of Transport, he quoted a current icebreaker escort fee of $4.59/t for summer transits and $5.97/t for winter transits by UL-class ships. The winter season was defined as 1 November through 30 June. For ULA-class ships, the escort fees were reportedly $3.72 and $4.39 per ton for summer and winter transits, respectively. In a telephone communication with Director Mikhailichenko of the ANSR,† we were provided similar icebreaker fees. He stated that the fees for

* T. Ramsland, Foundation for Research in Economics and Business Administration, Bergen-Sandviken, Norway, personal communication, 1995.

† V. Mikhailichenko, Administration of the Northern Sea Route, personal communication, 1995.

escorting a UL-class ship were \$4.54/t in summer and \$5.45/t in winter and that the summertime fee for a ULA-class ship was \$3.79/t. He did not specify upon which type of tonnage the fee was calculated.

Ramsland also stated that his source did not indicate whether these rates were for deadweight tons, gross registered tons, net registered tons, or displacement tonnage. However, the hypothetical example discussed by Wergeland bases the icebreaker fee on displacement tonnage. We followed this same convention in our assumptions.

If we apply Ramsland's rates to displacement tonnage in the fashion of Wergeland, we arrive at the following total icebreaker fees:

August and October transits

1 (*Noril'sk*)	= 31,200* t × \$3.72/t	= \$116,000	
2 (*Lunni*)	= 26,100† t × \$4.59/t	= \$120,000	(26,100 t × 3.72/t = \$97,100)††
3 (*Strekalovsky*)	= 27,300** t × \$4.59/t	= \$125,000	

April and June transits

1	= 31,200 t × \$4.39/t	= \$137,000	
2	= 26,100 t × \$5.97/t	= \$156,000	(26,100 t × 4.39/t = \$115,000)††
3	= 27,300 t × \$5.97/t	= \$163,000	

* Maximum displacement as listed in L. Tunik (1994).
† Calculated from *Uikku* specifications provided by Neste Shipping Co., Espoo, Finland (Fig. 7)
** Loaded displacement as listed in Murmansk Shipping Company literature (Fig. 8)
†† The icebreaker fee if the ULA-class rate is used, as instructed by Ramsland (see 2nd footnote, p. 15).

The above fees are fixed rates per voyage. Since we have little information about the average duration of voyages outside the summer season, we have chosen to apply these icebreaker rates in the model as fixed miscellaneous fees.

Mikhailichenko related that a dedicated breaker can be chartered at the daily rate of \$50,000. The class of icebreaker was not specified, but Wergeland (1991) listed the various icebreaker types and their respective rates, which we show as Table 9. We assumed, however, that this scenario would be more costly for transit voyages than the flat fees proposed above and therefore chose not to simulate it.

Miscellaneous passage fees

These costs are handled as fixed transit costs in our model, regardless of the time required for passage. Miscellaneous components of the total NSR passage cost reported by Wergeland (1991) included fees for pilotage, an ice helmsman, maps, guide books, and so forth. These amounted to \$4,330. His "pilot fee" includes guidance by reconnaissance aircraft, hydrographic and meteorological forecasting services, and the use of communication systems. He also lists many other miscellaneous fees that could add substantially to the total cost of passage. Such additional fees may include, for example, bunker filling, water delivery, special required vessel guidance in or near ports along the way, emergency services, local taxes, and tariffs.

In response to our request to INSROP for passage fees, Ramsland*** provided us with a copy of the Administration's schedule of port fees and service charges (RSMOT 1994). Our translation of this document is included as Appendix G. He stated that these scheduled fees were a fraction of what is currently being levied in actual practice in the port cities of Murmansk, Archangel'sk, and Kandalaksha. In other words, the fee schedule does not reflect the rapidly evolving market conditions, and fees can fluctuate substantially and with short notice.

Our simulations did not account for intermediate stops in Russian ports and therefore we assumed these fees and service charges would not apply. Without a basis for knowing what miscellaneous charges would apply, and assuming that they would be a relatively minor component of total cost, we chose to disregard all such additional fees at this time. We did, however, as stated above, choose to apply icebreaker rates as a fixed fee in our final time and cost simulations.

Table 9. Daily rates for icebreaker assistance to foreign vessels when not under flat-fee contract for escort. (From Wergeland 1991).

Icebreaker class	*Rate (\$US/day)*
Arktika	55,000
Vaygach	50,000
Yermak	40,000
Kapitan Sorokin	30,000
Moskva	15,000

*** T. Ramsland, Coordinator of INSROP's Sub-Programme on Trade and Commercial Shipping Aspects of the NSR, personal communication, 1995.

Detailed simulation logic

Following the stepwise logic used in the model, this section descibes how the simulated ship's base speed is first established and then adjusted for the current environmental conditions. Figure 11 shows a generalized flowchart of steps completed at the start of each segment of the simulation procedure. We define a simulation segment as any portion of a transit for which all variables remain constant. Variables are re-evaluated according to steps in the shaded box every 8 transit hours, which is the longest period of time spanned by a single segment. Segments may be shorter if, for instance, the simulation clock indicates that the sun rises or sets within an 8-hr period, or if the ship reaches a data point or decision node before a full 8-hr segment is completed. The objective of the logic outlined in Figure 11 is twofold: a) to establish the steaming speed that the cargo vessel will maintain during the entire transit segment that is about to begin, and, once speed has been established, b) to keep track of ship position and distance traveled so that simulation variables (heading, ice, wind, fog, currents, etc.) can be updated when the next data or decision node is reached.

Ship speed is considered as a function of four groups of variables: a) ice conditions, b) sea state, c) fog, snowstorms, icing, and darkness as they affect visibility and maneuvering ability, and d) ocean currents. Ice conditions determine the initial speed, which subsequently is adjusted downward if warranted by environmental factors such as wind, waves, and conditions that degrade visibility and maneuverability.

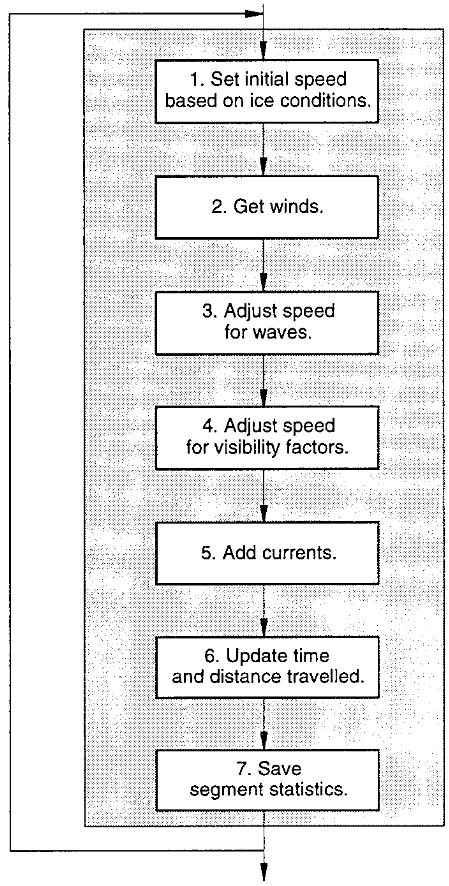


Figure 11. Simplified flowchart of steps performed during each simulation segment.

Set initial speed for ice conditions (step 1)

We established an initial speed for the cargo vessel by evaluating sea ice conditions. Ice conditions not only determine the maximum forward speed that the vessel can maintain, but also whether escort by an *Arktika*-class icebreaker is needed. The initial speed of the cargo ship is established by selecting values for sea-ice concentration and thickness using the MC algorithm. Table 10 gives initial speed as a function of ice

Table 10. Base ship speed initialized as a function of sea-ice thickness and concentration. Shaded cells indicate conditions that trigger icebreaker escort.

		Ice thickness (cm)				
		Ice free	<120	120–180	180–240	>240
Ice concentration (%)	Ice free	Full speed*				
	<30	Full speed*	8	8	7	6
	30–60		8	8	7	6
	60–80		6	10	10	10
	80–100		8	6	6	4

*Full speed values: a) *Noril'sk* (containerized cargo): 17.0 kn; b) *Lunni* (liquid bulk cargo): 14.5 kn; *Strekalovsky* (dry bulk cargo): 15.2 kn.

Table 11. Maneuvering factors applied to initial base speed to compensate for deviations from a straight-line track between data points. Shaded block marks conditions that trigger icebreaker escort.

<table>
<tr><td colspan="2"></td><td colspan="5">Ice thickness (cm)</td></tr>
<tr><td colspan="2"></td><td>Ice free</td><td><120</td><td>120–180</td><td>180–240</td><td>>240</td></tr>
<tr><td rowspan="5">Ice concentration (%)</td><td>Ice free</td><td colspan="5">100</td></tr>
<tr><td><30</td><td rowspan="4"></td><td colspan="4" rowspan="2">0.97</td></tr>
<tr><td>30–60</td></tr>
<tr><td>60–80</td><td></td><td colspan="3" rowspan="2">0.95</td></tr>
<tr><td>80–100</td><td></td></tr>
</table>

thickness and concentration, derived from Buzuyev and Gordienko (1976) and Brigham.* Icebreaker support is deemed to be necessary whenever ice concentration exceeds 80%, or when ice concentration is between 60% and 80% and ice thickness is 120 cm or greater. We established these conditions based on our interpretation of Arikaynen and Chubakov (1987) and Brigham.*

After ship speed is initialized, it is adjusted by two factors. The first compensates for lengthening of the transit track due to maneuvering for easier passage through leads and thin ice and to avoid massive ridges and hummocks. Instead of increasing the distance traveled, we address the issue by reducing the ship's speed according to the values in Table 11.

A second factor compensates for the occurrence of ice pressure. Ice pressure, which is characterized in relative terms as none, low, medium, and high, is selected using the MC algorithm, but only if the ice concentration is in the highest category (80–100%). If the pack is exerting pressure, then speed is slowed by applying the factor appropriate to the level of pressure that is present (Table 12). Ship speed is multiplied by this factor regardless of the slowing factor imposed subsequently by snowstorms, topside icing, fog, and darkness. In the case of high pressure, the ship and escort are considered to be dead in the water, and the only motion applied to ship speed is that due to wind-induced and permanent currents. Under such circumstances, negative speeds will result if the action of currents is counter to forward motion of the ship. In this case, the ship locked in the ice is drifting backward with the ice pack along the transit track in response to the summary ocean current.

Table 12. Slowing factors applied to base ship speed to account for ice pressure.

Relative ice pressure	*Slowing factor*
None	1.00
Low	0.75
Medium	0.50
High	0.00

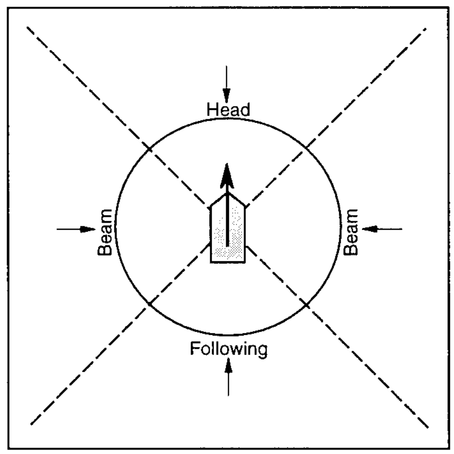


Figure 12. Relationship between wind direction, ship direction, and seas.

Adjust speed for wind and waves (steps 2 and 3)

We use wave height, selected using the MC algorithm, in conjunction with ice concentration to determine whether conditions exist that require the forward speed of the ship to be adjusted downward. Table 13 shows how we adjust the speed for wind direction and wave height depending on the ice concentration. This scheme was formulated on the basis of input from Brigham.* If ice concentra-

* L.W. Brigham, former commanding officer of the U.S. Coast Guard icebreaker *Polar Sea*, personal communication, 1995.

Table 13. Ship speeds under different ice, wave, and wind conditions.

Ice concentration	*Wave height*	*Wind direction vs. ship heading* — *Head sea*	*Beam sea*	*Following sea*
Ice free (full sea)	<3 m	(full speed) – 1 kn	full speed	full speed
	3 to 5 m	(full speed) – 2 kn	full speed	(full speed) + 1 kn
	>5 m	(full speed) – 6 kn	(full speed) – 3 kn	(full speed) – 3 kn
0–30% (partial sea)	<1 m		8 kn	
	1 to 2 m		7 kn	
	2 to 3 m		6 kn	
	3 to 5 m		5 kn	
	5 to 7 m		4 kn	
	>7 m		3 kn	
>30% (no sea)	0 m		full speed	

tion is 30% or greater, insufficient fetch is present for a slowing sea to develop, and the base speed established in step 1 is maintained. If ice concentration is less than 30%, slowing may be necessary. Wind direction is then used to determine whether head seas, following seas, or beam seas are present (Fig. 12), and the ship speed is slowed according to values given in the table. Larger waves in the presence of a partial ice cover (<30%) is cause for greater slowing than waves in open water, due to the increased risk of damage from collision with ice.

Adjust speed for visibility and maneuverability factors (step 4)

Ship speed may be slowed by four environmental variables that lead to degraded visibility or maneuverability: fog, topside icing, snowstorms, and darkness. Fog, icing, and snow are selected by applying the MC algorithm to PDFs that describe the likelihood that each condition will occur. Darkness is set by the simulation clock and depends on approximations of day length for the months in which the transits occurs. We assumed night to be 16 hours long in October, and four hours long in April and August. June has 24 hours of daylight. These factors only come into play if the cargo vessel is not under icebreaker escort. In addition, only the factor that has the greatest impact on speed is actually applied to slow the rate of progress. The extent to which the ship speed is slowed by visibility and maneuverability factors such as these is not well documented in the literature. As a result, the magnitude of our reduction factors is subjective. Values of some factors were adjusted upward during earlier test runs because the extent of slowing seemed too great. Discussions with Brigham lead us to believe that our current reduction values are not unrealistic.

Fog. If fog is determined to be present and the cargo vessel is not under icebreaker escort, then a slowing factor between 0.5 and 1.0 is chosen at random. Ship speed is multiplied by this factor only if it is determined to have a greater effect on speed than factors attributed to superstructure icing, snowstorms, and darkness. If fog is determined not to be present or if the cargo ship is under escort, then no slowing is imposed; i.e., the slowing factor is set to 1.0.

Superstructure icing. If topside icing is determined to be in progress and the cargo vessel is not under icebreaker escort, then a slowing factor between 0.85 and 1.0 is chosen at random to account for decreased maneuverability and visibility. Ship speed is multiplied by this factor only if it is determined to have a greater effect on speed than factors attributed to fog, snowstorms, and darkness. If icing is determined not to be in progress, or if the cargo ship is under escort, then the slowing factor is set to 1.0.

Snowstorms. Decreased visibility is considered to be the primary effect of falling snow, and ship speed may be decreased if the cargo vessel is not under icebreaker escort. If a snowstorm is raging and the cargo vessel is not under icebreaker escort, then a slowing factor between 0.5 and 1.0 is chosen at random. Ship speed is multiplied by this factor only if it is determined to have a greater effect on speed than factors attributed to superstructure icing, fog, and darkness. If snow is determined not to be falling or if the cargo ship is under escort, then the slowing factor is set to 1.0.

Darkness. The simulation clock keeps track of the time of day, and for those segments traversed in darkness, a randomly selected reduction factor between 0.5 and 1.0 is applied to the ship's speed. This speed reduction factor only applies if the ship is not under escort, and it is the largest of all those affecting visibility. If it isn't dark, then the slowing factor is set to 1.0.

Adjust speed for ocean currents (step 5)

Two types of currents contribute to ship speed: a) currents induced by wind in either the marine surface layer or, in the case of ice-covered seas, the pack ice cover itself, and b) permanent marine currents that arise from local- and basin-scale patterns of ocean circulation. Currents, in effect, represent a bias that is present in the medium through which the ship moves. That is to say that underlying currents move the water and ice through which the ship sails regardless of ice characteristics and visibility conditions. Effects of currents are superimposed on and largely independent of all other factors that influence speed. The contribution they make to ship speed therefore is added at the end of the algorithm after all other speed-related factors are accounted for.

Wind-induced currents. Wind-induced current is calculated in subroutine ADDWCUR by multiplying wind speed by a factor of 0.025. Winds used are those selected in Step 2 using the MC algorithm in subroutine WINDS. The magnitude of the wind-induced current is assumed to be independent of ice conditions. Under ice-free conditions, winds induce a current that moves parallel to the wind direction in the surface mixed layer of the open ocean. For ice-covered seas, the wind is assumed to push the pack in the direction the wind is blowing. Ship speed is adjusted for wind-induced current by calculating the component of the wind vector that acts in the direction of ship motion and adding it to the ship speed (or subtracting it in cases of head winds).

Permanent currents. Permanent ocean currents are assumed to remain constant with regard to both speed and direction throughout the year. Fixed values assigned to each data and node point are read from the PCRRNT.DAT file (Table B.8) in subroutine ADDCCUR. Ship speed is adjusted for permanent current by calculating the component of the current vector that acts in the direction of ship motion and adding it to the ship speed. This vector is recalculated at each data node and each time the ship direction changes.

Update time and distance traveled (step 6)

Once ship speed has been established for the segment at hand, the length of the segment in time and distance can be calculated. Segment length is determined by two parameters in addition to ship speed: a) time in decimal hours remaining until the next sunrise (during darkness) or sunset (during daylight), and b) distance in nautical miles from the ship's position at the beginning of the segment to the next data or decision node.

The algorithm first checks to see if the time remaining to the next sunrise or sunset is less than 8 hours. If it is, then the time-length of the segment is set to the time remaining to the next sunrise/sunset; otherwise time length is set to 8 hours. Next the distance traveled is calculated by multiplying ship speed by the segment time that has just been established. This distance is compared with the distance from the ship position at the start of the segment to the next data point or decision node. If distance falls short of the next point, then the calculated time and distance are accepted. If the ship overshoots the point or node (that is, if the calculated distance traveled is greater than the distance to the next point), then the distance is reset to the distance to the next node, time is adjusted downward, and calculations for the segment are complete.

Save segment statistics (step 7)

With all parameters set, they are saved to a data structure such that summary statistics can be calculated at the end of each voyage and when the entire transit simulation is complete. If detailed output of segment parameters is requested, values assigned to virtually all variables are written to the print file at this point in the algorithm. Finally, a check is made to determine whether the transit end point has been reached. If not, the logic checks to see if a data node has been reached, and control in the loop ultimately transfers back to step 1 and the procedure repeats.

Running the model

The program is invoked by entering the name of the executable program file (NSR) followed by a series of command line arguments at the DOS prompt. Individual command line arguments are separated by spaces and include variables that specify the month in which simulated transits are to occur, the type of ship making the voyage, the direction in which the Northern Sea Route will be traversed, the level of detail desired in the output file, the number of transits to be made in the current run, and a flag that indicates whether some variables will be set manually to test sensitivity of the model to specific conditions. The general form of the command line is as follows:

NSR
- [month of transit:
  - 4 = April,
  - 6 = June,
  - 8 = August, or
  - 10 = October]
- [ship class:
  - 1 = *Noril'sk* (container cargo),
  - 2 = *Lunni* (liquid bulk cargo), or
  - 3 = *Strekalovsky* (dry bulk cargo)]
- [transit direction:
  - 1 = west to east (Murmansk to Bering Sea), or
  - 2 = east to west (Bering Sea to Murmansk)]
- [print option:
  - 0 = short (summary statistics for entire run only),
  - 1 = medium (statistics for each transit and summary for entire run), or
  - 2 = long (log of values assigned by the model each time a variable changes, plus all summary statistics for output options 0 and 1)]
- [number of transits to make in current run (500 or fewer)]
- [sensitivity mode:
  - 0 = off (let the model determine values assigned to all variables), or
  - 1 = on (manual control of values assigned to some or all variables)].

For example, to run the model for April, using a *Noril'sk*-class ship transiting from Murmansk to the Bering Sea, printing only summary statistics for 200 voyages, in which the model determines values assigned to all variables, enter

```
NSR 4 1 2 0 200 0
```

To run the model for October, using a *Strekalovsky* dry bulk carrier, transiting from the Bering Sea to Murmansk, providing detailed output for five voyages, enter

```
NSR 10 3 2 2 5 0
```

Note that the command line arguments are delimited by spaces, not commas.

Input files structure

NSRSIM01 makes decisions based on information read from files that give probabilities that different sets of conditions will occur or that a particular route will be followed. Appendix B describes these input files and the associated data formats required to run NSRSIM01. The files must be located in the same directory as the executable file (NSR.EXE). For most variables, data for different months are stored in separate files. Exceptions are data that describe permanent ocean currents and cost data. The currents data are assumed to remain constant year round and the cost data file must be altered by the user to reflect the changing seasonal fees. File names are constructed to reflect the type of data in the file and, when applicable, the month to which it corresponds:

{datatype}	{month}.DAT
CONC	04
COST	06
ICEFOG	08
ICEPRE	10
ICTHCK	
NDESEW	
NDESWE	
PCRRNT	
WAVE	
WINDS	

For example, the file named ICEPRE06.DAT contains ice pressure information for June, WAVE10.DAT contains wave height information for October, and PCRRNT.DAT lists permanent current information for all months.

When the model is invoked, only files that contain data for the month and transit direction specified in command line arguments are opened. If the model is run to simulate east-to-west transits in April, only the cost file (COST.DAT), permanent current file (PCRRNT.DAT), east-to-west nodes file (NDESEW04.DAT) and files with root names that end in 04 (CONC04.DAT, ICEFOG04.DAT, etc.) need be present in the directory for the program to run properly. Information that describes the probability that different environmental conditions will occur at a given node or data point are read from these files. The order in which data are listed for a specific point is critical, inasmuch as NSRSIM01 identifies a given data point by its position within the file, rather than any identification information included in the data record. If the order of data points is changed, the program may appear to run properly but the results will not be accurate since probabilities will be assigned incorrectly to the wrong data node.

Output files and print options

Each time the model is run, simulation results are written to an ASCII print file named NSRSIM1.PRN. If the file already exists, previous results are overwritten; if it does not exist, it is created. To preserve results from a run, NSRSIM1.PRN must either be printed or renamed before another simulation is run. NSRSIM01 allows for three levels of detail in output written to the print file. At the most general level (print option = 0), the program prints only statistics that describe the entire transit simulation. At the intermediate level (print option = 1), the program prints additional statistics that summarize parameters used to make each individual voyage. At the most detailed level (print option = 2), the program prints, in addition to summary statistics provided by options 0 and 1, a step-by-step log of each voyage and lists values assigned to each variable every time any parameter changes value. Appendix C contains examples of the three available print options.

Print option 0 (Simulation summary). The output consists of a series of eight tables. The first table summarizes minimum and maximum values observed over all transits for

a) transit time, speed, distance, and cost,

b) time with icebreaker escort,

c) time with environmental variables that caused reduced speed (fog, icing, snowstorm, darkness, waves) and the range of speed reduction factors attributed to each variable,

d) the range of permanent and wind-induced currents, and

e) hours and distance over which open, ice-free ocean was encountered.

Mean values as well as variance and standard deviation for these parameters are also provided. The remaining seven tables give statistics that summarize the time and distance over which different environmental phenomena were in effect over different legs of the transit network. Tables are provided for fog, icing, snowstorm, darkness, sea ice, icebreaker escort, and the number of times each leg was traversed during the current simulation.

Print option 1 (Voyage summary). Printed output for option 1 includes that provided under option 0 plus three tables for every voyage that summarize environmental variables in effect and the estimated cost of the voyage in U.S. dollars. The first table gives summary statistics (minimum, maximum, mean, variance, and standard and average deviations) for values assigned to permanent and wind-induced currents, waves, winds, environmental factors that slow ship speed (fog, icing, snowstorm, and darkness), and ship speed. The second table tabulates the length of time and the total distance over which different conditions (fog, icing, waves, snowstorm, darkness, ice concentration, and ice thickness) were encountered during the current transit. The third table presents the cost of the transit in terms of time and money.

Print option 2 (Listing of variables). Printed output for option 2 includes the tables provided under options 0 and 1 plus a table that gives a running log of the values assigned to each variable for the entire simulation. A new entry is made in the table each time any of the simulation variables changes value, and a separate table is constructed for each voyage.

Sensitivity analysis mode

During a typical run, the model assigns values to each variable according to MC methods and other techniques embodied in the simulation code. Under some circumstances it becomes advantageous to examine the extent to which transit duration and cost depend on a particular variable or series of variables. Sensitivity analysis, as this approach is sometimes called, can be applied by setting the sensitivity variable in the command line to 1. When the model is run in sensitivity mode, the program prompts the user with regard to how values are assigned to each variable. Fixed values that are held constant throughout the run can be entered from the keyboard for some variables at the same time that others are selected randomly. To run the second example above in sensitivity mode, change the last digit from 0 to 1, as shown:

```
NSR 10 3 2 2 5 1
```

This will produce output for an October transit of a *Strekalovsky*-class dry bulk carrier traveling east to west and will provide detailed output for a five-voyage simulation. The short output saves only the summary statistics for the run. The medium output choice saves the statistics for each repetition and the final summary statistics. Long output is available to show each trip segment's variables and values, the statistics for each repetition, and the final summary statistics. The long output is useful for debugging and for very detailed analysis of a voyage. It is generally used for just a few repetitions. Otherwise, the amount of output can be unmanageable.

RESULTS OF SIMULATIONS

Sensitivity analyses

Model repeatability

We tested the model's repeatability by running the same set of user inputs several times. For this test, we assumed a *Noril'sk*-class ship having a daily cost of $23,000 and a daily escort rate of $7,500. A flat miscellaneous fee was not applied. The summaries of two separate runs, each simulating 500 voyages in April, are presented in Table 14. We then switched to simulations of 100 voyages in each of the four months, with the same user inputs. For each month, we repeated the runs five times, and the results of the April and August transits are also presented in Table 14.

The output shows relatively small deviations in all cases for all months. The standard deviations, in general, are only 1–2% of the means for all categories of interest, except for hours of icebreaker escort required in August, for which it was 3.4%. This analysis establishes an objective measure of the model's inherent scatter due to nothing more than the chance variation from using probabilistic data.

Number of voyages

The model is capable of simulating any number of voyages between zero and 500. We conducted a series of runs to determine what effect, if any, the number of voyages had on the categories of interest. To be economical with our time, we wanted to simulate as few voyages with each set of input parameters as possible as long as there was no appreciable degradation of results. As previously mentioned, a simulation of 500 voyages required approximately 2 min to complete when generating the short output format. A 100-voyage simulation took only 21 s.

We used the same set of parameters as for the repeatability study (see *Model repeatability*), and progressively lowered the number of voy-

Table 14. Sensitivity study of model repeatability.

No. of voyages	*Time (hr)*	*Speed (kn)*	*IB escort (hr)*	*Total cost (US$)*	*Cost/hr (US$)*	*Cost/mi (US$)*
500	566	5.6	520	720,456	1272	230
500 (repeat)	562	5.6	517	715,153	1272	229
April transits						
100	563	5.5	514	715,400	1271	230
100	564	5.6	516	716,695	1271	229
100	567	5.6	522	720,410	1270	229
100	566	5.5	522	720,170	1273	231
100	563	5.6	517	717,220	1273	230
Mean (100 voyages)	565	5.6	518	717,979	1272	230
Std. dev.	2	0.05	4	2213	1.3	0.8
Std. dev. relative to the mean (%)	0.4	0.9	0.8	0.3	0.1	0.4
August transits						
100	325	9.7	71	349,635	1076	112
100	324	9.7	76	349,760	1079	112
100	324	9.7	77	351,350	1084	112
100	326	9.6	77	352,960	1083	113
100	317	10.0	74	342,105	1077	109
Mean (100 transits)	323	9.7	75	349,162	1080	112
Std. dev.	4	0.15	3	4171	3.6	1.5
Std. dev. relative to the mean (%)	0.4	1.6	3.4	1.2	0.3	1.4

Table 15. Sensitivity study of number of voyages.

No. of voyages and (run time in s)	*Time (hr)*	*Speed (kn)*	*IB escort (hr)*	*Total cost (US$)*	*Time (hr)*	*Speed (kn)*	*IB escort (hr)*	*Total cost (US$)*
	West-to-east transits				**East-to-west transits**			
500 (129)	566	5.6	520	720,456	566	5.6	498	713,338
400 (113)	562	5.6	517	715,401	564	5.7	497	712,069
300 (56)	565	5.6	520	719,785	562	5.7	494	708,238
250 (49)	565	5.6	517	717,270	566	5.7	498	714,362
200 (44)	564	5.6	515	716,892	557	5.7	489	701,133
100 (21)	563	5.6	517	717,220	568	5.6	500	716,035
Mean	564	5.6	581	717,837	564	5.6	496	710,862
Std. dev.	1.5	0	2.0	1907	3.9	0.1	3.9	5443
Std. dev. relative to the mean (%)	0.3	0	0.3	0.3	0.7	0.9	0.8	0.8
500 (repeat)	562	5.6	517	715,153	564	5.6	494	710,236

ages simulated. These results are summarized in Table 15.

The data show that there is no appreciable effect due to the number of voyages simulated. The variation between runs was extremely small as the standard deviations for the categories of interest were all less than 0.4% of the means. The number of transits had even less of an effect on the results than repeatedly running the same set of conditions. In fact, when we repeated the 500-voyage west-to-east case, its results along with the earlier 500-voyage run bracketed all other runs shown in the table. That is, the transit times of 566 and 562 hours are the extremes, and the same is true for mean ship speed, hours of icebreaker escort, and total cost of the transit. The variability in all categories was greater for east-to-west transits, but the standard deviations were still less than 1% of the means.

It is clear from these data that 100-voyage runs allow for the chance variation to be exercised adequately in our model. Therefore, all later time and cost simulations reported for this study are the mean results of 100-voyage runs.

Directionality

Comparing the mean values derived in Table 15, we find little difference between eastward and westward transits. The respective means for time and speed were identical, and the means for total cost differed by only 1%. We found a significant directionality difference (15%) only in the mean number of hours that an icebreaker escort would be required.

A more robust test of directional dependence was conducted, and these results are presented in Table 16. These data include the means and standard deviations that were calculated for each simulation's 100 voyages. We tested identical scenarios in both directions for the months of April and August for all three ship types. We then calculated the percentage difference, D_n, between each pair of values using the formula

$$D_n = [(\text{westward value}/\text{eastward value}) - 1]\,100\,. \qquad (4)$$

For example, D_n of the mean speed of a *Noril'sk*-class vessel in April is

$$[(5.53/5.68) - 1]\,100 = -3\%$$

and D_n of the SD for the mean speed is

$$[(0.29/0.36) - 1]\,100 = -19\%.$$

For many parameters, D_n for the SDs are quite high and, in general, those for the means are very low. This fact shows that the variability between each run's 100 voyages is more directionally sensitive than is the parameter itself. Even though greater variability was apparent, we were mainly interested in the effect of direction on the mean values for our study. The absolute values of D_n for the means were all less than 3%, except for icebreaker escort hours and this was greatest for a *Strekalovsky*-class ship in August, at nearly 20%.

The two parameters of greatest interest to this study were the means for elapsed time and cost. These were less than 2% in all cases. We concluded that with the environmental data we currently have, there is no significant difference in time and

Table 16. Sensitivity study of transit directionality. Means and standard deviations shown for simulations of 100 voyages each.

Cost variables:

Daily ship costs: *Noril'sk* = \$1725; *Lunni* = \$13,500; *Strekalovsky* = \$11,250

Daily escort fee = \$0; Fixed tariff = \$100,000

Ship type	*Mean elapsed time (hr)*	*Std. dev.*	*Mean speed (kn)*	*Std. dev.*	*Mean IB escort (hr)*	*Std. dev.*	*Mean total cost (\$)*	*Std. dev.*	*Mean cost/hr (\$)*	*Std. dev.*	*Mean cost/mi (\$)*	*Std. dev.*
April	**West-to-east**											
Noril'sk	567	40.8	5.53	0.29	516	44.3	516,070	29,856	911.7	16.72	165.1	7.39
Lunni	570	36.2	5.54	0.30	524	39.5	427,375	20,250	750.2	14.54	135.8	6.18
Strekalovsky	566	40.0	5.50	0.26	513	41.9	371,472	19,298	656.7	13.62	119.6	4.87
April	**East-to-west**											
Noril'sk	565	45.6	5.68	0.36	498	43.1	515,380	32,219	913.7	20.16	161.3	8.10
Lunni	568	47.5	5.61	0.35	495	44.0	426,565	27,318	751.8	16.78	134.3	6.50
Strekalovsky	561	45.4	5.67	0.38	495	45.5	368,312	21,296	657.6	16.79	116.4	6.03
	Percentage directional difference:				**[(West/east) – 1) *100]**							
	0	–11.0	–3.0	–19.0	4	3.0	0	–7	–0.0	–17.0	2.0	–9.0
	0	–24.0	–1.0	–14.0	6	–10.0	0	–26	–0.0	–13.0	1.0	–5.0
	1	–12.0	–3.0	–32.0	4	–8	1	–9	–0.0	–19.0	3.0	–19.0
August	**West-to-east**											
Noril'sk	329	26.7	9.59	0.80	75	42.3	345,468	19,897	1052.0	31.65	110.2	6.81
Lunni	345	27.6	9.17	0.67	73	40.0	301,015	16,494	875.1	26.14	95.8	5.12
Strekalovsky	341	26.0	9.24	0.71	78	42.0	265,375	12,437	780.1	26.52	84.7	4.38
August	**East-to-west**											
Noril'sk	327	30.7	9.83	0.90	67	34.4	344,950	22,337	1056.2	37.07	108.0	6.46
Lunni	351	26.9	9.12	0.65	69	39.0	303,850	15,170	867.4	25.74	95.5	4.95
Strekalovsky	341	27.3	9.43	0.78	66	43.4	265,038	12,798	780.2	27.75	83.1	4.58
	Percentage directional difference:											
	1	–13.0	–2.0	–11.0	12	23.0	0	–11	–0.0	–15.0	2.0	5.0
	–2	3.0	1.0	3.0	6	3.0	–1	9	1.0	2.0	0.0	3.0
	0	–5.0	–2.0	–9.0	19	–3.0	0	–3	–0.0	–4.0	2.0	–4.0

cost between eastward and westward transits. We will therefore only present the results for Murmansk-to-Bering Strait transits.

Shipping costs

The model calculates total cost of transit using three factors that can be modified by the user. These are cargo ship rates (CSR) in US\$/day, icebreaker rates (IBR) in US\$/day, and miscellaneous fees (MF) in US\$/voyage. In the case of CSR and IBR, the program logic calculates the total time of transit and the time that icebreaker escort was required and multiplies these by their respective rates. The MF is a fixed amount that is added at the end of the voyage regardless of transit time. The total cost (TC) in US\$ of any single voyage can thus be written as

$$TC = (CSR \times TT) + (IBR \times ET) + MF \qquad (5)$$

where TT = total transit time (days)
ET = escort time (rounded up to the next full day)

Once the average times of transit and escort have been calculated by the model, we can then use eq 2 to obtain quick total cost estimates for various scenarios. These results will not exactly match MC-modeled output, since rerunning the model each time produces an average cost of multiple-voyage transits. However, they are apparently accurate to within about 3% of modeled costs, as we shall demonstrate. To measure the model's sensitivity to each of the cost factors, we performed tests in which each was varied in systematic fashion. The effect that each had on total cost for 500-voyage *Noril'sk*-class runs during the months of April and August (representing the two extremes in total cost) are presented below.

First, CSR was varied while holding IBR and MF constant. IBR was held at zero and MF was held at $137,000 for April and $116,000 for August. These values represented the fixed miscellaneous fees that we used in our final simulations for those months. The total transit time (TT) for April was 566.11 hours, or 23.588 days, and for August it was 326.43 hours, or 13.601 days (see Transit Time, under *Final simulations* below). Equation 5 then becomes:

$$TC = (CSR \times 23.588 \text{ days}) + \$137{,}000$$

for April transits and

$$TC = (CSR \times 13.601 \text{ days}) + \$116{,}000$$

for August transits. The results of varying CSR are presented in Table 17 and Figure 13. The values appearing in column B are those predicted using the simple equation above. Those appearing in column C are modeled results. The least-squares linear fit to the modeled results is well represented by the equation

$$TC = 23.402 \text{ CSR} + \$146{,}448$$

for April transits, as the r^2 statistic is 0.9989. The slope of this line shows that for every $1 change in the vessel's daily rate, there is a resulting change of $23.40 in the total cost. The difference values in column D show that the simple equation slightly underpredicts the numerical model.

For August transits, the linear fit to the numerically modeled results was

$$TC = 14.173 \text{ CSR} + \$113{,}827$$

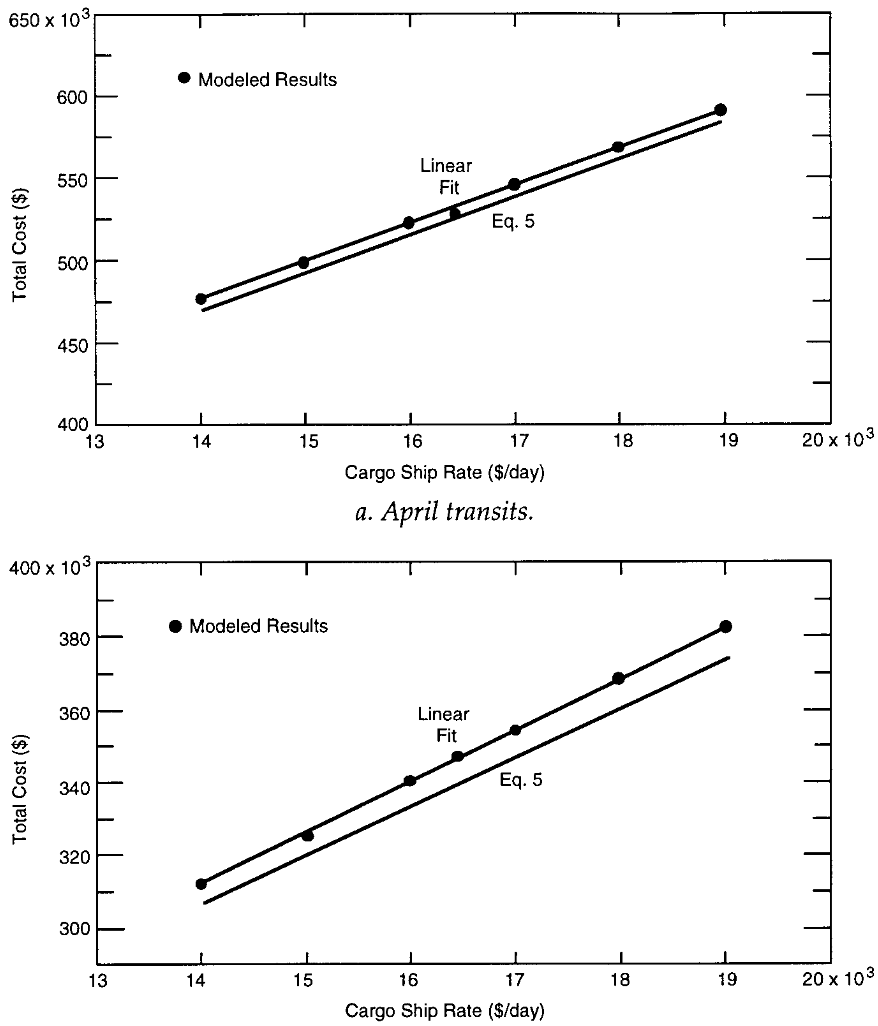
and the corresponding r^2 statistic is also 0.9989. The change in total cost is 14.173 times the change in the cargo ship rate. The difference between the simple prediction equation and the numerical result is only slightly greater but can still be well approximated for any value of CSR once the total transit and icebreaker escort times have been obtained from the numerical model.

IBR was then varied while holding CSR and MF constant. MF was held at zero and CSR was held at $16,450/day. The average amount of time an escort was required for April transits was 518.96 hr, which gets rounded up to 22 days by our model. For August, ET was 77.02 hr, rounded to 4 days.

Table 17. Tabular results from varying cargo ship rates for *Noril'sk* multipurpose cargo ship transits.

	Total cost ($)			
A Ship rate ($/day)	*B* Simple prediction	*C* Model results	*D* Difference* (%)	*Linear fit to model results*
April transits				
14,000	467,231	474,120	–1.47	
15,000	490,818	497,366	–1.33	
16,000	514,407	522,564	–1.59	TC = 23.402 (CSR) + 146,448
16,450	525,021	528,850	–0.73	r^2 = 0.9989
17,000	537,995	544,728	–1.25	(see Fig. 13a)
18,000	561,582	568,388	–.21	
19,000	585,170	590,834	–0.97	
August transits				
14,000	306,418	312,168	–1.88	
15,000	320,019	325,220	–1.63	
16,000	333,620	341,120	–2.25	TC = 14.173 (CSR) + 113,827
16,450	339,741	347,945	–2.41	r^2 = 0.9989
17,000	347,221	355,291	–2.32	(see Fig. 13b)
18,000	360,822	369,116	–2.30	
19,000	374,424	382,228	–2.08	

* The difference between the simple model derived from eq 5 and the numerical model output is calculated by subtracting the model results (col. C) from the predicted results (col. B) and dividing by the predicted value (i.e., [B–C]/B). Multiplying by 100 then gives the percentage difference shown in col. D.



a. April transits.

b. August transits.

Figure 13. The effect of cargo ship rates on total shipping costs.

For this scenario, eq 5 then becomes:

$$TC_{Apr} = (\$16{,}450 \times 23.588 \text{ days}) + (IBR \times 22 \text{ days})$$

and

$$TC_{Aug} = (\$16{,}450 \times 13.601 \text{ days}) + (IBR \times 4 \text{ days}),$$

and the results of varying IBR are presented in Table 18 and Figure 14. The least-squares linear fit to the modeled results for April was

$$TC_{Apr} = 21.810 \text{ IBR} + \$396{,}808$$

with an r^2 statistic of 0.9995. The slope shows that for every $1 change in the icebreaker's daily rate, there is a resulting $21.81 change in the total cost of transit. Again, the difference values in column D show that the simple equation insignificantly underpredicts the numerical model.

For August transits, the linear fit to the numerically modeled results is

$$TC_{Aug} = 3.310 \text{ IBR} + \$233{,}166$$

and the corresponding r^2 statistic is 0.9775. The change in total cost is 3.31 times the change in the icebreaker rate. The difference between the simple prediction equation and the numerical result is similar in magnitude to the April differences.

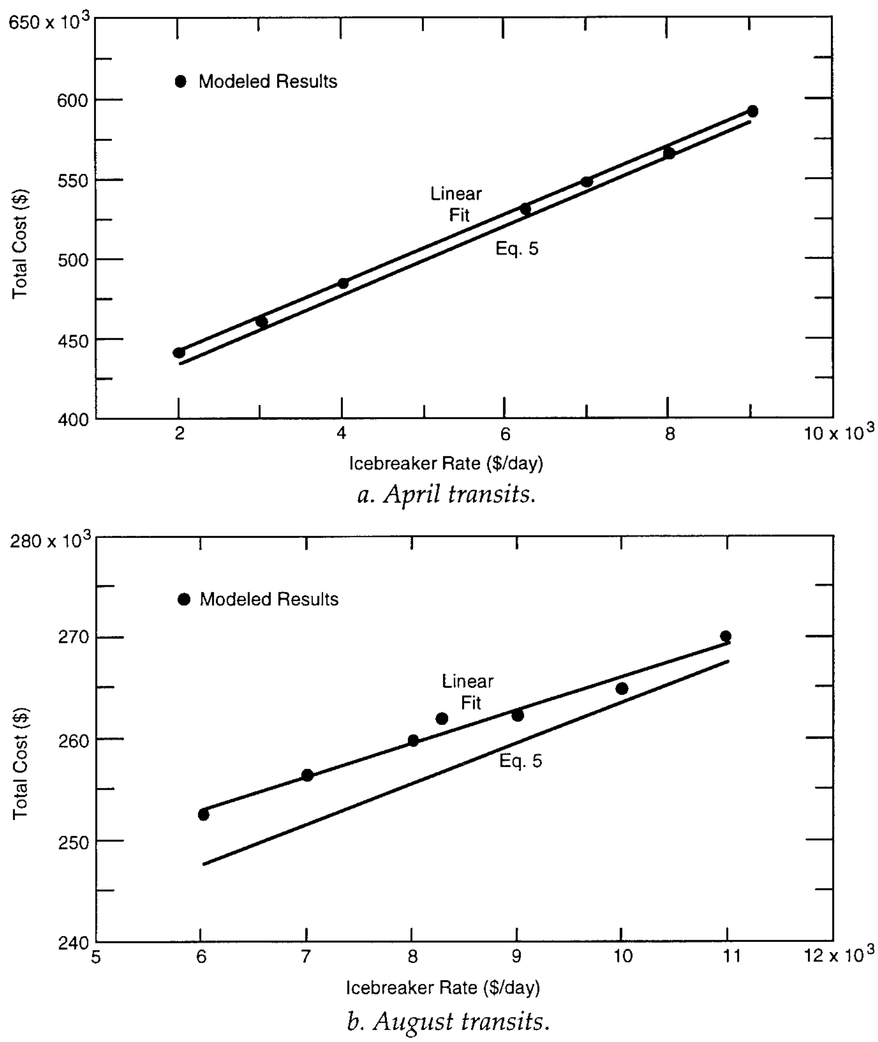
Finally, MF was varied while holding CSR and IBR constant. CSR was held at $16,450/day while IBR was held at zero. For this scenario, eq 5 then becomes

$$TC_{Apr} = (\$16{,}450 \times 23.588 \text{ days}) + MF$$

Table 18. Tabular results from varying icebreaker escort rates for *Noril'sk* multipurpose cargo ship transits.

Icebreaker cost ($/day)	*Total cost ($)* *Simple prediction*	*Model results*	*Difference* (%)*	*Linear fit to model results*
April transits				
2000	432,021	440,414	–1.94	
3000	454,021	461,639	–1.68	
4000	476,021	485,376	–1.97	TC = 21.810 (IBR) + 396,808
6227	525,015	532,124	–1.35	r^2 = 0.9995
7000	542,021	549,813	–1.44	(see Fig. 14a)
8000	564,021	569,077	–0.90	
9000	586,021	594,768	–1.49	
August transits				
6000	247,741	252,472	–1.91	
7000	251,741	256,367	–1.84	
8000	255,741	259,986	–1.66	TC = 3.310 (IBR) + 233,166
8286	256,885	261,980	–1.98	r^2 = 0.9775
9000	259,741	262,533	–1.08	(see Fig. 14b)
10000	263,741	264,985	–0.47	
11000	267,741	270,081	–0.87	

*See Table 17.



a. April transits.

b. August transits.

Figure 14. The effect of icebreaker rates on total shipping costs.

and

$$TC_{Aug} = (\$16,450 \times 13.601 \text{ days}) + MF,$$

and the results of varying MF are presented in Figure 15 and Table 19. The least-squares linear fit to the modeled results was

$$TC_{Apr} = 1.0177 \text{ MF} + \$391,317$$

with an r^2 statistic of 0.9966. The slope shows that for every $1 change in the fixed voyage fee there is a resulting $1.02 change in the total cost of transit. Again, the difference values in column D show that the simple equation insignificantly underpredicts the numerical model.

For August transits, the linear fit to the numerically modeled results is

$$TC_{Aug} = 1.0258 \text{ MF} + \$227,843$$

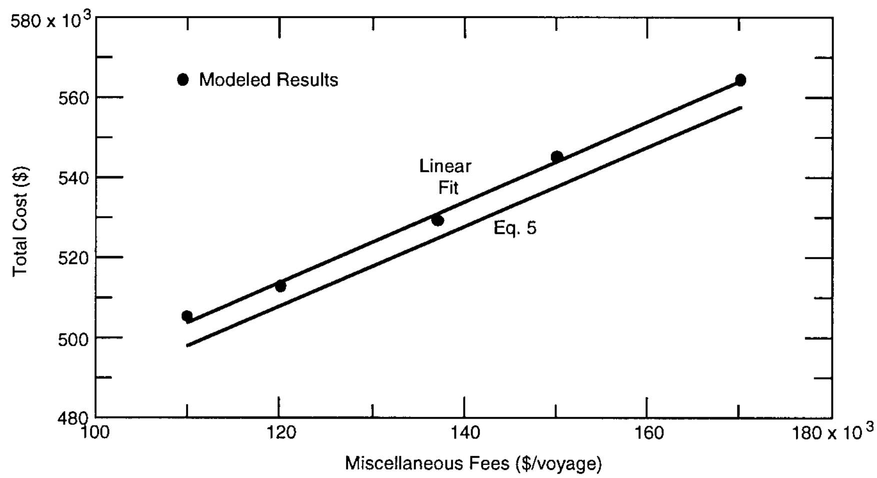
and the corresponding r^2 statistic is 0.9977. The change in total cost is 1.03 times the change in the fixed fee. The differences between the simple equation predictions and the numerical results are slightly but insignificantly greater than those calculated for April.

Final simulations

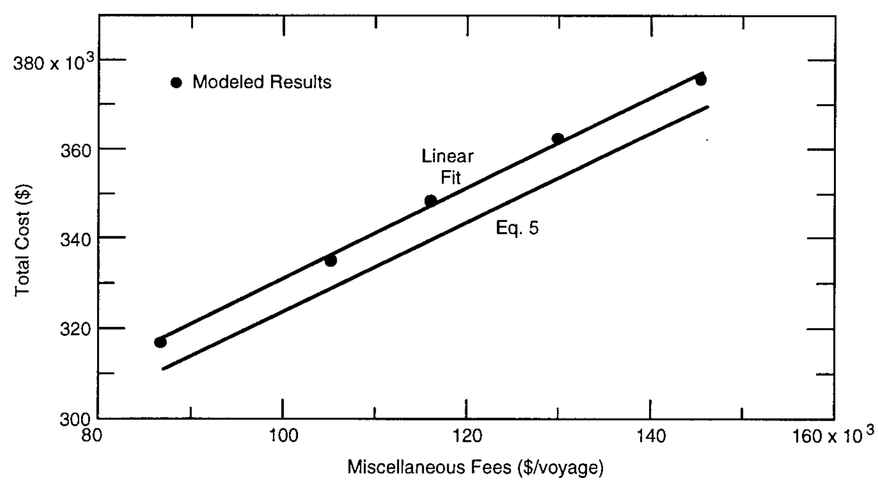
The final simulations were run using the costs scenario discussed above under *The Transit Model.* That is,

Cargo ship costs ($/day):

Noril'sk-class	=	16,450
Lunni-class	=	16,775
Strekalovsky-class	=	10,200



a. April transits.



b. August transits.

Figure 15. The effect of miscellaneous fees on total shipping costs.

Table 19. Tabular results from varying miscellaneous fees for *Noril'sk* multipurpose cargo ship transits.

Misc. fees ($/voyage)	*Total cost ($)* *Simple prediction*	*Model results*	*Difference** *(%)*	*Linear fit to model results*
April transits				
110,000	498,021	504,668	–1.33	
120,000	508,021	512,497	–0.88	TC = 1.0177 (MF) + 391,317
137,000	525,021	528,850	–0.73	$r^2 = 0.9966$
150,000	538,021	545,195	–1.33	(see Fig. 15a)
170,000	558,021	564,503	–1.16	
August transits				
87,000	310,741	316,641	–1.90	
105,000	328,741	334,937	–1.88	TC = 1.0258 (MF) + 227,843
116,000	339,741	347,945	–2.41	$r^2 = 0.9977$
130,000	353,741	362,374	–2.44	(see Fig. 15b)
145,000	368,741	375,332	–1.79	

*See Table 17.

The icebreaker daily rate was set at zero and was instead applied as a fixed miscellaneous fee. That is, the miscellaneous fees ($/voyage) were:

		April & June	August & October
Noril'sk-class	=	137,000	116,000
Lunni-class	=	156,000	120,000
Strekalovsky-class	=	163,000	125,000

One-hundred-voyage simulations were run for all three vessels for each of the four months of interest. Each simulation was repeated five times. These results were averaged and are summarized in Table 20.

Transit time

Transit times for June and October were, as expected, intermediate to those of April and August. On average, the three ships required 567 hours for April transits, while June, October, and August transits required 516, 488, and 338 hours, respectively. There was no significant difference between the transit times of the three vessel types

Table 20. Final results of Monte Carlo time and cost simulations. Mean values and standard deviations are shown for five repetitions each of 100-voyage transits.

	Elapsed time (hr)	*Std. dev.*	*Mean speed (kn)*	*Std. dev.*	*Escort time (hr)*	*Std. dev*	*Total cost ($)*	*Std. dev.*	Lunni *(as ULA)* *Total cost ($)**
April									
Noril'sk	566.11	38.61	5.55	0.30	518.96	38.97	528,850	27,030	
Lunni	565.53	39.58	5.57	0.28	518.02	42.23	559,439	27,897	518,439
Strekalovsky	568.18	38.23	5.54	0.29	519.75	41.23	409,677	16,509	
June									
Noril'sk	511.99	28.83	6.64	0.37	174.47	56.93	495,939	19,797	
Lunni	520.52	27.57	6.53	0.33	170.60	50.88	528,137	19,604	487,137
Strekalovsky	515.04	28.30	6.61	0.35	175.09	50.91	387,012	12,608	
August									
Noril'sk	326.43	30.59	9.69	0.89	77.02	38.71	347,945	21,280	
Lunni	344.54	26.80	9.13	0.68	77.01	40.10	369,642	19,345	346,742
Strekalovsky	341.68	27.39	9.20	0.73	76.35	39.91	275,470	11,905	
October									
Noril'sk	484.23	40.66	6.61	0.52	122.69	42.56	457,009	28,050	
Lunni	492.52	37.93	6.48	0.46	125.64	42.09	473,416	26,737	450,516
Strekalovsky	486.47	36.27	6.55	0.45	125.38	42.09	337,507	15,745	

* Total cost if ULA-class icebreaker fees are used for the *Lunni* vessel, as instructed by Ramsland (see 2nd footnote, p. 15).

in any season. The times ranged only from 566 to 568 hours for the most difficult month (April) to between 326 and 345 hours for the easiest month (August). The data show that time differences during the intermediate months of June and October were similarly insignificant, with less than 9 hours' difference in the mean times between the fastest ship and the slowest.

It seems apparent from the similarity in transit times that our ship in-ice performance inputs need better definition. This fact is further amplified by the similarity in the hours that each ship type required icebreaker escort. As was stated earlier, our model was fine-tuned using historical data of *Noril'sk* transits in August. Although we had no historical data for the other ship types, we believe that the ULA-class multipurpose vessel should have a significantly faster transit time and need less icebreaker support time than the UL-class tanker and dry bulker, due to its greater in-ice capabilities. We also believe that the time difference should be most apparent during the intermediate months of June and October, when ice conditions would most likely border between the ULA capabilities and those of the UL-class ships. During the summer season, most of the route is open water and weak ice so that neither ship type should be seriously impeded. On average, icebreaker support was needed for only four days of the approximately 14-day voyage. During the winter period, both ship types are maximally impeded by thick, concentrated ice under great pressure, and icebreaker escort was needed for about 22 days of the 24-day voyage.

We did not have adequate data to establish a greater distinction between the various ships' speeds for the range of conditions encountered. Since some published data was available, our greatest confidence is in the *Noril'sk* transit times, and we caution that those for the liquid and dry bulk carriers may be optimistic.

Transit cost

As expected, and similar to transit time, the costs for transits in June and October were intermediate to those for the extreme months of April and August. The highest transit costs occurred in April, during which the average for all three ships was about $499,000. August costs averaged approximately $331,000, while June and October's were $470,000 and $423,000, respectively.

Unlike transit time, there *was* a significant difference between ship types regarding the total cost of transit. In all seasons, the *Strekalovsky*-type dry bulk carrier yielded the most economical transits, while the *Lunni*-type liquid bulk carrier was the least economical. Even though the miscellaneous voyage fee was highest for the dry bulk ship, it was offset by its very low daily ship rate relative to the other ship types. Transits by the *Strekalovsky* ranged from about $275,500 in August to $409,700 in April and averaged $352,000 for all seasons. The *Lunni*'s seasonal costs ranged between $370,000 in August and $559,000 in April and averaged $483,000. For the *Noril'sk,* the range was $348,000 to $529,000, and the mean for all seasons was $457,000.

If the *Lunni*-type liquid bulk carrier is assumed to be ULA-class, as instructed by Ramsland* its total voyage costs are reduced, as shown in the last column of Table 20. For each of April and June, total cost fell by $22,900 and became $518,000 and $487,000, respectively. Total costs for August and October each fell by $41,000, becoming $347,000 and $451,000, respectively. These reductions, ranging from 5 to 8%, were significant enough in all seasons to virtually eliminate the cost difference between the *Lunni*- and the *Noril'sk*-type vessels. The LBC's mean total cost for all seasons was $451,000 when considered as a ULA-class vessel.

Based on the above discussion concerning transit time, the costs for dry and liquid bulk shipments over the Northern Sea Route are most likely conservative. Since we believe that our transit times for those ship types are optimistic, slower speeds would translate to longer transit times and, hence, greater cost. Without additional shipping information from those who have conducted such transits, it is impossible for us to speculate further about how costs may vary from these results.

Trials using hypothetically larger cargo ships

After analyzing the above results, the Alaska District (USAED) requested further simulations that would illustrate the effect that cargo ship capacity has on total voyage cost. We were asked to run seasonal simulations for hypothetical vessels having twice the cargo-carrying capacity of today's ships. The ships in current use on the NSR have approximately 25% of the carrying capacity of cargo vessels using the traditional warm-water trade routes. This means that it requires at least four trips along the NSR to deliver the same

* T. Ramsland of Norway's Foundation for Research in Economics and Business Administration states that the *Lumni* should be considered ULA-class.

Table 21. Estimated ownership and operating costs for a hypothetical double-capacity NSR container ship or general cargo ship.

	From USACE (1995) 42,000 *dwt* (2,500 *TEU*) *foreign containership*		*Estimate for NSR simulations* *Hypothetical* 42,000 *dwt* (2,000 *TEU*) *ULA multipurpose ship*	
Length	242 m		242 m	
Beam	33 m		33 m	
Draft	11.9 m		11.9 m	
Horsepower	35,000 shp		38,500 shp	
Speed	19 kn		19 kn	
Replacement cost		$56,093,000	× 1.2 =	$67,312,000
Annual capital cost		5,607,307	× 1.2 =	6,729,000
Total fixed annual operating cost:		3,930,040		4,792,000
(including insurance)		861,899	× 2.0 =	1,724,000
Total annual fixed cost:		9,537,347		11,521,000
Total daily fixed cost:		27,250		32,920
Daily fuel cost at sea:		7,204	× 1.25 =	9,005
Daily fuel cost in port:		721	× 1.25 =	901
Total daily cost at sea		34,454		41,925

amount of cargo that can be delivered in one trip through the Suez Canal, for example. The distance advantage enjoyed by the NSR is thus eliminated if larger ships cannot be used. For these simulations, we assumed that the proposed ships had the same ice classification as those currently in use. Ship speeds under various ice, wind, and visibility conditions were also left unchanged, with the exception of the ships' open-water speeds. As prescribed by USAED, the open-water speed of the multipurpose cargo ship (MPC) was increased by 2 kn over the current *Noril'sk* capability, from 17 to 19 kn. Open-water speeds for the new liquid-bulk (LBC) and dry bulk (DBC) vessels were each set at 15 kn, which was a 0.5-kn increase over the *Lunni*-class and a 0.2-kn decrease relative to the *Strekalovsky*-class. USAED provided us with the projected ownership and operating costs presented in Tables 21 through 23. Using calculated displacement tonnages and the 1995 Russian rate structure, the per-voyage icebreaker fees for the three ship types are as follows:

August and October transits

1 (MPC carrier)	=	69,960 t × $3.72/t	=	$260,250	
2 (LBC carrier)	=	43,510 t × $4.59/t	=	199,710	(43,510 t × $3.72/t = $161,860*)
3 (DBC carrier)	=	48,340 t × $4.59/t	=	221,880	

April and June transits

1	=	69,960 t × $4.39/t	=	$307,120	
2	=	43,510 t × $5.97/t	=	259,750	(43,510 t × $4.39/t = $191,010*)
3	=	48,340 t × $5.97/t	=	288,590	

*The icebreaker fee if the ULA-class rate is used, as instructed by Ramsland (see footnote, p. 43). Applying this rate would result in a $38,750 decrease in total costs for August and October transits and a $68,740 decrease in April and June transit costs.

New simulations produced the time, speed, and cost values shown in Table 24. In general, the resulting elapsed time and mean speed values were essentially unchanged from the previous simulations, with the exception of those for the container ship in August. It can be seen that elapsed time for the MPC carrier decreased by 16.7 hours, and the mean transit speed increased by half a knot. In all other seasons, there is not enough open water along the route to significantly change the container ship's elapsed time and mean speed from earlier trials.

In terms of total cost, the seasonal trends were similar to the earlier simulations. April transits were the most costly, averaging $919,000 for the three ship types. August was the least costly time for transit at $598,000. June and October's means were $863,000 and $775,000, respectively.

Due to the large increase in daily ownership and operating costs for the MPC vessel relative to the other two types, its transits now became the most costly in all seasons, displacing the liquid bulk carrier as the most costly transporter in earlier trials. To double the cargo capacity, daily MPC costs increased 2.55 times, from $16,450 per day to $41,925 per day. This yielded an increase of 2.46 times in total transit costs during the winter months and an

Table 22. Estimated ownership and operating costs for a hypothetical double-capacity NSR tanker.

	From USACE (1995) *40,000 dwt foreign double-hull tanker*			*Estimate for NSR simulations* *Hypothetical 35,000 dwt UL tanker*	
Length	186 m				186 m
Beam	28 m			28 m	
Draft	10.7 m			10.7 m	
Horsepower	13,000 shp			14,300 shp	
Speed	14 kn			15 kn	
Replacement cost:		$29,650,000	× 1.2 =		$35,580,000
Annual capital cost		2,963,916	× 1.2 =		$3,557,900
Total fixed annual operating cost:		2,226,846			2,484,100
(including insurance)		257,283	× 2.0 =		514,566
Total annual fixed cost:		5,190,762			6,042,000
Total daily fixed cost:		14,831			17,263
Daily fuel cost at sea:		2,754	× 1.25 =		3,442
Daily fuel cost in port:		412	× 1.25 =		515
Total daily cost at sea		17,584			20,705

Table 23. Estimated ownership and operating costs for a hypothetical, dbl-capacity NSR dry bulk ship.

	From USACE (1995) *40,000 dwt foreign dry bulk ship*			*Estimate for NSR simulations* *Hypothetical 40,000 dwt UL dry bulk ship*	
Length	194 m			194 m	
Beam	28 m			28 m	
Draft	11.4 m			11.4 m	
Horsepower	13,000 shp			14,300 shp	
Speed	14 kn			15 kn	
Replacement cost:		$23,120,000	× 1.2 =		$27,744,000
Annual capital cost		2,311,218	× 1.2 =		$2,744,300
Total fixed annual operating cost:		1,535,706			1,774,600
(including insurance)		239,060	× 2.0 =		478,000
Total annual fixed cost:		3,846,924			4,548,900
Total daily fixed cost:		10,991			13,000
Daily fuel cost at sea:		2,972	× 1.25 =		3,715
Daily fuel cost in port:		515	× 1.25 =		644
Total daily cost at sea		13,963			16,715

average of 2.39 times during the summer months. The new MPC transit costs averaged $1,114,000 for the entire year.

Liquid bulk became the next most costly cargo to ship via the NSR. Average double-capacity LBC transit costs were $653,000 for the year, up from the *Lunni*'s $483,000. For liquid bulk, we increased the daily ship costs by only a factor of 1.23 (from $16,775 to $20,705), and this produced an increase in total transit cost of 1.36 times over previous *Lunni*-class simulations.

Daily ship costs for dry bulk were increased 1.64 times (from $10,200 to $16,715). Double-capacity DBC transits averaged $598,000 for the year, a 1.7-fold increase in total cost over those generated by the *Strekalovsky*-class ship.

At this juncture, it is important to remind the reader not to be misled by this partial analysis. It should be remembered that only shipping costs incurred between Murmansk and the Bering Strait are considered here. For a true picture of total transit costs, these NSR-related costs should be spread

Table 24. Final Monte-Carlo time and cost estimates for hypothetical double-capacity cargo ships.

	Elapsed time	*Std. dev.*	*Mean speed*	*Std. dev.*	*Escort time*	*Std. dev.*	*Total cost ($)*	*Std. dev.*
April								
Noril'sk	561.15	37.29	5.57	0.30	514.55	40.26	1,307,535	65,969
Lunni	565.80	37.96	5.55	0.30	518.70	41.90	758,162	33,257
Strekalovsky	565.32	40.04	5.55	0.30	517.57	40.06	690,886	28,372
June								
Noril'sk	510.34	29.21	6.67	0.38	175.89	54.01	1,219,659	52,605
Lunni	513.66	28.21	6.61	0.35	180.23	52.29	713,026	25,114
Strekalovsky	516.46	30.73	6.59	0.38	176.42	55.63	656,487	21,956
August								
Noril'sk	309.74	31.59	10.19	1.06	75.71	39.88	822,884	56,361
Lunni	339.88	27.86	9.25	0.76	76.49	40.00	503,372	24,579
Strekalovsky	339.60	26.66	9.27	0.71	71.93	37.62	466,855	19264
October								
Noril'sk	471.28	38.36	6.77	0.52	125.18	43.30	1,106,968	67,430
Lunni	495.11	34.93	6.45	0.41	124.30	41.73	638,325	3,0616
Strekalovsky	499.08	37.68	6.41	0.45	119.78	43.90	578,344	26,284

over the entire voyage from port of origin to port of destination, that is, for example, from Yokohama to Rotterdam. Additional open-water distance offsets the higher costs associated with the NSR portion of the voyage and reduces the overall average transit cost.

Extending these model results to estimate the total origin-to-destination shipping costs was the ultimate purpose of the NSR reconnaissance study and the role of the Alaska District. We invite the reader to review the District's full reconnaissance report (USAED 1995) to see how this modeling effort was incorporated into the overall result. Alternatively, a summary of the reconnaissance study is available as Smith (1995). Here, we shall simply state that these results, when spread over full origin-to-destination transits between northern Europe and the Far East, did promise more economical per-ton transportation rates than can be realized with today's ships.

CONCLUSIONS

As part of an 18-month reconnaissance study, the U.S. Army Corps of Engineers constructed a Monte Carlo-based FORTRAN model to calculate transit time and costs for cargo shipments between Murmansk and the Bering Strait using the Northern Sea Route. The model enabled the Corps to compare the costs of shipping via the NSR with those of alternative routes, which then allowed a prediction of future commodity movements. The computer model was a method for organizing and quantifying the extensive data that were assembled during the reconnaissance study.

Interest in the NSR is currently high and there have, no doubt, been proprietary efforts to model its utility. To our knowledge, however, there was no such software available in the public domain that could be used for Corps reconnaissance purposes. Some recent empirical data on NSR trafficability have been published by the International Northern Sea Route Programme (INSROP) and Russia's NSR Administration in an effort to foster greater international interest. These data have primarily been in terms of average ship speeds for various routes, months of the year, and broad categories of ice conditions. The problem with making projections based on these data is that few foreign ships have made the voyage and complete information on their experiences is not readily obtainable for analysis. To overcome the scarcity of data, we employed a MC method to select the environmental conditions encountered on a voyage and predicted transit time based on expected vessel speeds under those conditions.

Russian researchers have collected weather, ice, and oceanographic data in the Arctic Basin for many decades and they have developed probability-of-occurrence relationships for a multitude of environmental parameters that affect polar navigation. These extensive data, published in atlases, monographs, reference books, and articles were the cornerstone of our model. The large amount and form of the Russian data on the route's environmental conditions allowed us to construct a model that predicts NSR passage based on combinations of their probabilities of occurrence. Each transit scenario can then be programmed to run between 1 and 500 times to allow the statistical distributions in the data to be adequately exercised to produce a single mean value each for transit time and cost.

Our model lets the environmental conditions determine a base ship velocity which we then modify with slowing factors or the need for icebreaker escort. The base velocity is obtained from empirical estimates that are stored in lookup tables. This velocity and the slowing factors can easily be modified for ship types with different capabilities for sea keeping and ice navigation. The strength of our model lies in its ability to predict transit speeds for times of the year when few or no voyages have occurred. Predictions can be made if the modeled ship's speed is reasonably estimated for the range of conditions encountered on the NSR. These speed estimates can be based on NSR experience or on sea trials under similar conditions in other polar regions.

For each voyage, the ice, sea, and atmospheric conditions are used to determine the speed of a vessel between data and decision nodes along the route. Data nodes are mesh points where the navigation conditions are set for the next trip segment. These are generally spaced less than 250 nm apart along the commonly used shipping lanes. Decision nodes are similar to data nodes but with the additional feature of marking where two or more route choices exist; for example, where a choice is made to follow the coastal route or a more northerly variant. For each data node, we assembled probability distributions for ice thickness, concentration, and pressure, wind speed and direction, wave heights, occurrence of fog, snowstorms, and topside icing. The magnitude of each condition, or its mere existence (in the case of fog, snowstorm, and icing) is established by random selection, or a "roll of the die" based on its probability distribution. After a particular set of conditions is set, it is held constant for 8 hours, until sunrise or sunset, or until the next node is reached, whichever occurs first.

Four different months were modeled to cover the easiest (August), intermediate (June and October), and most difficult (April) transit periods. Three different ice-strengthened ship types were modeled: a *Noril'sk*-class multipurpose cargo ship, a *Strekalovsky*-class dry bulk freighter, and a *Lunni*-class tanker. We assumed an *Arktika*-class icebreaker escort in our simulations, but other types could easily be modeled. The user may select travel in either the east or west direction, although the results are not significantly different given our current resolution of environmental data.

The model's cost components are applied as three separate inputs: daily cargo ship rates, the daily icebreaker escort rate, and a fixed fee for miscellaneous passage charges. Any or all of these can be modified by the user. For ship costs, we began with standard Corps of Engineers estimates of daily rates for conventional ships plying the conventional routes and modified these according to standard accounting principles to account for ice strengthening and Arctic operations. That is, we increased construction, insurance, and fuel costs. We then discounted these rates to account for the age of the current fleet of cargo ships, its surplus capacity, and to attract first-time foreign involvement. These charter rates can be easily modified as more NSR shipping information becomes available. We present sensitivity studies on the effect that these various cost appications have on the results. Our final simulations, however, were obtained by adding the current icebreaker rates as a fixed fee to other miscellaneous fees (i.e., setting the escort daily rate to zero).

The user can select from three choices of output formats: 1) a short version that provides only a summary of the mean voyage, 2) a longer version that provides summary data for each voyage and the mean voyage, and 3) the longest version, which supplies these two summaries plus a detailed log showing where each variable changes during every voyage. Generating the shortest output, the program takes approximately 2 min to simulate 500 voyages on an IBM-PC 486-33 with a math coprocessor, and takes only 21 s for 100 voyages.

Mean transit time and cost for the four months and three ship types were obtained by averaging five repetitions each of 100-voyage simulations. We show these 100-voyage simulations are not significantly different from simulating 500 voyages. Results show that nonstop transits from Murmansk to the Bering Strait during August (the easiest period of navigation) averaged approximately 14 days for the three ship classes, with a standard deviation of about 1.2 days. The mean vessel speed was 9.3 knots and for approximately 20% of the time an icebreaker escort was required. The current version assumes an icebreaker to be instantly available when needed. We also have not programmed for in-port time or administrative delays that may occur. The total cost for a transit in

August ranged from around $276,000 for a *Strekalovsky*-type dry cargo vessel to about $370,000 for a *Lunni*-type tanker.

For our simulated April transits, voyages averaged 23.6 days, with a standard deviation of 1.6 days. This is the period when navigation conditions are most difficult, and an icebreaker escort was required approximately 90% of the time. Mean vessel speed for April was only 5.55 kn. The total cost for a transit in April ranged from around $410,000 for the *Strekalovsky*-type vessel to about $559,000 for the *Lunni*-type vessel. This same ascending order of cost was realized for transits in June and October. The milder environmental conditions in October produced shipping costs for the three ship types ranging from $338,000 to $473,000. The corresponding range in June costs were $387,000 to $528,000.

The ships in current use on the NSR have approximately 25% of the carrying capacity of cargo vessels using the traditional warm-water trade routes. This means that 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 Suez Canal, for example. The distance advantage enjoyed by the NSR is thus eliminated if larger ships cannot be used. Additional transit simulations were made of hypothetical ships that have twice the capacity of today's NSR vessels to assess this future possibility. These results, when spread over full origin-to-destination transits between northern Europe and the Far East, did look promising, with more economical per-ton transportation rates than can be realized with today's ships. The reader is advised that further information concerning the model's application to international economics can be found in the full NSR reconnaissance report (USAED 1995).

We believe that our ice, sea, and atmospheric data are adequate to simulate the important environmental conditions that affect navigation. Weaknesses in the current version involve cargo ship charter rates and the speeds that both icebreakers and cargo ships might maintain under various combinations of environmental conditions. Our analysis uses estimates of ownership and operating costs for warm-water vessels of similar dimensions and powerplant size, modified for in-ice operations and depreciated to allow for the current age and surplus availability. Actual shipping costs from NSR officials and shipping operators would be more desirable, but they were not available at this time. We believe that our estimated vessel speeds are reasonable for the conditions expected, but they could obviously be improved with input from experienced NSR captains and ice pilots. Most importantly, our model is easily modified to take advantage of new information when and if it becomes available.

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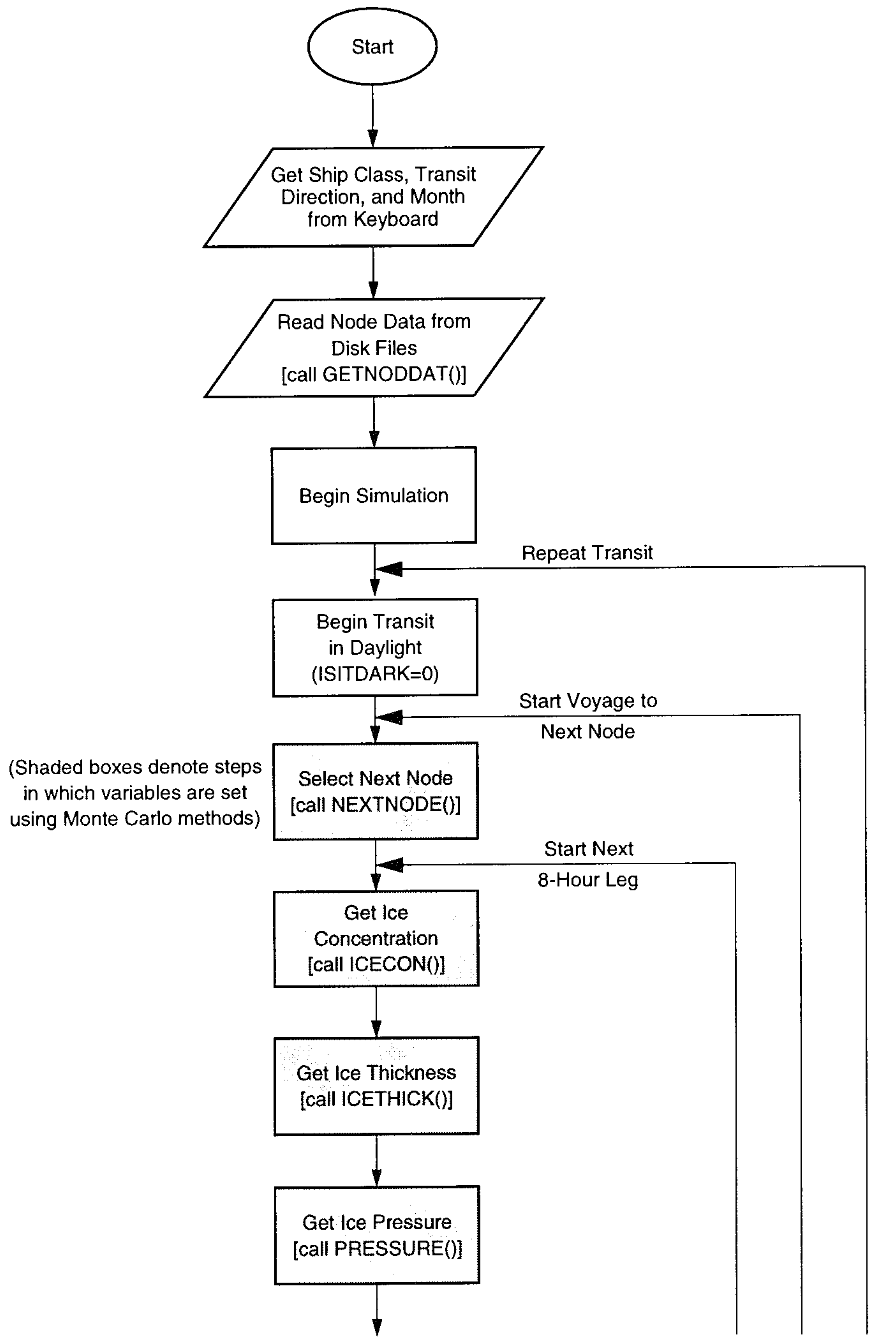
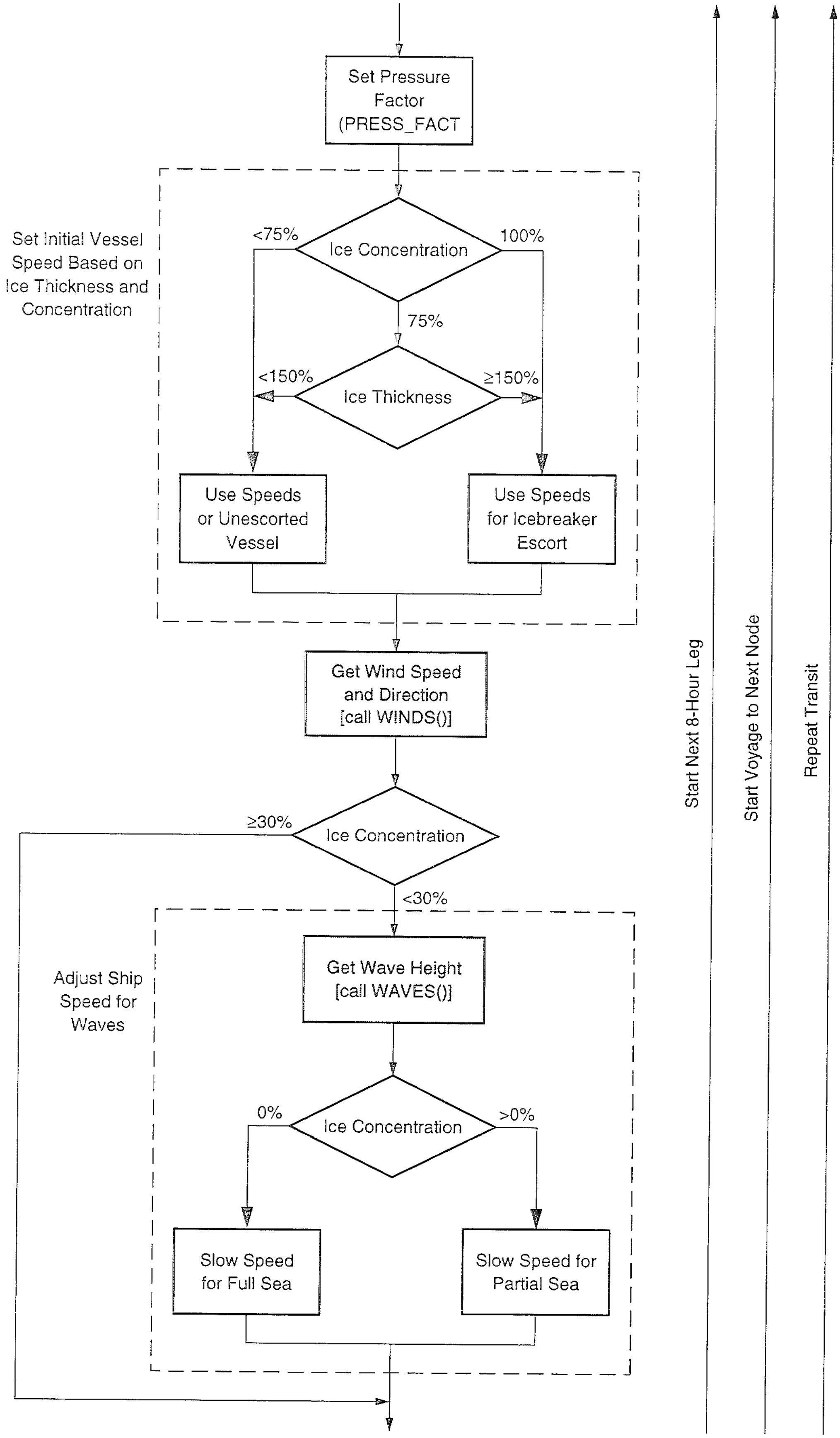
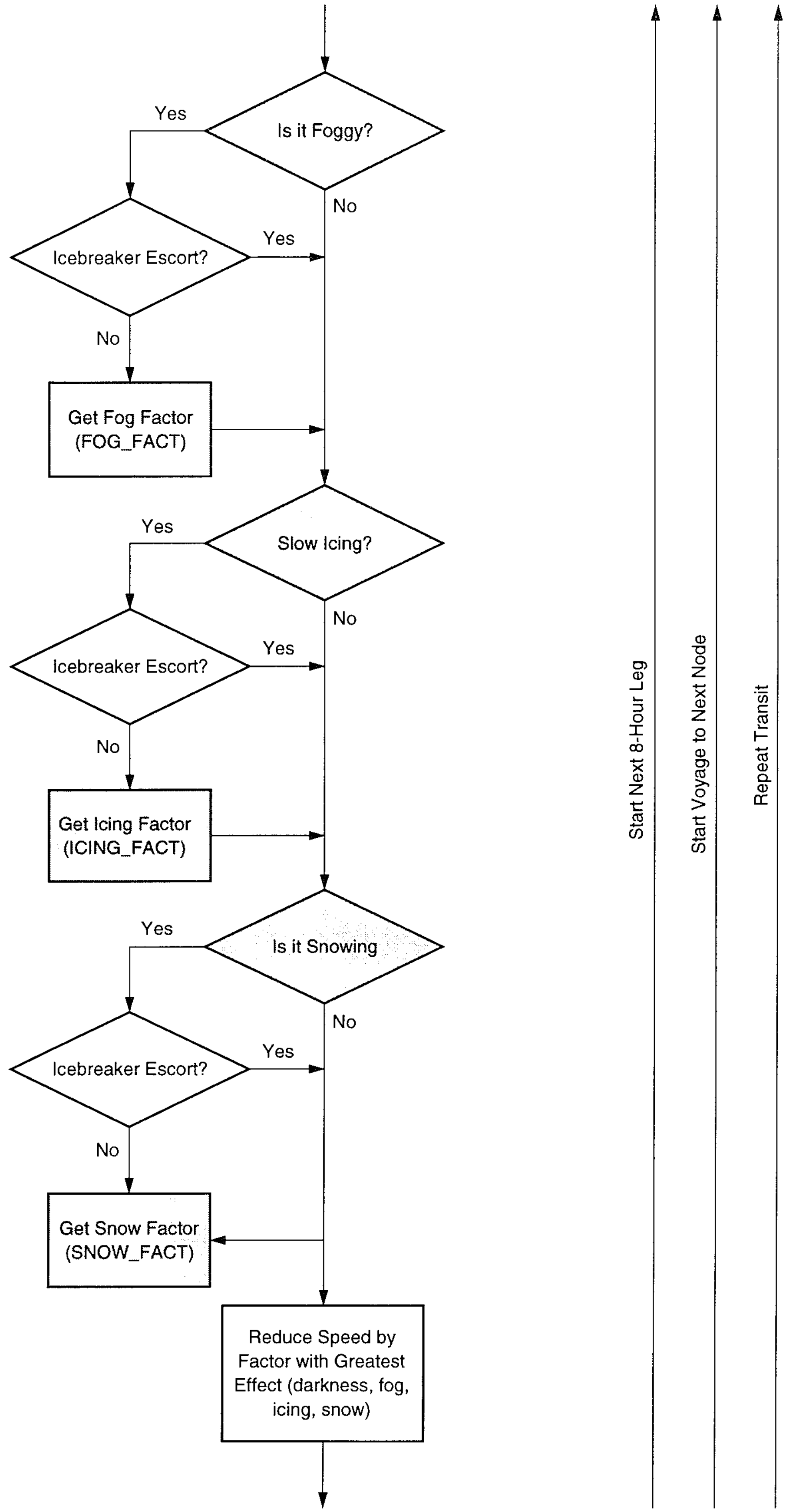
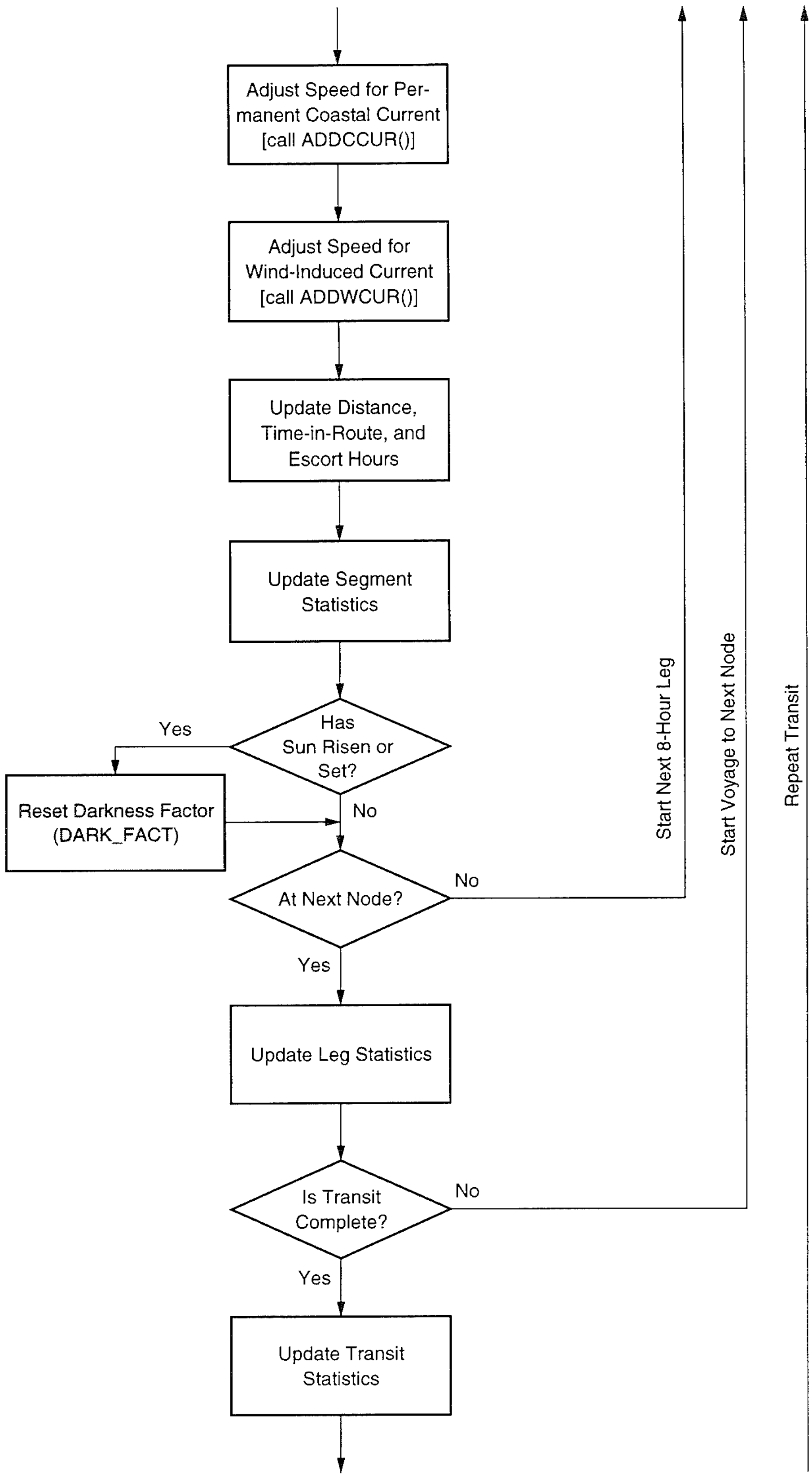
APPENDIX A: DETAILED NSRSIM01.FOR FLOWCHARTS

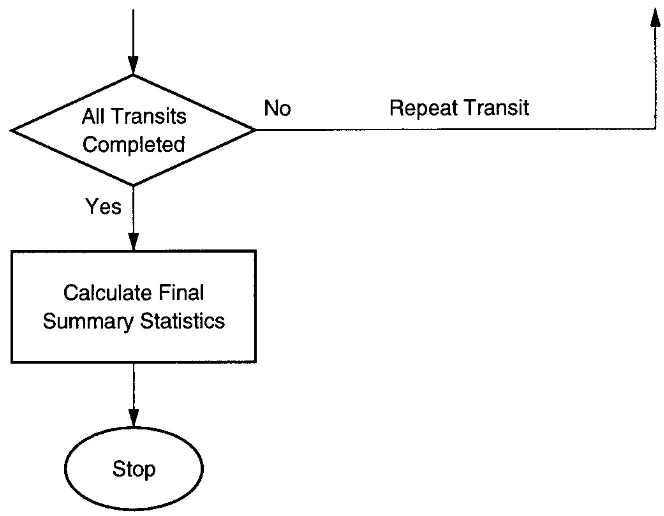



Set Pressure Factor (PRESS_FACT
Set Initial Vessel Speed Based on Ice Thickness and Concentration
Ice Concentration
<75%
100%
75%
Ice Thickness
<150%
≥150%
Use Speeds or Unescorted Vessel
Use Speeds for Icebreaker Escort
Get Wind Speed and Direction [call WINDS()]
Ice Concentration
≥30%
<30%
Adjust Ship Speed for Waves
Get Wave Height [call WAVES()]
Ice Concentration
0%
>0%
Slow Speed for Full Sea
Slow Speed for Partial Sea
Start Next 8-Hour Leg
Start Voyage to Next Node
Repeat Transit

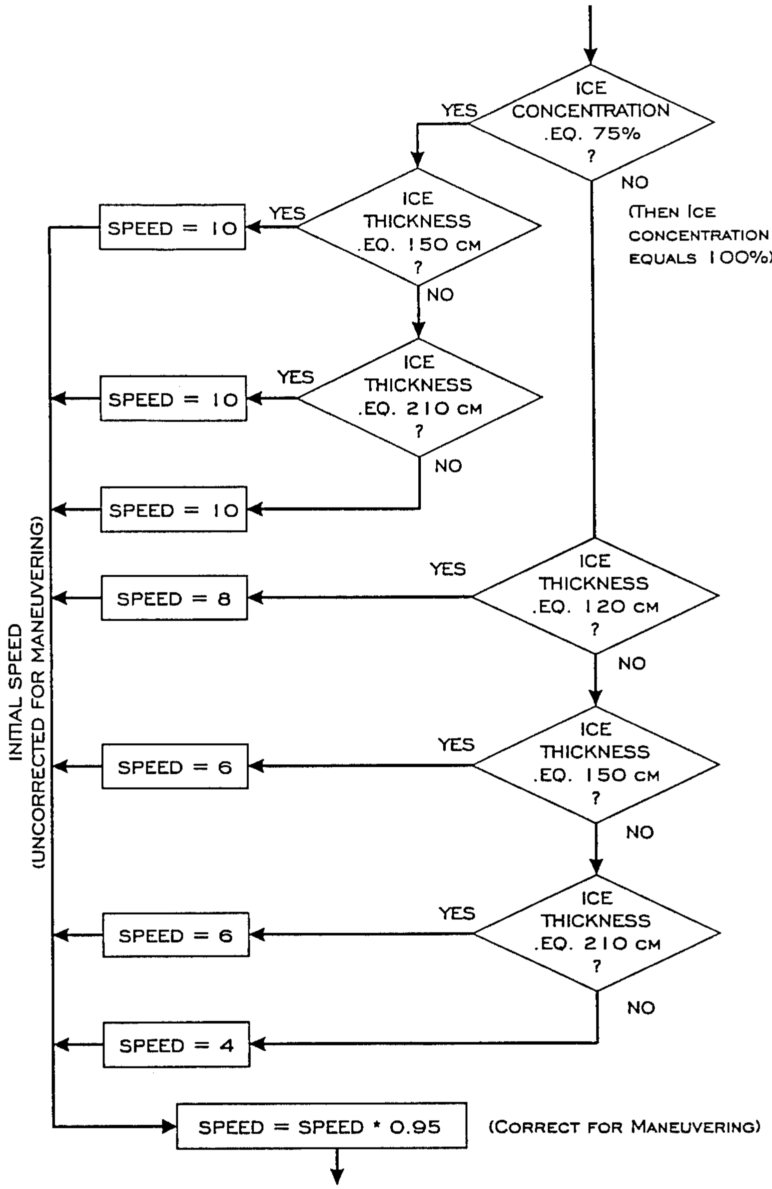


Is it Foggy?
Yes
No
Icebreaker Escort?
Yes
No
Get Fog Factor (FOG_FACT)
Slow Icing?
Yes
No
Icebreaker Escort?
Yes
No
Get Icing Factor (ICING_FACT)
Is it Snowing
Yes
No
Icebreaker Escort?
Yes
No
Get Snow Factor (SNOW_FACT)
Reduce Speed by Factor with Greatest Effect (darkness, fog, icing, snow)
Start Next 8-Hour Leg
Start Voyage to Next Node
Repeat Transit

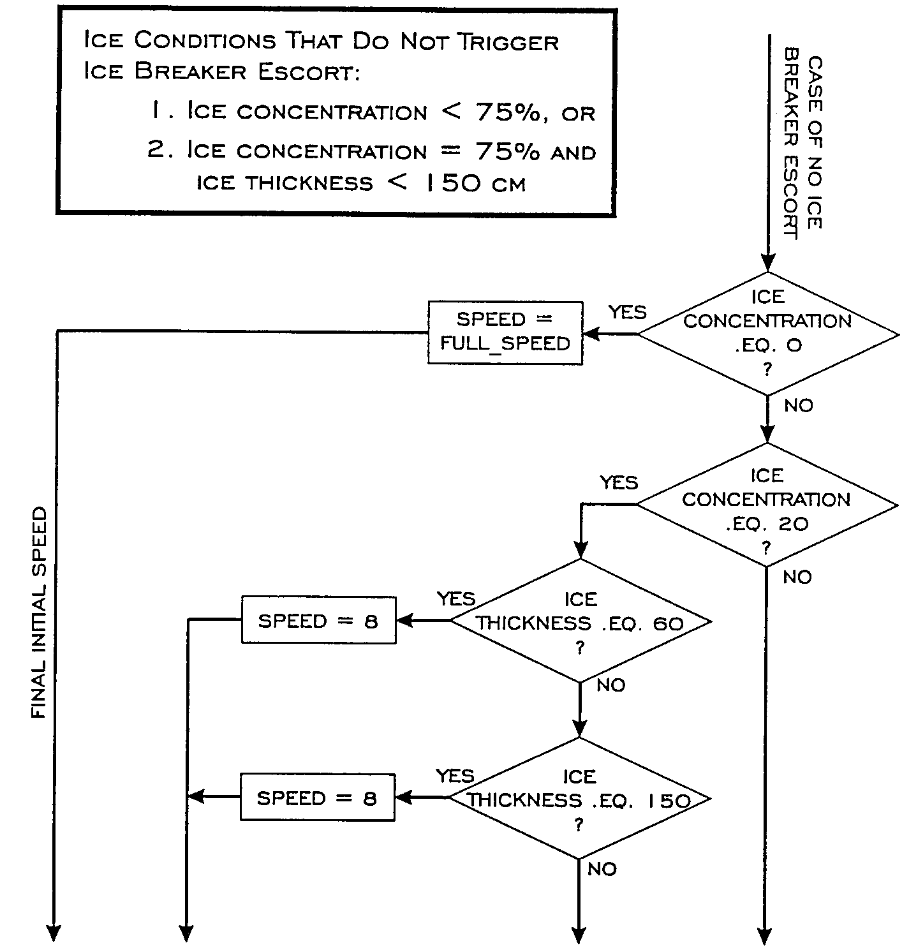

Adjust Speed for Permanent Coastal Current [call ADDCCUR()]
Adjust Speed for Wind-Induced Current [call ADDWCUR()]
Update Distance, Time-in-Route, and Escort Hours
Update Segment Statistics
Has Sun Risen or Set?
Yes
Reset Darkness Factor (DARK_FACT)
No
At Next Node?
No
Yes
Update Leg Statistics
Is Transit Complete?
No
Yes
Update Transit Statistics
Start Next 8-Hour Leg
Start Voyage to Next Node
Repeat Transit


All Transits Completed
No
Repeat Transit
Yes
Calculate Final Summary Statistics
Stop

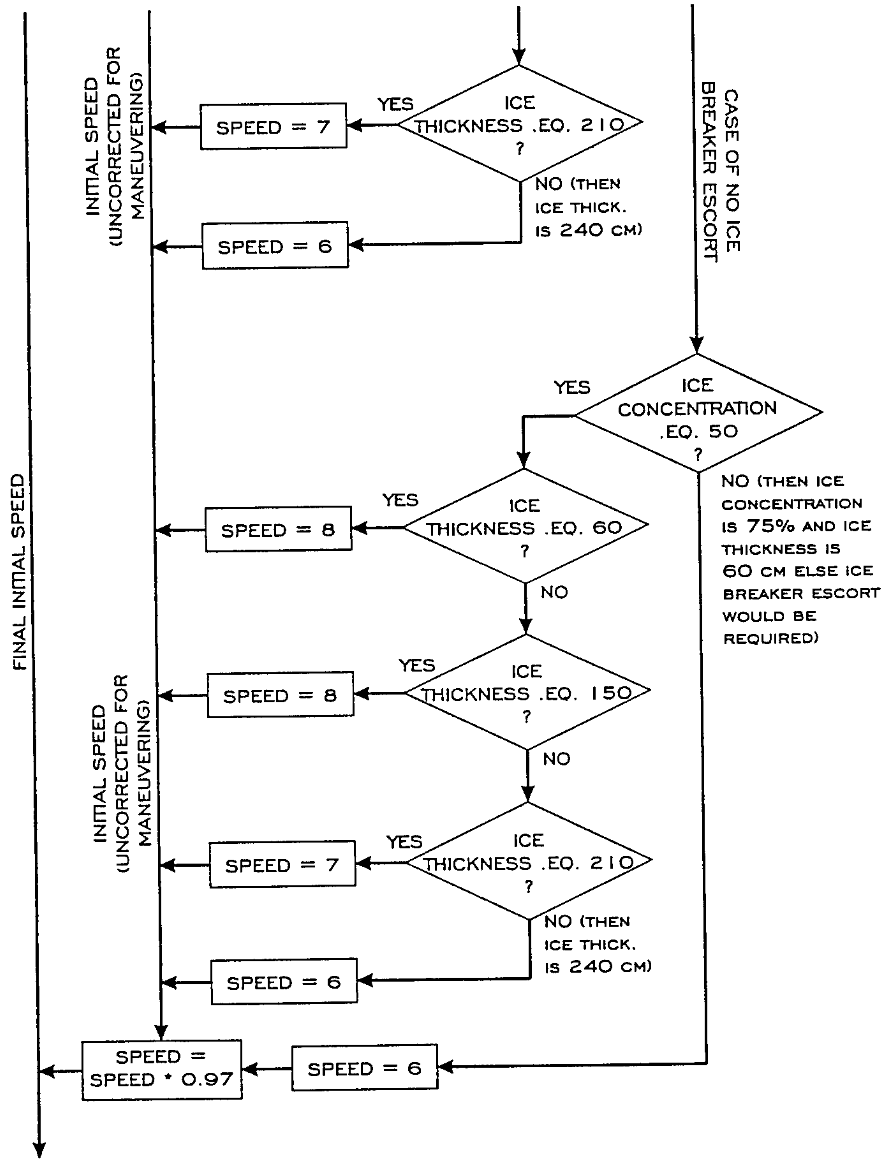
DETAIL OF SPEED INITIALIZATION ALGORITHM
(Escorted Vessels)



SPEED INITIALIZATION ALGORITHM
(Unescorted Vessels)



SPEED INITIALIZATION ALGORITHM
(Unescorted Vessels (cont'd.)



APPENDIX B: INPUT FILE FORMATS

Table B.1. List of data files required to run NSRSIM01.FOR.

File name	Description	Month
CONC04.DAT	Ice concentration probability density functions (Table B.2)	April
CONC06.DAT		June
CONC08.DAT		August
CONC10.DAT		October
COST.DAT	Ship cost data. (Table B.3)	All
ICEFOG04.DAT	Probability of icing, fog, and snowstorms (Table B.4)	April
ICEFOG06.DAT		June
ICEFOG08.DAT		August
ICEFOG10.DAT		October
ICEPRE04.DAT	Ice pressure probability density functions (Table B.5)	April
ICEPRE06.DAT		June
ICEPRE08.DAT		August
ICEPRE10.DAT		October
ICTHCK04.DAT	Ice thickness probability density functions (Table B.6)	April
ICTHCK06.DAT		June
ICTHCK08.DAT		August
ICTHCK10.DAT		October
NDESEW04.DAT	East-to-west leg lengths, azimuths, and transit probabilities (Table B.7)	April
NDESEW06.DAT		June
NDESEW08.DAT		August
NDESEW10.DAT		October
NDESWE04.DAT	West-to-east leg lengths, azimuths, and transit probabilities (Table B.7)	April
NDESWE06.DAT		June
NDESWE08.DAT		August
NDESWE10.DAT		October
PCRRNT.DAT	Speed and direction of permanent ocean currents (Table B.8)	All
WAVE04.DAT	Wave height probability density functions (Table B.9)	April
WAVE06.DAT		June
WAVE08.DAT		August
WAVE10.DAT		October
WINDS04.DAT	Wind speed and direction probability density functions (Table B.10 and B.11)	April
WINDS06.DAT		June
WINDS08.DAT		August
WINDS10.DAT		October

Ice concentration files (CONC**.DAT)

Number of header records: 2

Length of data record: 53 bytes

Table B.2. Data record format specifications for ice concentration files.

Data	First byte	Last byte	Format
Record number	1	2	I2
Node or data point identification	3	5	A3
Leg identification	6	11	A6
Probability of ice free	12	19	F8.2
Probability of 10–30% concentration	20	27	F8.2
Probability of 40–60% concentration	28	35	F8.2
Probability of 70–80% concentration	36	43	F8.2
Probability of 90–100% concentration	44	51	F8.2
Carriage control characters (hex 0D0A)	52	53	A2

Partal listing of CONC08.DAT.

```
ICE CONCENTRATION (AUGUST-SEPTEMBER)
                Ice free 10-30   40-60   70-80  90-100
 1 1  Murma      1.00     0.00    0.00    0.00    0.00
 2 0  node       1.00     0.00    0.00    0.00    0.00
 3 1  0-2A       1.00     0.00    0.00    0.00    0.00
 4 2  0-2A       1.00     0.00    0.00    0.00    0.00
 5 5  0-2A       1.00     0.00    0.00    0.00    0.00
 6 2A node       0.70     0.20    0.05    0.05    0.00
 7 6B node       0.50     0.15    0.05    0.05    0.25
 8 27 6B-7       0.20     0.20    0.05    0.05    0.50
 9 28 6B-7       0.00     0.03    0.07    0.15    0.75
10 29 6B-7       0.00     0.25    0.00    0.15    0.60
11 7  node       0.20     0.50    0.25    0.05    0.00
12 37 7-8        0.40     0.30    0.20    0.10    0.00
13 38 7-8        0.75     0.20    0.05    0.00    0.00
14 8  node       1.00     0.00    0.00    0.00    0.00
15 3  0-2        1.00     0.00    0.00    0.00    0.00
16 4  0-2        1.00     0.00    0.00    0.00    0.00
17 2  node       1.00     0.00    0.00    0.00    0.00
```

Cost file (COST.DAT)

Number of header records: 2

Length of data record: 52 bytes

Table B.3. Data record format specifications for cost file.

Data	First byte	Last byte	Format
Ship class	1	14	A14
Daily cost of cargo ship (US$)	15	26	F12.2
Daily cost of escort vessel (US$)	27	38	F12.2
Tariffs and fees	39	50	F12.2
Carriage control characters (hex 0D0A)	51	52	A2

Example of COST.DAT file:

```
SHIP COST DATA in US$ (Current to 4-6-95)
 Ship Class        Daily Cost  Escort Cost    Tariffs
1 NORISLK           17250.00          0.00  100000.00
2 LUNNI             13500.00          0.00  100000.00
3 STREKALOVSKI      11250.00          0.00  100000.00
```

Icing–fog–snowstorm files (ICEFOG**.DAT)

Number of header records: 2

Length of data record: 25 bytes

Table B.4. Data record format specifications for icing–fog–snowstorm files.

Data	First byte	Last byte	Format
Record number	1	2	I2
Node or data point identification	3	5	A3
Probability of icing conditions	6	11	F6.2
Probability of fog	12	17	F6.2
Probability of snowstorms	18	23	F6.2
Carriage control characters (hex 0D0A)	24	25	A2

Partial listing of ICEFOG08.DAT:

```
Slow Icing, Fog, and Snow (August)
Point P(ice) P(fog) P(sno)
 1  1  0.00  0.30  0.00
 2  0  0.00  0.25  0.00
 3  1  0.00  0.24  0.00
 4  2  0.05  0.23  0.00
 5  5  0.10  0.25  0.00
 6 2A  0.20  0.20  0.00
 7 6B  0.50  0.20  0.00
 8 27  0.50  0.25  0.00
 9 28  0.60  0.25  0.00
10 29  0.45  0.25  0.00
11  7  0.25  0.20  0.00
12 37  0.15  0.10  0.00
13 38  0.07  0.20  0.00
14  8  0.01  0.20  0.00
15  3  0.00  0.25  0.00
16  4  0.00  0.20  0.00
17  2  0.01  0.10  0.00
18 15  0.02  0.10  0.00
19 16  0.04  0.10  0.00
```

Ice pressure files (ICEPRE**.DAT)

Number of header records: 2

Length of data record: 46 bytes

Table B.5. Data record format specifications for ice pressure files.

Data	First byte	Last byte	Format
Record number	1	2	I2
Node or data pont identification	3	6	A4
Leg identification	7	12	A6
Percent of instances with no pressure	13	20	F8.1
Percent of instances with low pressure	21	28	F8.1
Percent of instances with medum pressure	29	36	F8.1
Percent of instances with high pressure	37	44	F8.1
Carriage control characters (hex 0D0A)	45	46	A2

Partial listing of ICEPRE08.DAT:

```
Ice Pressure (August)
 SEGMENT           NONE    LIGHT  MEDIUM    HIGH
 1  1  Murma       51.6     3.4    18.9    26.2
 2  0  node        44.9    54.3     0.8     0.0
 3  1  0-2A        40.4    57.9     1.7     0.0
 4  2  0-2A        49.8    49.8     0.4     0.0
 5  5  0-2A        44.4    55.5     0.1     0.0
 6  2A node        42.3    55.1     2.6     0.0
 7  6B node        44.9    54.7     0.5     0.0
 8  27 6B-7        46.5    52.9     0.6     0.0
 9  28 6B-7        49.7    50.0     0.3     0.0
10  29 6B-7        37.7    62.1     0.2     0.0
11  7  node        52.4    46.8     0.8     0.0
12  37 7-8         49.8    48.6     1.6     0.0
13  38 7-8         43.7    55.9     0.4     0.0
14  8  node        68.9    29.6     1.5     0.0
15  3  0-2         43.8    55.6     0.6     0.0
16  4  node        45.0    54.8     0.2     0.0
17  2  2-4         42.2    57.5     0.3     0.0
18  15 2-4         39.5    60.0     0.5     0.0
19  16 2-4         46.8    52.6     0.7     0.0
```

Ice thickness files (ICTHCK**.DAT)

Number of header records: 2

Length of data record: 59 bytes

Table B.6. Data record format specifications for ice thickness files.

Data	First byte	Last byte	Format
Record number	1	2	I2
Node or data point identification	3	5	A3
Leg identification	6	12	A7
Minimum ice thickness	13	17	F5.0
Maximum ice thickness	18	22	F5.0
Mean ice thickness	23	27	F5.0
Probability of no ice	28	33	F6.2
Probability of ice <120 cm thick	34	39	F6.2
Probability of ice 120–180 cm thick	40	45	F6.2
Probability of ice 180–240 cm thick	46	51	F6.2
Probability of ice >240 cm thick	52	57	F6.2
Carriage control characters (hex 0D0A)	58	59	A2

Partial listing of ICTHCK08.DAT:

```
OCCURRENCE OF ICE THICKNESS (AUGUST - SEPTEMBER)
            MAX MIN MEAN  NONE  <120 120-180 180-240 >240 cm
 1 1  Murman  0.   0.   0.  1.00  0.00  0.00  0.00  0.00
 2 0  node    0.   0.   0.  1.00  0.00  0.00  0.00  0.00
 3 1  0-2A    0.   0.   0.  1.00  0.00  0.00  0.00  0.00
 4 2  0-2A    0.   0.   0.  1.00  0.00  0.00  0.00  0.00
 5 5  0-2A    0.   0.   0.  1.00  0.00  0.00  0.00  0.00
 6 2A node   60.   0.  30.  0.70  1.00  0.00  0.00  0.00
 7 6B node  180.   0.  70.  0.50  1.00  0.00  0.00  0.00
 8 27 6B-7  180.   0.  70.  0.20  0.63  0.37  0.00  0.00
 9 28 6B-7  240.  40. 130.  0.00  0.50  0.50  0.00  0.00
10 29 6B-7  200.  30. 120.  0.05  0.47  0.53  0.00  0.00
11 7  node  180.   0.  70.  0.05  1.00  0.00  0.00  0.00
12 37 7-8   180.   0.  50.  0.60  1.00  0.00  0.00  0.00
13 38 7-8   180.   0.  20.  0.75  1.00  0.00  0.00  0.00
```

Network node files (NDESEW**.DAT and NDESWE**.DAT)

Number of header records: 2

Length of data record: Variable (35, 68, 98, or 128 bytes, dependong on whether 0, 1, 2, or 3 routes can be followed from a given node)

Table B.7. Data record format specifications for network node files.

Data			First byte	Last byte	Format
Record number			1	2	I2
Node or data point identification			3	5	A3
Leg identification			6	16	A11
Latitude of node	Degree		17	19	I3
	Minutes		20	22	I3
Longitude of node	Degree		23	26	I4
	Minutes		27	29	I3
Number of possible routes (branches) to follow			30	33	I4
If the number of branches is greater than zero, then one block of data is given for each branch describing which node to head for.					
First branch (if there is one)	Record number of next node		34	36	I3
	Identification of next node		37	39	A3
	Probability of using route		40	44	F5.2
	Probability of icebreaker escort		45	51	F5.2
	Distance to next node (nm)		52	58	F7.2
	Initial heading to next node (deg)		59	66	F7.2
Second branch (if there is one)	Record number of next node		67	69	I3
	Identification of next node		70	72	A3
	Probability of using route		73	77	F5.2
	Probability of icebreaker escort		78	82	F5.2
	Distance to next node (nm)		83	89	F7.2
	Initial heading to next node (deg)		90	96	F7.2
Third branch (if there is one)	Record number of next node		97	99	I3
	Identification of next node		100	102	A3
	Probability of using route		103	107	F5.2
	Probability of icebreaker escort		108	112	F5.2
	Distance to next node (nm)		113	119	F7.2
	Initial heading to next node (deg)		120	126	F7.2
Carriage control characters come only once, at the end of the record; the length of the record and the position of the carriage control characters depend on the number of branches.					
Carriage control characters (hex 0D0A)		If no branches	34	35	A2
		If one branch	67	68	
		If two branches	97	98	
		If three branches	127	128	

Partial listing of NDESEW08.DAT.

```
NODE DATA (east to west transit; August)
POINT   SEGMENT   LAT    LON  BRNCHS  NXT_ND, LEG, P(use), P(esc), LEN(nm), HEADING, ...
 1  1   Murma    69 24   34 26   0
 2  0    node    69 57   35 43   1     1  1 1.00 0.00  42.55 219.63
 3  1    2A-0    72 30   40 00   1     2  3 1.00 0.00 173.93 210.44
 4  2    2A-0    74 13   50 57   1     3  3 1.00 0.00 214.04 246.62
 5  5    2A-0    75 55   56 30   1     4  3 1.00 0.00 133.33 222.78
 6 2A    node    77 39   71 46   1     5  3 1.00 0.00 232.80 251.16
 7 6B    node    76 46 140 54   2    45 26 0.50 0.00 119.05 280.49 26 15 0.50 0.35 233.30 230.20
 8 27   7-6B     75 36 150 20   1     7 18 1.00 0.35 152.12 301.91
 9 28   7-6B     74 44 161 37   1     8 18 1.00 0.35 180.71 292.11
10 29   7-6B     71 36 172 48   1     9 18 1.00 0.18 269.25 319.31
11  7    node    70 11 177 03   3    32 21 0.34 0.18 122.30 303.50 40 20 0.33 0.18 151.29 306.29 10 18 0.33 0.18 119.23 317.51
12 37    8-7     68 36 182 36   1    11 24 1.00 0.03 150.91 311.60
13 38    8-7     67 32 187 44   1    12 24 1.00 0.03 131.74 301.45
14  8   Berin    66 41 189 03   2    13 24 0.50 0.03  59.64 329.53 49 25 0.50 0.00 298.35 309.38
15  3    2-0     70 30   40 00   1     2  2 1.00 0.00  93.11 251.24
16  4    2-0     71 10   50 43   1    15  2 1.00 0.00 214.54 264.36
17  2    node    70 13   56 09   1    16  2 1.00 0.00 122.02 300.42
18 15    4-2     71 40   65 52   1    17  5 1.00 0.00 208.99 250.09
19 16    4-2     73 12   76 32   1    18  5 1.00 0.00 213.54 249.68
20  3    4-2     73 21   81 21   1    19  5 1.00 0.00  83.76 266.13
21 11    4-2     75 47   90 43   1    20  5 1.00 0.37 208.57 230.27
22 13    23-4    77 39 108 38   1    23 12 1.00 0.37  66.75 275.12
23  4    node    77 42 103 26   2    21  5 0.50 0.38 208.73 242.99 42  9 0.50 0.38 122.68 257.36
24 23    node    76 10 117 29   1    22 12 1.00 0.37 149.51 310.75
25 24    5-23    75 22 122 09   1    24 13 1.00 0.37  84.02 307.13
26  5    node    74 00 130 00   2    25 13 0.50 0.37 148.97 307.13 46 14 0.50 0.00 263.53 270.00
27 26    6-5     72 56 135 03   1    26 17 1.00 0.35 107.47 308.99
28  6    node    72 39 141 38   1    27 17 1.00 0.35 118.17 281.41
29 33    7-6     73 52 146 12   1    28 21 1.00 0.35 107.61 229.44
30 34    7-6     72 32 153 38   1    29 21 1.00 0.35 151.69 305.35
31 35    7-6     72 06 165 55   1    30 21 1.00 0.35 224.90 282.45
32 36    7-6     71 14 171 46   1    31 21 1.00 0.18 122.12 297.98
```

Permanent current file (PCRRNT.DAT)

Number of header records: 2
Length of data record: 16 bytes

Table B.8. Data record format for permanent current files.

Data	First byte	Last byte	Format
Record number	1	2	I2
Node or data point identification	3	5	A3
Current direcyion (deg)	6	10	F5.0
Current speed (kn)	11	14	F4.1
Carriage control characters (hex 0D0A)	15	16	A2

Partial listing of PCRRNT.DAT:

```
Permanent Currents
   N  DIR VEL
 1 1    0. 0.0
 2 0   45. 0.2
 3 1    0. 0.2
 4 2    0. 0.2
 5 5    0. 0.3
 6 2A 270. 0.1
 7 6B 315. 0.3
 8 27  45. 0.1
 9 28 225. 0.1
10 29   0. 0.2
11 07 270. 0.2
12 37 225. 0.1
13 38  90. 0.1
14  8  45. 0.5
15  3  90. 0.4
16  4  90. 0.2
17  2  90. 0.3
18 15  45. 0.2
19 16   0. 0.1
20 03  90. 0.1
21 11   0. 0.1
22 13  90. 0.3
```

Wave height files (WAVE**.DAT)

Number of header records: 2
Length of data record: 55 bytes

Table B.9. Data record format specifications for wave height files.

Data	First byte	Last byte	Format
Record number	1	2	I2
Node or data point identification	3	5	A3
Leg identification	6	11	A6
Number of cases of waves 0–1 m high	12	18	F7.0
Number of cases of waves 1–2 m high	19	25	F7.0
Number of cases of waves 2–3 m high	26	32	F7.0
Number of cases of waves 3–5 m high	33	39	F7.0
Number of cases of waves 5–7 m high	40	46	F7.0
Number of cases of waves 7–9 m high	47	53	F7.0
Carriage control characters (hex 0D0A)	54	55	A2

Partial listing of WAVE08.DAT:

```
PROBABILITY OF WAVE HEIGHTS (AUGUST)
                  0-1    1-2    2-3    3-5    5-7    7-9
 1 1 MURMAN  1330.     0.     0.     0.     0.     0.
 2 0  1-2A    511.   613.   160.    39.     6.     0.
 3 1  1-2A    502.   648.   140.    38.     2.     0.
 4 2  1-2A    561.   609.   122.    35.     3.     0.
 5 5  1-2A    564.   594.   135.    33.     3.     0.
 6 2A 2A-3B   511.   648.   135.    34.     2.     0.
 7 6B 6B-7    559.   627.   120.    23.     1.     0.
 8 27 6B-7    593.   599.   116.    20.     2.     0.
 9 28 6B-7    565.   639.   102.    24.     0.     0.
10 29 6B-7    623.   593.    97.    17.     0.     0.
11 7  7-8     661.   561.    94.    14.     0.     0.
12 37 7-8     605.   590.   109.    23.     0.     0.
13 38 7-8     568.   594.   117.    49.     0.     0.
14 8  7-8     703.   520.    94.    11.     2.     0.
15 3  1-2     486.   639.   170.    31.     4.     0.
16 4  1-2     470.   684.   147.    27.     2.     0.
17 2  2-3     484.   672.   147.    25.     2.     0.
```

Wind files (WINDS**.DAT)

Number of header records: 2
Length of data record: 81 bytes

The first two records of winds files are headers that give the file title and column headings. Eight records of wind observation data, one for each of eight compass directions, are provided for each node. Table B.10 specifies the format for each of these data records. A header record that identifies the node precedes each block of eight data records (Table B.11).

Table B.10. Data record format specifications for ice thickness files.

Data		First byte	Last byte	Format
Wind direction (deg)		1	8	A8
Number of observations		9	14	F6.0
Maximum wind (kn)		15	20	F6.1
Mean wind (kn)		21	24	F4.1
Wind speed (number of obervations)	0–5 kn	25	29	F5.0
	5–10 kn	30	34	F5.0
	10–15 kn	35	39	F5.0
	15–20 kn	40	44	F5.0
	20–25 kn	45	49	F5.0
	25–30 kn	50	54	F5.0
	30–35 kn	55	59	F5.0
	35–40 kn	60	64	F5.0
	40–45 kn	65	69	F5.0
	45–50 kn	70	74	F5.0
	>50 kn	75	79	F5.0
Carriage control characters (hex 0D0A)		80	81	A2

Table B.11. Header record format specification for wind file data records.

Data	First byte	Last byte	Format
Node number	1	2	I2
Node or data point identification	3	5	A3
Leg identification	6	14	A9
Carriage control characters (hex 0D0A)	15	16	A2

Partial listing of WINDS08.DAT:

```
WIND SPEED AND DIRECTION  (August)
   DIR     N   Max  Mean 0-5 5-10 10-15 5-20 20-25 25-30 30-35 35-40 40-45 45-50 >50
 1 1  Murmansk
 000-045  200.  21.6 6.7  68. 104.  25.   2.   1.   0.   0.   0.   0.   0.   0.
 045-090  166.  12.4 6.2  61.  84.  21.   0.   0.   0.   0.   0.   0.   0.   0.
 090-135  173.  26.2 6.5  81.  59.  22.   9.   1.   1.   0.   0.   0.   0.   0.
 135-180  183.  16.8 6.2  70.  92.  19.   2.   0.   0.   0.   0.   0.   0.   0.
 180-225  137.  15.3 5.6  61.  63.  12.   1.   0.   0.   0.   0.   0.   0.   0.
 225-270  133.  12.8 5.2  70.  58.   5.   0.   0.   0.   0.   0.   0.   0.   0.
 270-315  156.  18.7 6.4  64.  67.  20.   5.   0.   0.   0.   0.   0.   0.   0.
 315-360  182.  22.6 7.5  60.  80.  27.  13.   2.   0.   0.   0.   0.   0.   0.
 2 0  node
 000-045  184.  20.0 6.8  64.  87.  29.   3.   1.   0.   0.   0.   0.   0.   0.
 045-090  191.  15.9 6.4  68.  97.  22.   4.   0.   0.   0.   0.   0.   0.   0.
 090-135  170.  27.9 7.2  69.  61.  24.  13.   2.   1.   0.   0.   0.   0.   0.
 135-180  170.  16.3 6.3  65.  87.  16.   2.   0.   0.   0.   0.   0.   0.   0.
 180-225  140.  16.2 5.5  62.  68.   9.   1.   0.   0.   0.   0.   0.   0.   0.
 225-270  143.  15.7 5.7  62.  70.  10.   1.   0.   0.   0.   0.   0.   0.   0.
 270-315  168.  22.5 6.7  61.  77.  25.   4.   1.   0.   0.   0.   0.   0.   0.
 315-360  164.  22.3 7.3  60.  66.  25.  11.   2.   0.   0.   0.   0.   0.   0.
 3 1  1-2A
 000-045  199.  20.4 6.8  73.  93.  22.  10.   1.   0.   0.   0.   0.   0.   0.
 045-090  179.  16.6 6.3  62.  97.  16.   4.   0.   0.   0.   0.   0.   0.   0.
 090-135  175.  16.9 6.6  64.  81.  25.   5.   0.   0.   0.   0.   0.   0.   0.
 135-180  150.  12.7 6.1  57.  76.  17.   0.   0.   0.   0.   0.   0.   0.   0.
 180-225  136   21.7 5.9  51.  74.   8.   2.   1.   0.   0.   0.   0.   0.   0.
 225-270  145.  16.9 5.7  70.  59.  12.   4.   0.   0.   0.   0.   0.   0.   0.
 270-315  170.  19.1 6.5  59.  87.  18.   6.   0.   0.   0.   0.   0.   0.   0.
 315-360  176.  19.1 6.6  66.  81.  22.   7.   0.   0.   0.   0.   0.   0.   0.
 4 2  1-2A
 000-045  254.  23.1 6.9  89. 118.  33.  13.   1.   0.   0.   0.   0.   0.   0.
 045-090  166.  18.6 5.9  68.  84.  12.   2.   0.   0.   0.   0.   0.   0.   0.
 090-135  138.  17.0 5.8  60.  66.   8.   4.   0.   0.   0.   0.   0.   0.   0.
```

APPENDIX C: PRINT FILE FORMATS

Example of output for print option 0.

```
SUMMARY STATISTICS FOR 100 TRANSITS
         month = AUGUST
     direction = Murmansk to Bering Sea [W to E]
    ship class = NORILSK
```

	MIN	MAX	MEAN	VARIANCE	STANDARD DEVIATION
ELAPSED TIME (hr)	256.71	409.12	331.44	762.67	27.62
MEAN SPEED (kt)	-.40	18.50	9.49	.65	.81
DISTANCE TRAVELLED (nm)	2910.77	3388.67	3126.51	13189.67	114.85
ESCORT TIME (hr)	.00	204.19	75.99	1798.71	42.41
HOURS WITH FOG	23.44	129.34	76.03	552.32	23.50
PERCENT ALL HOURS WITH FOG	6.84	36.14	22.83	40.77	6.39
FOG FACTOR	.50	1.00	.80	.00	.06
HOURS WITH ICING	24.22	190.46	87.26	760.01	27.57
PERCENT ALL HOURS WITH ICING	7.87	49.30	26.20	56.94	7.55
ICING FACTOR	.85	1.00	.95	.00	.02
HOURS WITH SNOW STORMS RAGING	.00	.00	.00	.00	.00
PERCENT ALL HOURS WITH SNOW	.00	.00	.00	.00	.00
SNOW STORM RAGE FACTOR	1.00	1.00	1.00	.00	.00
HOURS WITH DARKNESS	40.00	68.00	53.75	22.87	4.78
PERCENT ALL HOURS WITH DARKNESS	15.58	16.66	16.21	.08	.29
DARKNESS FACTOR	.50	1.00	.81	.00	.04
HOURS WITH WAVES	102.17	299.11	206.18	2226.69	47.19
PERCENT ALL HOURS WITH WAVES	28.74	93.47	62.57	213.34	14.61
MEAN WAVE HEIGHT	.50	6.00	1.22	.01	.12
PERMANENT CURRENT VECTOR	-.48	.37	.00	.00	.02
WIND-INDUCED CURRENT VECTOR	-.44	.44	-.01	.00	.02
ICE FREE HOURS	72.26	161.15	114.06	391.14	19.78
PERCENT HOURS ICE FREE	19.72	57.08	34.99	68.65	8.29
ICE FREE DISTANCE (nm)	1096.82	2382.01	1736.45	83229.34	288.49
PERCENT DISTANCE ICE FREE (nm)	36.37	74.93	55.47	74.56	8.64
TOTAL COST (US$)	289750.00	410500.00	347710.00	**********	20295.28
COST PER HOUR (US$)	980.18	1128.69	1051.42	1020.37	31.94
COST PER MILE (US$)	94.60	129.64	111.33	51.29	7.16

FOG STATISTICS for EACH LEG

LEG	ID	LENGTH (nm)	TOTAL PASSES	PASSES w/FOG	PERCENT w/FOG	ELAPSED TIME WITH FOG (hr) MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION	DISTANCE TRAVELLED WITH FOG (nm) MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION
1	MURMANSK <--> Node 0	42.55	100	23	23.00	2.49	4.97	3.67	.0862	.67	.82	.73	42.55	42.55	42.55	1.000	.00	.00	.00
2	Node 0 <--> Node 2	429.67	56	37	66.07	.93	15.08	6.89	.0160	15.72	3.97	3.27	10.12	253.18	87.08	.203	2969.47	54.49	41.36
3	Node 0 <--> Node 2A	754.10	44	43	97.73	.68	41.02	14.47	.0192	87.46	9.35	7.31	7.43	344.81	154.19	.204	7830.17	88.49	74.86
4	Node 2 <--> Node 3A	414.05	28	23	82.14	.29	13.81	7.41	.0179	18.28	4.28	3.67	3.82	204.67	90.70	.219	3159.66	56.21	47.66
5	Node 2 <--> Node 4	923.59	28	26	92.86	4.00	40.00	17.01	.0184	91.73	9.58	8.15	7.46	233.42	115.07	.125	3970.33	63.01	53.06
6	Node 2A <--> Node 3A	212.28	44	26	59.09	.18	16.88	7.76	.0366	17.64	4.20	2.97	1.26	210.66	86.71	.408	2447.20	49.47	38.85
7	Node 2A <--> Node 3B	364.53	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
8	Node 3A <--> Node 3B	543.65	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
9	Node 3A <--> Node 4	462.62	72	71	98.61	1.01	37.19	16.89	.0365	82.49	9.08	7.21	5.69	225.02	102.55	.222	3131.40	55.96	43.96
10	Node 3B <--> Node 5	633.33	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
11	Node 3B <--> Node 6B	578.11	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
12	Node 4 <--> Node 23	216.26	50	40	80.00	1.14	24.00	8.37	.0387	23.89	4.89	3.67	5.58	146.16	56.31	.260	945.90	30.76	24.43
13	Node 23 <--> Node 5 (24)	232.99	32	23	71.88	.59	23.64	8.76	.0376	39.17	6.26	4.96	4.10	203.64	71.01	.305	2912.19	53.96	42.51
14	Node 23 <--> Node 5 (F1)	404.31	18	16	88.89	.60	24.00	8.53	.0211	44.24	6.65	4.78	7.41	200.89	66.45	.164	2955.24	54.36	44.60
15	Node 5 <--> Node 6B	233.30	6	5	83.33	4.00	12.00	8.00	.0343	16.00	4.00	3.20	21.76	69.73	45.68	.196	460.31	21.45	18.10
16	Node 5 <--> Node 6A	201.28	15	7	46.67	3.50	13.43	9.07	.0450	17.21	4.15	3.37	22.28	152.86	81.76	.406	2282.84	47.78	38.80
17	Node 5 <--> Node 6	225.64	29	13	44.83	.12	12.00	6.10	.0270	10.67	3.27	2.62	.51	115.53	53.50	.237	1341.77	36.63	29.51
18	Node 6B <--> Node 7	721.31	17	17	100.00	3.41	39.84	23.49	.0326	112.94	10.63	8.37	25.88	244.44	135.15	.187	3998.26	63.23	51.15
19	Node 6B <--> Node F2	251.22	39	28	71.79	1.53	18.41	8.28	.0330	24.59	4.96	3.84	8.46	159.72	65.04	.259	1430.93	37.83	31.85
20	Node 6A <--> Node 7	546.79	6	6	100.00	12.00	53.53	29.63	.0542	297.68	17.25	15.05	63.82	278.52	186.55	.341	7501.83	86.61	70.61
21	Node 6 <--> Node 7	728.62	7	7	100.00	10.82	43.76	27.90	.0383	188.95	13.75	11.68	69.00	315.47	178.18	.245	8129.14	90.16	72.62
22	Node 6A <--> Node F2	139.70	9	3	33.33	3.41	12.27	7.89	.0565	19.60	4.43	2.99	43.00	139.70	101.98	.730	2676.69	51.74	39.32
23	Node 6 <--> Node F2	114.83	22	12	54.55	.67	8.03	4.49	.0391	5.84	2.42	1.88	10.81	114.83	44.10	.384	1366.99	36.97	28.72
24	Node 7 <--> BERING SEA	342.29	30	21	70.00	1.45	21.50	8.41	.0246	23.32	4.83	3.52	18.71	160.66	74.35	.217	1525.80	39.06	31.98
25	Node F2 <--> BERING SEA	917.54	70	70	100.00	5.16	60.02	24.28	.0265	143.51	11.98	9.27	27.02	470.96	181.75	.198	7058.58	84.02	63.02
26	Node 4 <--> Node 6B	498.28	50	47	94.00	.87	51.60	17.33	.0348	100.60	10.03	7.71	6.47	295.31	109.64	.220	4839.74	69.57	55.49

ICING STATISTICS for EACH LEG

LEG	ID	LENGTH (nm)	TOTAL PASSES	PASSES w/ICNG	PERCENT w/ICING	ELAPSED TIME WITH ICING (hr) MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION	DISTANCE TRAVELLED WITH ICING (nm) MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION
1	MURMANSK <--> Node 0	42.55	100	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
2	Node 0 <--> Node 2	429.67	56	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
3	Node 0 <--> Node 2A	754.10	44	32	72.73	1.65	20.00	8.49	.0113	29.44	5.43	4.62	11.68	266.05	84.37	.112	4745.14	68.88	53.99
4	Node 2 <--> Node 3A	414.05	28	4	14.29	.46	7.76	3.98	.0096	8.93	2.99	1.91	6.80	66.57	49.87	.120	835.34	28.90	21.53
5	Node 2 <--> Node 4	923.59	28	26	92.86	4.00	45.95	20.56	.0223	128.11	11.32	8.37	14.70	232.92	129.55	.140	3462.93	58.85	45.18
6	Node 2A <--> Node 3A	212.28	44	11	25.00	.18	17.17	7.08	.0333	29.08	5.39	4.29	1.26	212.28	84.00	.396	3778.14	61.47	43.66
7	Node 2A <--> Node 3B	364.53	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
8	Node 3A <--> Node 3B	543.65	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
9	Node 3A <--> Node 4	462.62	72	71	98.61	4.00	43.49	20.72	.0448	101.67	10.08	8.55	22.75	305.23	132.66	.287	4634.78	68.08	58.06
10	Node 3B <--> Node 5	633.33	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
11	Node 3B <--> Node 6B	578.11	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
12	Node 4 <--> Node 23	216.26	50	43	86.00	.69	26.91	11.50	.0532	38.11	6.17	5.11	5.36	216.26	82.35	.381	2206.60	46.97	37.53
13	Node 23 <--> Node 5 (24)	232.99	32	21	65.63	.49	19.34	7.33	.0314	23.03	4.80	3.76	2.77	172.83	68.71	.295	2431.04	49.31	40.01
14	Node 23 <--> Node 5 (F1)	404.31	18	15	83.33	.60	14.67	6.81	.0169	16.89	4.11	3.33	5.47	108.78	50.79	.126	911.98	30.20	24.31
15	Node 5 <--> Node 6B	233.30	6	6	100.00	9.82	22.47	18.20	.0780	23.89	4.89	3.85	96.93	233.30	148.19	.635	2447.92	49.48	36.20
16	Node 5 <--> Node 6A	201.28	15	8	53.33	4.14	23.32	10.62	.0528	57.77	7.60	6.13	24.56	172.33	85.51	.425	2943.05	54.25	44.35
17	Node 5 <--> Node 6	225.64	29	12	41.38	.83	14.96	5.86	.0260	18.67	4.32	3.41	10.26	165.84	72.78	.323	3252.24	57.03	49.70
18	Node 6B <--> Node 7	721.31	17	17	100.00	23.90	80.66	48.40	.0671	234.77	15.32	12.00	163.81	513.37	318.23	.441	10540.13	102.67	80.03
19	Node 6B <--> Node F2	251.22	39	26	66.67	1.22	17.15	7.65	.0305	15.48	3.93	2.93	18.01	194.46	85.44	.340	2625.80	51.24	42.99
20	Node 6A <--> Node 7	546.79	6	6	100.00	25.26	52.00	39.42	.0721	111.83	10.57	8.39	153.08	393.26	277.28	.507	8994.46	94.84	75.32
21	Node 6 <--> Node 7	728.62	7	7	100.00	23.12	41.05	31.08	.0427	30.91	5.56	3.83	152.05	249.35	202.24	.278	980.26	31.31	22.40
22	Node 6A <--> Node F2	139.70	9	4	44.44	1.08	8.98	6.49	.0465	13.24	3.64	2.70	16.45	139.70	88.19	.631	2809.96	53.01	38.10
23	Node 6 <--> Node F2	114.83	22	8	36.36	2.46	11.59	6.45	.0562	12.22	3.50	2.96	29.36	104.02	64.41	.561	723.05	26.89	22.38
24	Node 7 <--> BERING SEA	342.29	30	14	46.67	1.04	16.00	6.84	.0200	19.08	4.37	3.58	10.76	104.14	42.64	.125	750.79	27.40	22.05
25	Node F2 <--> BERING SEA	917.54	70	70	100.00	2.63	54.58	28.04	.0306	138.01	11.75	9.23	17.93	420.38	211.65	.231	7894.51	88.85	71.65
26	Node 4 <--> Node 6B	498.28	50	49	98.00	9.98	62.36	35.28	.0708	170.80	13.07	10.79	71.34	401.14	261.87	.526	5826.52	76.33	60.56

SNOWSTORM STATISTICS for EACH LEG

LEG	ID	LENGTH (nm)	TOTAL PASSES	PASSES w/SNOW	PERCENT w/SNOW	ELAPSED TIME WITH SNOW STORMS (hr) MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION	DISTANCE TRAVELLED WITH SNOW STORMS (nm) MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION
1	MURMANSK <--> Node 0	42.55	100	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
2	Node 0 <--> Node 2	429.67	56	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
3	Node 0 <--> Node 2A	754.10	44	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
4	Node 2 <--> Node 3A	414.05	28	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
5	Node 2 <--> Node 4	923.59	28	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
6	Node 2A <--> Node 3A	212.28	44	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
7	Node 2A <--> Node 3B	364.53	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
8	Node 3A <--> Node 3B	543.65	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
9	Node 3A <--> Node 4	462.62	72	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
10	Node 3B <--> Node 5	633.33	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
11	Node 3B <--> Node 6B	578.11	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
12	Node 4 <--> Node 23	216.26	50	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
13	Node 23 <--> Node 5 (24)	232.99	32	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
14	Node 23 <--> Node 5 (F1)	404.31	18	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
15	Node 5 <--> Node 6B	233.30	6	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
16	Node 5 <--> Node 6A	201.28	15	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
17	Node 5 <--> Node 6	225.64	29	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
18	Node 6B <--> Node 7	721.31	17	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
19	Node 6B <--> Node F2	251.22	39	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
20	Node 6A <--> Node 7	546.79	6	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
21	Node 6 <--> Node 7	728.62	7	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
22	Node 6A <--> Node F2	139.70	9	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
23	Node 6 <--> Node F2	114.83	22	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
24	Node 7 <--> BERING SEA	342.29	30	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
25	Node F2 <--> BERING SEA	917.54	70	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
26	Node 4 <--> Node 6B	498.28	50	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00

DARKNESS STATISTICS for EACH LEG

						ELAPSED TIME WITH DARKNESS (hr)							DISTANCE TRAVELLED WITH DARKNESS (nm)						
LEG	ID	LENGTH (nm)	TOTAL PASSES	PASSES w/DARK	PERCENT w/DARK	MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION	MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION
1	MURMANSK <--> Node 0	42.55	100	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
2	Node 0 <--> Node 2	429.67	56	56	100.00	4.00	4.00	4.00	.0093	.00	.00	.00	34.06	69.07	50.77	.118	108.95	10.44	9.07
3	Node 0 <--> Node 2A	754.10	44	44	100.00	8.00	12.00	9.04	.0120	2.99	1.73	1.51	60.94	123.04	90.24	.120	210.03	14.49	11.52
4	Node 2 <--> Node 3A	414.05	28	28	100.00	4.00	4.00	4.00	.0097	.00	.00	.00	31.01	71.58	50.58	.122	123.72	11.12	9.15
5	Node 2 <--> Node 4	923.59	28	28	100.00	12.00	24.00	14.99	.0162	10.20	3.19	2.56	73.95	156.53	123.05	.133	331.57	18.21	13.93
6	Node 2A <--> Node 3A	212.28	44	22	50.00	.17	4.00	3.19	.0150	1.75	1.32	1.08	2.10	52.88	31.24	.147	241.83	15.55	13.75
7	Node 2A <--> Node 3B	364.53	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
8	Node 3A <--> Node 3B	543.65	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
9	Node 3A <--> Node 4	462.62	72	72	100.00	6.40	16.00	11.66	.0252	5.76	2.40	1.65	34.11	113.34	72.24	.156	280.73	16.75	12.78
10	Node 3B <--> Node 5	633.33	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
11	Node 3B <--> Node 6B	578.11	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
12	Node 4 <--> Node 23	216.26	50	49	98.00	1.96	8.00	4.77	.0220	2.20	1.48	1.18	11.93	68.39	32.18	.149	184.94	13.60	10.59
13	Node 23 <--> Node 5 (24)	232.99	32	31	96.88	.53	6.87	4.10	.0176	1.09	1.05	.51	.21	68.92	36.03	.155	333.11	18.25	15.79
14	Node 23 <--> Node 5 (F1)	404.31	18	18	100.00	4.00	12.00	7.54	.0187	7.02	2.65	1.99	23.39	92.60	59.69	.148	272.55	16.51	13.08
15	Node 5 <--> Node 6B	233.30	6	4	66.67	6.37	8.00	7.17	.0307	.51	.71	.57	33.68	45.30	39.76	.170	39.16	6.26	5.40
16	Node 5 <--> Node 6A	201.28	15	14	93.33	.59	8.00	3.97	.0197	3.48	1.86	1.00	9.33	50.26	26.89	.134	172.52	13.13	10.65
17	Node 5 <--> Node 6	225.64	29	21	72.41	.61	8.00	3.96	.0175	2.16	1.47	.77	6.93	60.10	33.53	.149	187.83	13.71	11.06
18	Node 6B <--> Node 7	721.31	17	17	100.00	16.00	20.00	18.31	.0254	3.35	1.83	1.67	76.63	148.22	109.91	.152	320.85	17.91	13.06
19	Node 6B <--> Node F2	251.22	39	33	84.62	.35	8.00	4.39	.0175	2.32	1.52	.98	3.44	59.73	36.97	.147	204.96	14.32	11.34
20	Node 6A <--> Node 7	546.79	6	6	100.00	12.00	19.68	15.21	.0278	7.91	2.81	2.02	70.44	145.53	103.79	.190	805.88	28.39	23.80
21	Node 6 <--> Node 7	728.62	7	7	100.00	12.00	20.00	15.96	.0219	13.83	3.72	3.24	65.49	148.84	108.26	.149	840.61	28.99	23.39
22	Node 6A <--> Node F2	139.70	9	4	44.44	.47	4.00	2.87	.0205	2.61	1.62	1.20	4.17	52.00	30.16	.216	464.39	21.55	17.35
23	Node 6 <--> Node F2	114.83	22	15	68.18	2.46	4.00	3.75	.0326	.23	.48	.37	12.57	68.48	36.59	.319	312.36	17.67	14.39
24	Node 7 <--> BERING SEA	342.29	30	30	100.00	4.00	8.00	5.82	.0170	3.85	1.96	1.92	14.88	85.90	43.62	.127	360.68	18.99	14.59
25	Node F2 <--> BERING SEA	917.54	70	70	100.00	12.00	23.60	17.13	.0187	9.45	3.07	2.62	68.47	174.35	130.66	.142	505.39	22.48	17.24
26	Node 4 <--> Node 6B	498.28	50	50	100.00	4.00	16.00	10.96	.0220	7.67	2.77	2.16	17.73	121.16	73.83	.148	362.19	19.03	14.26

ICE STATISTICS for EACH LEG

LEG	ID	LENGTH (nm)	TOTAL PASSES	PASSES w/ICE	PERCENT w/ICE	ELAPSED TIME WITH ICE (hr) MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION	DISTANCE TRAVELLED WITH ICE (nm) MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION
1	MURMANSK <--> Node 0	42.55	100	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
2	Node 0 <--> Node 2	429.67	56	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
3	Node 0 <--> Node 2A	754.10	44	14	31.82	32.39	52.13	40.36	.0535	42.71	6.54	5.57	232.80	232.80	232.80	.309	.00	.00	.00
4	Node 2 <--> Node 3A	414.05	28	1	3.57	10.12	10.12	10.12	.0244	.00	.00	.00	66.57	66.57	66.57	.161	.00	.00	.00
5	Node 2 <--> Node 4	923.59	28	28	100.00	27.61	123.83	55.70	.0603	632.09	25.14	20.22	208.73	626.29	335.47	.363	16583.55	128.78	111.86
6	Node 2A <--> Node 3A	212.28	44	5	11.36	29.44	36.73	32.60	.1536	7.23	2.69	1.92	212.28	212.28	212.28	1.000	.00	.00	.00
7	Node 2A <--> Node 3B	364.53	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
8	Node 3A <--> Node 3B	543.65	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
9	Node 3A <--> Node 4	462.62	72	72	100.00	32.49	92.47	65.29	.1411	262.22	16.19	12.47	245.98	462.62	414.48	.896	8226.11	90.70	74.89
10	Node 3B <--> Node 5	633.33	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
11	Node 3B <--> Node 6B	578.11	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
12	Node 4 <--> Node 23	216.26	50	46	92.00	8.43	39.59	28.63	.1324	41.27	6.42	4.88	66.75	216.26	193.80	.896	1566.84	39.58	32.23
13	Node 23 <--> Node 5 (24)	232.99	32	24	75.00	11.02	39.84	19.49	.0837	74.42	8.63	6.84	84.02	232.99	127.79	.548	3144.08	56.07	47.42
14	Node 23 <--> Node 5 (F1)	404.31	18	13	72.22	20.82	62.67	38.68	.0957	241.91	15.55	13.17	140.78	404.31	250.19	.619	13947.42	118.10	101.00
15	Node 5 <--> Node 6B	233.30	6	4	66.67	33.31	38.24	35.13	.1506	4.75	2.18	1.55	233.30	233.30	233.30	1.000	.00	.00	.00
16	Node 5 <--> Node 6A	201.28	15	7	46.67	13.03	32.91	19.23	.0955	45.01	6.71	4.53	93.96	201.28	115.02	.571	1491.54	38.62	24.65
17	Node 5 <--> Node 6	225.64	29	12	41.38	13.96	34.76	22.37	.0991	78.49	8.86	7.89	107.47	225.64	149.54	.663	3178.77	56.38	50.74
18	Node 6B <--> Node 7	721.31	17	17	100.00	74.78	124.63	106.08	.1471	250.53	15.83	13.00	449.96	721.31	673.42	.934	6835.15	82.67	67.60
19	Node 6B <--> Node F2	251.22	39	13	33.33	34.63	42.16	37.52	.1494	6.24	2.50	1.92	251.22	251.22	251.22	1.000	.00	.00	.00
20	Node 6A <--> Node 7	546.75	6	6	100.00	60.97	115.09	80.63	.1475	356.42	18.88	13.18	369.04	698.08	507.01	.927	15469.29	124.38	91.98
21	Node 6 <--> Node 7	728.62	7	7	100.00	33.94	101.89	77.94	.1070	653.29	25.56	21.33	244.42	621.01	496.66	.682	22779.61	150.93	129.52
22	Node 6A <--> Node F2	139.70	9	1	11.11	18.93	18.93	18.93	.1355	.00	.00	.00	139.70	139.70	139.70	1.000	.00	.00	.00
23	Node 6 <--> Node F2	114.83	22	5	22.73	15.83	19.86	16.86	.1468	2.92	1.71	1.20	114.83	114.83	114.83	1.000	.00	.00	.00
24	Node 7 <--> BERING SEA	342.29	30	21	70.00	17.66	47.73	29.60	.0865	98.40	9.92	8.30	131.74	282.65	186.72	.546	3896.58	62.42	54.81
25	Node F2 <--> BERING SEA	917.54	70	70	100.00	37.43	114.55	72.41	.0789	654.50	25.58	24.46	284.63	619.19	470.96	.513	23900.87	154.60	152.47
26	Node 4 <--> Node 6B	498.28	50	49	98.00	10.07	89.80	57.02	.1144	382.32	19.55	15.68	66.87	498.28	362.90	.728	13527.56	116.31	89.37

ESCORT STATISTICS for EACH LEG

LEG	ID	LENGTH (nm)	TOTAL PASSES	PASSES w/ESCT	PERCENT w/ESCRT	ELAPSED TIME WITH ICE BREAKER ESCORT (hr)							DISTANCE TRAVELLED WITH ICE BREAKER ESCORT (nm)						
						MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION	MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION
1	MURMANSK <--> Node 0	42.55	100	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
2	Node 0 <--> Node 2	429.67	56	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
3	Node 0 <--> Node 2A	754.10	44	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
4	Node 2 <--> Node 3A	414.05	28	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
5	Node 2 <--> Node 4	923.59	28	14	50.00	27.20	86.38	40.76	.0441	293.48	17.13	13.08	208.57	417.30	223.59	.242	3108.35	55.75	27.67
6	Node 2A <--> Node 3A	212.28	44	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
7	Node 2A <--> Node 3B	364.53	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
8	Node 3A <--> Node 3B	543.65	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
9	Node 3A <--> Node 4	462.62	72	60	83.33	15.72	80.93	33.83	.0731	264.12	16.25	13.15	122.68	462.62	205.89	.445	9556.04	97.75	85.57
10	Node 3B <--> Node 5	633.33	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
11	Node 3B <--> Node 6B	578.11	0	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
12	Node 4 <--> Node 23	216.26	50	28	56.00	8.27	29.48	18.15	.0839	48.89	6.99	5.76	66.75	216.26	130.06	.601	2385.84	48.85	40.70
13	Node 23 <--> Node 5 (24)	232.99	32	5	15.63	11.02	21.06	15.53	.0667	22.36	4.73	3.92	84.02	148.97	110.00	.472	1265.55	35.57	31.18
14	Node 23 <--> Node 5 (F1)	404.31	18	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
15	Node 5 <--> Node 6B	233.30	6	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
16	Node 5 <--> Node 6A	201.28	15	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
17	Node 5 <--> Node 6	225.64	29	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
18	Node 6B <--> Node 7	721.31	17	16	94.12	33.61	93.15	65.56	.0909	265.18	16.28	13.33	180.71	602.08	425.45	.590	15905.38	126.12	100.57
19	Node 6B <--> Node F2	251.22	39	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
20	Node 6A <--> Node 7	546.79	6	6	100.00	22.86	72.58	41.82	.0765	481.93	21.95	18.76	177.75	369.04	273.40	.500	10977.56	104.77	95.65
21	Node 6 <--> Node 7	728.62	7	6	85.71	15.72	55.61	30.18	.0414	260.50	16.14	12.69	122.12	376.59	198.79	.273	10122.23	100.61	76.67
22	Node 6A <--> Node F2	139.70	9	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
23	Node 6 <--> Node F2	114.83	22	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
24	Node 7 <--> BERING SEA	342.29	30	0	.00	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
25	Node F2 <--> BERING SEA	917.54	70	32	45.71	37.43	41.43	38.66	.0421	1.38	1.18	.97	284.63	284.63	284.63	.310	.00	.00	.00
26	Node 4 <--> Node 6B	498.28	50	43	86.00	8.53	71.91	39.41	.0791	317.30	17.81	14.31	66.77	498.28	258.58	.519	13078.89	114.36	89.66

TRANSIT STATISTICS for EACH LEG

LEG	ID	LENGTH (nm)	TOTAL PASSES	ELAPSED TRAVEL TIME (hr) MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION	DISTANCE TRAVELLED (nm) MINIMUM	MAXIMUM	MEAN RAW	MEAN NORM.	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION
1	MURMANSK <--> Node 0	42.55	100	2.32	4.97	2.79	.0655	.39	.62	.43	42.55	42.55	42.55	1.000	.00	.00	.00
2	Node 0 <--> Node 2	429.67	56	25.29	33.08	27.34	.0636	2.30	1.52	1.14	429.67	429.67	429.67	1.000	.00	.00	.00
3	Node 0 <--> Node 2A	754.10	44	46.33	85.70	57.89	.0768	141.94	11.91	10.20	754.10	754.10	754.10	1.000	.00	.00	.00
4	Node 2 <--> Node 3A	414.05	28	24.73	32.04	27.29	.0659	3.55	1.88	1.50	414.05	414.05	414.05	1.000	.00	.00	.00
5	Node 2 <--> Node 4	923.59	28	71.36	142.68	93.33	.1011	305.48	17.48	13.72	923.59	923.59	923.59	1.000	.00	.00	.00
6	Node 2A <--> Node 3A	212.28	44	12.33	36.73	16.01	.0754	38.47	6.20	3.91	212.28	212.28	212.28	1.000	.00	.00	.00
7	Node 2A <--> Node 3B	364.53	0	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
8	Node 3A <--> Node 3B	543.65	0	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
9	Node 3A <--> Node 4	462.62	72	45.93	92.47	68.53	.1481	123.49	11.11	8.52	462.62	462.62	462.62	1.000	.00	.00	.00
10	Node 3B <--> Node 5	633.33	0	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
11	Node 3B <--> Node 6B	578.11	0	.00	.00	.00	.0000	.00	.00	.00	.00	.00	.00	.000	.00	.00	.00
12	Node 4 <--> Node 23	216.26	50	13.21	39.59	28.97	.1339	33.22	5.76	4.09	216.26	216.26	216.26	1.000	.00	.00	.00
13	Node 23 <--> Node 5 (24)	232.99	32	14.28	39.84	23.65	.1015	43.84	6.62	5.16	232.99	232.99	232.99	1.000	.00	.00	.00
14	Node 23 <--> Node 5 (F1)	404.31	18	24.76	62.67	42.30	.1046	161.87	12.72	10.42	404.31	404.31	404.31	1.000	.00	.00	.00
15	Node 5 <--> Node 6B	233.30	6	15.04	38.24	28.90	.1239	96.90	9.84	8.31	233.30	233.30	233.30	1.000	.00	.00	.00
16	Node 5 <--> Node 6A	201.28	15	12.43	32.91	19.36	.0962	45.16	6.72	5.88	201.28	201.28	201.28	1.000	.00	.00	.00
17	Node 5 <--> Node 6	225.64	29	12.78	34.76	19.80	.0877	52.36	7.24	6.12	225.64	225.64	225.64	1.000	.00	.00	.00
18	Node 6B <--> Node 7	721.31	17	82.33	124.63	109.06	.1512	145.08	12.04	9.84	721.31	721.31	721.31	1.000	.00	.00	.00
19	Node 6B <--> Node F2	251.22	39	14.64	42.16	23.60	.0940	102.62	10.13	9.28	251.22	251.22	251.22	1.000	.00	.00	.00
20	Node 6A <--> Node 7	546.79	6	81.60	115.09	93.17	.1704	148.80	12.20	7.97	698.08	698.08	546.79	1.000	.00	.00	.00
21	Node 6 <--> Node 7	728.62	7	65.92	110.19	93.83	.1288	276.03	16.61	13.98	728.62	728.62	728.62	1.000	.00	.00	.00
22	Node 6A <--> Node F2	139.70	9	8.05	18.93	10.22	.0732	12.34	3.51	2.39	139.70	139.70	139.70	1.000	.00	.00	.00
23	Node 6 <--> Node F2	114.83	22	6.56	19.86	9.64	.0839	17.65	4.20	3.40	114.83	114.83	114.83	1.000	.00	.00	.00
24	Node 7 <--> BERING SEA	342.29	30	21.74	53.23	34.44	.1006	92.03	9.59	7.73	342.29	342.29	342.29	1.000	.00	.00	.00
25	Node F2 <--> BERING SEA	917.54	70	77.46	137.99	102.30	.1115	231.49	15.21	13.52	917.54	917.54	917.54	1.000	.00	.00	.00
26	Node 4 <--> Node 6B	498.28	50	37.89	89.80	65.55	.1316	163.22	12.78	10.34	498.28	498.28	498.28	1.000	.00	.00	.00

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COMMAND LINE VARIABLES:
   month =  4 = APRIL
   print option = 1 = Summary Stats Sent to Print File
   transit direction =  2 = Bering Sea to Murmansk [E to W]
   number of transits =    3
   ship class =  3 = STREKALOVSKI
       cost per day = $ 11250.00(US)
       cost of escort per day = $       .00(US)
       maximum speed = 15.2 knots
```

SUMMARY OF DATA LOGGED FOR TRANSIT 1

	MINIMUM	MAXIMUM	MEAN	VARIANCE	STANDARD DEVIATION	AVERAGE DEVIATION
Fog Factor	.52	1.00	.83	.04	.19	.17
Icing Factor	1.00	1.00	1.00	.00	.00	.00
Snow Storm Factor	.51	1.00	.90	.03	.18	.15
Darkness Factor	.67	1.00	.97	.01	.08	.05
Permanent Current Vector (kt)	-.40	.19	-.10	.02	.15	.13
Wind-Induced Current Vector (kt)	-.42	.44	.01	.02	.15	.11
Ship Speed (kt)	-.06	14.86	5.77	4.04	2.01	1.12
Wave Height (m)	.50	4.00	1.28	.54	.74	.51
Wind Speed (kt)	2.50	22.50	6.90	15.73	3.97	2.93

	FOG	ICING	WAVES	SNOW STM	DARKNESS	ICE CONCENTRATION (%)					ICE THICKNESS (cm)				
						ICE FREE	20	50	75	100	ICE FREE	<120	150	210	>240
TOTAL TIME ENCOUNTERED (hr)	34.96	.00	36.62	73.20	92.00	36.62	.00	.00	42.49	487.99	36.62	158.80	189.24	182.45	.00
PERCENT OF TRANSIT TIME	6.16	.00	6.46	12.91	16.22	6.46	.00	.00	7.49	86.05	6.46	28.00	33.37	32.17	.00
TOTAL DISTANCE ENCOUNTERED (nm)	228.85	.00	350.20	479.55	552.06	350.20	.00	.00	208.99	2715.20	350.20	977.66	1057.90	888.63	.00
PERCENT OF TRANSIT DISTANCE	6.99	.00	10.70	14.65	16.86	10.70	.00	.00	6.38	82.92	10.70	29.86	32.31	27.14	.00
TOTAL NUMBER OF SEGMENTS	8	0	8	10	24	8	0	0	8	89	8	31	33	33	0
PERCENT OF SEGMENTS	7.62	.00	7.62	9.52	22.86	7.62	.00	.00	7.62	84.76	7.62	29.52	31.43	31.43	.00

	HOURS	DAYS	DAILY RATE	COST
Cost of Cargo Vessel	567.10	24.00	11250.00	270000.00
Cost of Escort Vessel	487.99	21.00	.00	.00
Fees and Tariffs	----	----	----	100000.00
		TOTAL COST OF TRANSIT		370000.00
		COST PER NAUTICAL MILE		113.00
		COST PER HOUR		652.44

Example of output for print option 2[†]

Table C.1. Description of column headings for transit log table printed under output option 2.

Column heading		Description
FROM	REC	Record number of starting node or data point
	PT	Node or data point identification
TO	REC	Record number of ending node or data point
	PT	Node or data point identification
	LEG	Leg identification
	LAT	Latitude of ending node or data point (deg, min)
	LON	Longitude of ending node or data point (deg, min)
SEG		Segment number
FOG	Y/N	Is it foggy? 0 = No, 1 = Yes
	FACT	Slowing factor due to fog
ICING	Y/N	Are icing conditions present? 0 = No, 1 = Yes
	FACT	Slowing factor due to icing
SNOW-STORM	Y/N	Is there a snowstorm raging? 0 = No, 1 = Yes
	FACT	Slowing factor due to snowstorms
ICE	CONC	Sea ice concentration (%)
	THIC	Sea ice thickness (cm)
	PRES	Relative pressure exerted by the sea ice pack (none, low, medium, high)
	FACT	Slowing factor attributed to ice pack pressure
WIND	DIR	Wind direction (deg)
	SPD	Wind speed (kn)
WIND CUR	DIR	Direction of the wind-induced current (deg)
	SPD	Speed of the wind-induced current (kn)
	VEC	Speed of wind-induced current vector in the direction of the ship's heading (kn)
WAVE HT		Wave height (m)
PERM CUR	DIR	Direction of the permanent current (deg)
	SPD	Speed of the permanent current (kn)
	VEC	Speed of the permanent current vector in the direction of the ship's heading (kn)
ESCORT	Y/N	Is the ship under icebreaker escort? 0 = No, 1 = Yes
	HRS	Running total of icebreaker escort time (hr)
DARK	Y/N	Is it dark? 0 = No, 1 = Yes
	FACT	Slowing factor due to darkness
SPEED		Ship speed, adjusted for currents, slowing factors, ice conditions, and escort
HEAD		Initial ship heading from starting to ending node or data point (deg)
DISTANCE (nm)	SEGMENT	Distance travelled during this segment (nm)
	TOTAL	Cumulative distance travelled during this transit (nm)
ELAPSD TIME	SEGMENT	Elapsed time during this segment (hr)
	TOT	Cumulative time elapsed during transit (hr)

[†] Output for option 2 also includes summary statistics provided under options 0 and 1

COMMAND LINE VARIABLES:
month = 10 = OCTOBER
print option = 2 = Detailed Output Sent to Print File
transit direction = 1 = Murmansk to Bering Sea [W to E]
number of transits = 3
ship class = 2 = LUNNI
cost per day = $ 13500.00(US)
cost of escort per day = $ .00(US)
maximum speed = 14.5 knots

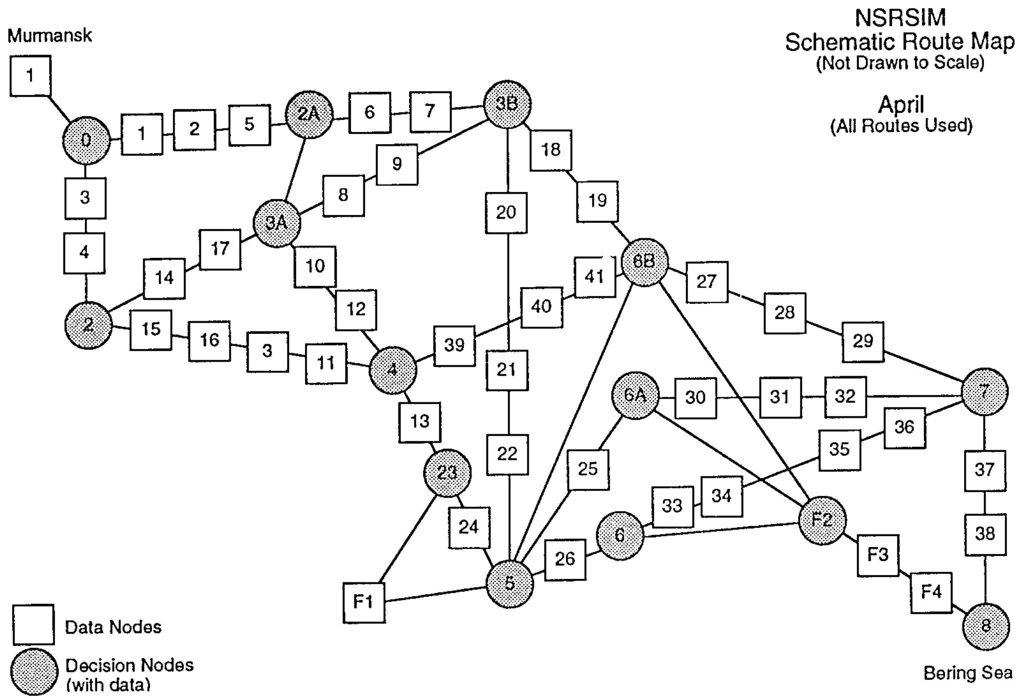
TABLE OF VALUES USED FOR EACH SEGMENT OF TRANSIT 2

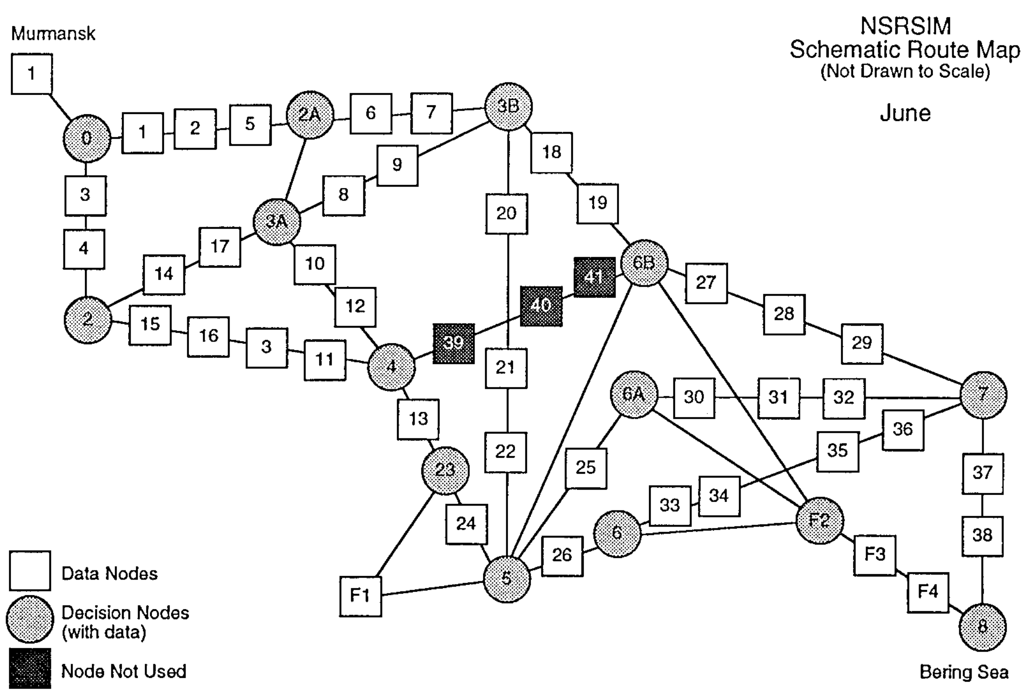
FROM REC	FROM PT	TO REC	TO PT	TO LEG	TO LAT	TO LON	SEG	FOG Y/N	FOG FACT	ICING Y/N	ICING FACT	SNOW STM Y/N	SNOW STM FACT	ICE CONC	ICE THIC	ICE PRES	ICE FACT	WIND DIR	WIND SPD	WIND CUR DIR	WIND CUR SPD	WIND CUR VEC	WAVE HT	PERM CUR DIR	PERM CUR SPD	PERM CUR VEC	ESCORT Y/N	ESCORT HRS	DARK Y/N	DARK FACT	SPEED	HEAD	DISTANCE (nm) SEGMENT	DISTANCE (nm) TOTAL	ELAPSD TIME SEGMNT	ELAPSD TIME TOT
1	1	2	0	node	69 57	35 43	1	0	1.00	0	1.00	0	1.00	0.	0.	NONE	1.00	157.5	2.5	337.5	.06	.03	2.50	45.0	.20	.20	0	.00	0	1.00	14.73	38.4	42.55	42.55	2.89	2.89
2	0	3	1	0-2A	72 30	40 00	1	0	1.00	0	1.00	0	1.00	0.	0.	NONE	1.00	247.5	7.5	67.5	.19	.13	1.50	.0	.20	.18	0	.00	0	1.00	14.82	22.9	75.74	118.29	5.11	8.00
2	0	3	1	0-2A	72 30	40 00	2	0	1.00	0	1.00	0	1.00	0.	0.	NONE	1.00	67.5	17.5	247.5	.44	-.31	1.50	.0	.20	.18	0	.00	1	.56	7.46	22.9	59.72	178.00	8.00	16.00
2	0	3	1	0-2A	72 30	40 00	3	0	1.00	0	1.00	0	1.00	0.	0.	NONE	1.00	112.5	2.5	292.5	.06	.00	1.50	.0	.20	.18	0	.00	1	.56	8.34	22.9	38.48	216.48	4.61	20.61
3	1	4	2	0-2A	74 13	50 57	1	0	1.00	1	.97	0	1.00	0.	0.	NONE	1.00	292.5	12.5	112.5	.31	.17	.50	.0	.20	.11	0	.00	1	.56	8.17	56.1	27.66	244.14	3.39	24.00
3	1	4	2	0-2A	74 13	50 57	2	1	.96	0	1.00	1	.77	0.	0.	NONE	1.00	67.5	2.5	247.5	.06	-.06	.50	.0	.20	.11	0	.00	0	1.00	10.49	56.1	83.91	328.05	8.00	32.00
3	1	4	2	0-2A	74 13	50 57	3	0	1.00	0	1.00	0	1.00	0.	0.	NONE	1.00	112.5	2.5	292.5	.06	-.03	.50	.0	.20	.11	0	.00	1	.58	8.44	56.1	67.54	395.60	8.00	40.00
3	1	4	2	0-2A	74 13	50 57	4	0	1.00	0	1.00	0	1.00	0.	0.	NONE	1.00	202.5	7.5	22.5	.19	.16	1.50	.0	.20	.11	0	.00	1	.58	8.63	56.1	34.92	430.52	4.05	44.05
4	2	5	5	0-2A	75 55	56 30	1	0	1.00	0	1.00	1	.54	0.	0.	NONE	1.00	337.5	12.5	157.5	.31	-.16	.50	.0	.30	.24	0	.00	1	.58	7.85	37.4	31.05	461.57	3.95	48.00
4	2	5	5	0-2A	75 55	56 30	2	0	1.00	1	.92	0	1.00	0.	0.	NONE	1.00	202.5	7.5	22.5	.19	.18	.50	.0	.30	.24	0	.00	0	1.00	13.76	37.4	102.28	563.85	7.43	55.43
5	5	6	2A	node	77 39	71 46	1	1	.78	1	.89	0	1.00	0.	0.	NONE	1.00	292.5	7.5	112.5	.19	.10	1.50	270.0	.10	-.08	0	.00	0	1.00	10.03	56.3	5.71	569.56	.57	56.00
5	5	6	2A	node	77 39	71 46	2	0	1.00	0	1.00	0	1.00	0.	0.	NONE	1.00	112.5	17.5	292.5	.44	-.24	1.50	270.0	.10	-.08	0	.00	1	.72	10.08	56.3	80.66	650.22	8.00	64.00
5	5	6	2A	node	77 39	71 46	3	0	1.00	1	1.00	0	1.00	0.	0.	NONE	1.00	247.5	7.5	67.5	.19	.18	.50	270.0	.10	-.08	0	.00	1	.72	10.48	56.3	83.87	734.09	8.00	72.00
5	5	6	2A	node	77 39	71 46	4	0	1.00	1	.86	0	1.00	0.	0.	NONE	1.00	337.5	2.5	157.5	.06	-.01	1.50	270.0	.10	-.08	0	.00	0	1.00	12.35	56.3	62.56	796.65	5.07	77.07
6	2A	35	3A	node	74 11	74 42	1	0	1.00	0	1.00	0	1.00	50.	60.	NONE	1.00	292.5	2.5	112.5	.06	-.01	.00	.0	.10	-.08	0	.00	0	1.00	7.42	212.3	21.79	818.44	2.93	80.00
6	2A	35	3A	node	74 11	74 42	2	0	1.00	0	1.00	0	1.00	50.	60.	NONE	1.00	202.5	22.5	22.5	.56	-.55	.00	.0	.10	-.08	0	.00	1	.95	6.48	212.3	51.85	870.29	8.00	88.00
6	2A	35	3A	node	74 11	74 42	3	1	.97	0	1.00	0	1.00	50.	60.	NONE	1.00	157.5	12.5	337.5	.31	-.18	.00	.0	.10	-.08	0	.00	1	.95	6.86	212.3	54.84	925.13	8.00	96.00
6	2A	35	3A	node	74 11	74 42	4	0	1.00	0	1.00	1	.77	50.	60.	NONE	1.00	337.5	2.5	157.5	.06	.04	.00	.0	.10	-.08	0	.00	0	1.00	5.77	212.3	46.16	971.29	8.00	104.00
6	2A	35	3A	node	74 11	74 42	5	0	1.00	0	1.00	0	1.00	50.	60.	NONE	1.00	22.5	7.5	202.5	.19	.18	.00	.0	.10	-.08	0	.00	1	.80	6.13	212.3	37.64	1008.93	6.14	110.14
35	3A	41	10	3A-4	76 12	86 28	1	0	1.00	0	1.00	0	1.00	75.	60.	NONE	1.00	202.5	7.5	22.5	.19	.17	.00	.0	.10	.06	0	.00	1	.80	4.56	50.6	36.49	1045.42	8.00	118.14
35	3A	41	10	3A-4	76 12	86 28	2	0	1.00	0	1.00	0	1.00	75.	60.	NONE	1.00	112.5	2.5	292.5	.06	-.03	.00	.0	.10	.06	0	.00	1	.80	4.37	50.6	8.13	1053.55	1.86	120.00
35	3A	41	10	3A-4	76 12	86 28	3	0	1.00	0	1.00	0	1.00	75.	60.	NONE	1.00	67.5	2.5	247.5	.06	-.06	.00	.0	.10	.06	0	.00	0	1.00	5.40	50.6	43.23	1096.78	8.00	128.00
35	3A	41	10	3A-4	76 12	86 28	4	0	1.00	0	1.00	0	1.00	75.	60.	NONE	1.00	157.5	7.5	337.5	.19	.05	.00	.0	.10	.06	0	.00	1	.66	3.70	50.6	29.63	1126.40	8.00	136.00
35	3A	41	10	3A-4	76 12	86 28	5	0	1.00	0	1.00	0	1.00	75.	60.	NONE	1.00	202.5	17.5	22.5	.44	.39	.00	.0	.10	.06	0	.00	1	.66	4.03	50.6	32.28	1158.68	8.00	144.00
35	3A	41	10	3A-4	76 12	86 28	6	0	1.00	0	1.00	0	1.00	75.	60.	NONE	1.00	112.5	7.5	292.5	.19	-.09	.00	.0	.10	.06	0	.00	0	1.00	5.38	50.6	43.00	1201.69	8.00	152.00
35	3A	41	10	3A-4	76 12	86 28	7	0	1.00	0	1.00	0	1.00	75.	60.	NONE	1.00	22.5	12.5	202.5	.31	-.28	.00	.0	.10	.06	0	.00	1	.87	4.50	50.6	23.88	1225.57	5.31	157.31

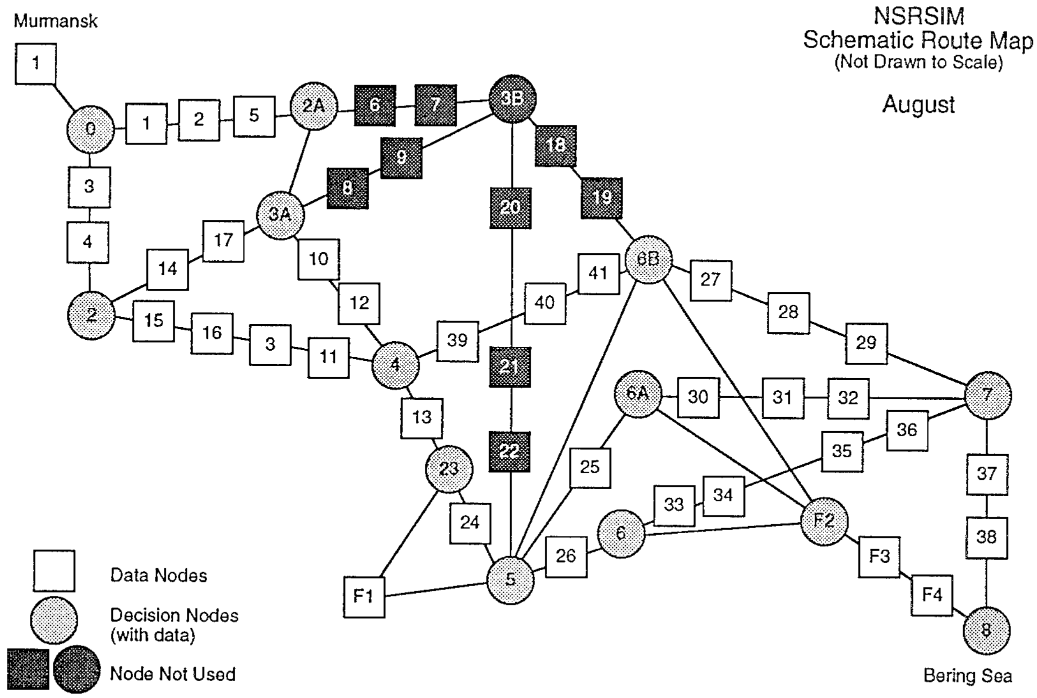
41 10	42 12 3A-4 77 06 94 28	1	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	22.5 12.5	202.5 .31 -.25	.00	.0 .30 .15	0 .00	1 .87	4.61	60.2	36.90 1262.47	8.00 165.31
41 10	42 12 3A-4 77 06 94 28	2	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	337.5 2.5	157.5 .06 -.01	.00	.0 .30 .15	0 .00	1 .87	4.85	60.2	13.05 1275.52	2.69 168.00
41 10	42 12 3A-4 77 06 94 28	3	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	112.5 7.5	292.5 .19 -.11	.00	.0 .30 .15	0 .00	0 1.00	5.43	60.2	43.48 1319.00	8.00 176.00
41 10	42 12 3A-4 77 06 94 28	4	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	202.5 7.5	22.5 .19 .15	.00	.0 .30 .15	0 .00	1 .56	3.31	60.2	26.48 1345.48	8.00 184.00
41 10	42 12 3A-4 77 06 94 28	5	0 1.00	1 .90	0 1.00	75. 60. NONE 1.00	157.5 2.5	337.5 .06 .01	.00	.0 .30 .15	0 .00	1 .56	2.86	60.2	3.39 1348.87	1.19 185.19
42 12	23 4 node 77 42 103 26	1	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	337.5 2.5	157.5 .06 .00	.00	225.0 .10 -.09	0 .00	1 .56	2.92	68.6	19.91 1368.78	6.81 192.00
42 12	23 4 node 77 42 103 26	2	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	157.5 2.5	337.5 .06 .00	.00	225.0 .10 -.09	0 .00	0 1.00	5.31	68.6	42.46 1411.24	8.00 200.00
42 12	23 4 node 77 42 103 26	3	0 1.00	1 .90	0 1.00	75. 60. NONE 1.00	337.5 12.5	157.5 .31 .01	.00	225.0 .10 -.09	0 .00	1 .67	3.16	68.6	25.30 1436.54	8.00 208.00
42 12	23 4 node 77 42 103 26	4	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	157.5 7.5	337.5 .19 .00	.00	225.0 .10 -.09	0 .00	1 .67	3.51	68.6	28.10 1464.64	8.00 216.00
42 12	23 4 node 77 42 103 26	5	0 1.00	1 .99	1 .92	75. 60. NONE 1.00	202.5 2.5	22.5 .06 .04	.00	225.0 .10 -.09	0 .00	0 1.00	4.90	68.6	6.91 1471.55	1.41 217.41
23 4	43 39 4-6B 77 54 122 53	1	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	337.5 7.5	157.5 .19 .03	.00	225.0 .10 -.08	0 .00	0 1.00	5.35	77.7	35.25 1506.80	6.59 224.00
23 4	43 39 4-6B 77 54 122 53	2	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	67.5 2.5	247.5 .06 -.06	.00	225.0 .10 -.08	0 .00	1 .50	2.57	77.7	20.53 1527.32	8.00 232.00
23 4	43 39 4-6B 77 54 122 53	3	0 1.00	1 .96	1 .55	75. 60. NONE 1.00	157.5 12.5	337.5 .31 -.06	.00	225.0 .10 -.08	0 .00	1 .50	2.46	77.7	19.65 1546.97	8.00 240.00
23 4	43 39 4-6B 77 54 122 53	4	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	202.5 7.5	22.5 .19 .11	.00	225.0 .10 -.08	0 .00	0 1.00	5.42	77.7	43.38 1590.35	8.00 248.00
23 4	43 39 4-6B 77 54 122 53	5	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	202.5 2.5	22.5 .06 .04	.00	225.0 .10 -.08	0 .00	1 .59	3.11	77.7	24.89 1615.25	8.00 256.00
23 4	43 39 4-6B 77 54 122 53	6	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	292.5 7.5	112.5 .19 .15	.00	225.0 .10 -.08	0 .00	1 .59	3.23	77.7	25.84 1641.09	8.00 264.00
23 4	43 39 4-6B 77 54 122 53	7	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	112.5 7.5	292.5 .19 -.15	.00	225.0 .10 -.08	0 .00	0 1.00	5.16	77.7	41.29 1682.38	8.00 272.00
23 4	43 39 4-6B 77 54 122 53	8	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	292.5 2.5	112.5 .06 .05	.00	225.0 .10 -.08	0 .00	1 .96	5.12	77.7	34.76 1717.14	6.78 278.78
43 39	44 40 4-6B 77 29 127 43	1	0 1.00	0 1.00	0 1.00	100. 60. NONE 1.00	67.5 2.5	247.5 .06 -.05	.00	45.0 .20 .09	1 8.00	1 1.00	7.64	109.7	61.11 1778.25	8.00 286.78
43 39	44 40 4-6B 77 29 127 43	2	0 1.00	1 1.00	0 1.00	100. 60. NONE 1.00	292.5 7.5	112.5 .19 .19	.00	45.0 .20 .09	1 8.72	1 1.00	7.87	109.7	5.66 1783.91	.72 287.50
44 40	45 41 4-6B 76 59 132 13	1	0 1.00	0 1.00	0 1.00	100. 60. NONE 1.00	202.5 7.5	22.5 .19 -.01	.00	315.0 .20 -.19	1 9.22	1 1.00	7.41	114.5	3.69 1787.60	.50 288.00
44 40	45 41 4-6B 76 59 132 13	2	0 1.00	0 1.00	0 1.00	100. 60. NONE 1.00	157.5 2.5	337.5 .06 -.05	.00	315.0 .20 -.19	1 17.22	0 1.00	7.37	114.5	58.94 1846.54	8.00 296.00
44 40	45 41 4-6B 76 59 132 13	3	0 1.00	0 1.00	0 1.00	100. 60. NONE 1.00	112.5 7.5	292.5 .19 -.19	.00	315.0 .20 -.19	1 17.80	1 1.00	7.23	114.5	4.24 1850.78	.59 296.59
45 41	7 6B node 76 46 140 54	1	0 1.00	0 1.00	0 1.00	100. 60. LOW .75	157.5 7.5	337.5 .19 -.18	.00	315.0 .30 -.30	1 25.80	1 1.00	5.22	137.0	41.80 1892.58	8.00 304.59
45 41	7 6B node 76 46 140 54	2	0 1.00	0 1.00	0 1.00	100. 60. NONE 1.00	22.5 2.5	202.5 .06 .03	.00	315.0 .30 -.30	1 33.22	1 1.00	7.33	137.0	54.31 1946.89	7.41 312.00
45 41	7 6B node 76 46 140 54	3	0 1.00	0 1.00	0 1.00	100. 60. LOW .75	247.5 2.5	67.5 .06 .02	.00	315.0 .30 -.30	1 37.45	0 1.00	5.42	137.0	22.94 1969.83	4.23 316.23
7 6B	47 F2 node 73 00 148 00	1	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	67.5 12.5	247.5 .31 -.04	.00	90.0 .20 .10	0 37.45	0 1.00	5.46	150.4	20.58 1990.41	3.77 320.00
7 6B	47 F2 node 73 00 148 00	2	0 1.00	1 .89	0 1.00	75. 60. NONE 1.00	247.5 2.5	67.5 .06 .01	.00	90.0 .20 .10	0 37.45	1 .67	3.30	150.4	26.38 2016.79	8.00 328.00
7 6B	47 F2 node 73 00 148 00	3	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	337.5 2.5	157.5 .06 .06	.00	90.0 .20 .10	0 37.45	1 .67	3.76	150.4	30.09 2046.88	8.00 336.00
7 6B	47 F2 node 73 00 148 00	4	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	247.5 2.5	67.5 .06 .01	.00	90.0 .20 .10	0 37.45	0 1.00	5.51	150.4	44.05 2090.93	8.00 344.00
7 6B	47 F2 node 73 00 148 00	5	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	112.5 7.5	292.5 .19 -.15	.00	90.0 .20 .10	0 37.45	1 .86	4.62	150.4	36.94 2127.87	8.00 352.00
7 6B	47 F2 node 73 00 148 00	6	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	22.5 7.5	202.5 .19 .12	.00	90.0 .20 .10	0 37.45	1 .86	4.88	150.4	39.05 2166.92	8.00 360.00
7 6B	47 F2 node 73 00 148 00	7	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	22.5 2.5	202.5 .06 .04	.00	90.0 .20 .10	0 37.45	0 1.00	5.54	150.4	44.30 2211.22	8.00 368.00
7 6B	47 F2 node 73 00 148 00	8	0 1.00	1 .91	0 1.00	75. 60. NONE 1.00	67.5 7.5	247.5 .19 -.02	.00	90.0 .20 .10	0 37.45	1 .99	4.93	150.4	9.83 2221.05	2.00 370.00
47 F2	48 F3 F2-8 71 00 162 00	1	0 1.00	1 .98	0 1.00	75. 60. NONE 1.00	292.5 2.5	112.5 .06 .06	.00	.0 .10 -.03	0 37.45	1 .99	5.27	108.0	42.12 2263.17	8.00 378.00
47 F2	48 F3 F2-8 71 00 162 00	2	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	292.5 2.5	112.5 .06 .06	.00	.0 .10 -.03	0 37.45	1 .99	5.36	108.0	32.17 2295.34	6.00 384.00
47 F2	48 F3 F2-8 71 00 162 00	3	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	67.5 7.5	247.5 .19 -.14	.00	.0 .10 -.03	0 37.45	0 1.00	5.23	108.0	41.81 2337.16	8.00 392.00
47 F2	48 F3 F2-8 71 00 162 00	4	0 1.00	0 1.00	1 .88	75. 60. NONE 1.00	157.5 2.5	337.5 .06 -.04	.00	.0 .10 -.03	0 37.45	1 .92	4.67	108.0	37.32 2374.48	8.00 400.00
47 F2	48 F3 F2-8 71 00 162 00	5	0 1.00	1 .96	0 1.00	75. 60. NONE 1.00	292.5 2.5	112.5 .06 .06	.00	.0 .10 -.03	0 37.45	1 .92	4.80	108.0	38.40 2412.87	8.00 408.00
47 F2	48 F3 F2-8 71 00 162 00	6	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	112.5 2.5	292.5 .06 -.06	.00	.0 .10 -.03	0 37.45	0 1.00	5.31	108.0	42.45 2455.33	8.00 416.00
47 F2	48 F3 F2-8 71 00 162 00	7	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	157.5 12.5	337.5 .31 -.20	.00	.0 .10 -.03	0 37.45	1 .61	3.07	108.0	24.55 2479.88	8.00 424.00
47 F2	48 F3 F2-8 71 00 162 00	8	0 1.00	1 .97	0 1.00	75. 60. NONE 1.00	157.5 2.5	337.5 .06 -.04	.00	.0 .10 -.03	0 37.45	1 .61	3.14	108.0	25.09 2504.97	8.00 432.00

47 F2	48 F3 F2-8 71 00 162 00	9	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	337.5 7.5	157.5 .19 .12	.00	.0 .10 -.03	0 37.45	0 1.00	5.49	108.0	.71 2505.68	.13 432.13
48 F3	49 F4 F2-8 69 30 178 00	1	0 1.00	0 1.00	1 .81	75. 60. NONE 1.00	67.5 7.5	247.5 .19 -.16	.00	270.0 .20 -.20	0 37.45	0 1.00	4.02	97.9	31.61 2537.29	7.87 440.00
48 F3	49 F4 F2-8 69 30 178 00	2	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	22.5 7.5	202.5 .19 -.05	.00	270.0 .20 -.20	0 37.45	1 .95	4.90	97.9	39.21 2576.51	8.00 448.00
48 F3	49 F4 F2-8 69 30 178 00	3	0 1.00	1 .97	0 1.00	75. 60. NONE 1.00	22.5 17.5	202.5 .44 -.11	.00	270.0 .20 -.20	0 37.45	1 .95	4.69	97.9	37.52 2614.03	8.00 456.00
48 F3	49 F4 F2-8 69 30 178 00	4	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	292.5 7.5	112.5 .19 .18	.00	270.0 .20 -.20	0 37.45	0 1.00	5.38	97.9	43.07 2657.10	8.00 464.00
48 F3	49 F4 F2-8 69 30 178 00	5	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	157.5 2.5	337.5 .06 -.03	.00	270.0 .20 -.20	0 37.45	1 .79	4.03	97.9	32.22 2689.31	8.00 472.00
48 F3	49 F4 F2-8 69 30 178 00	6	0 1.00	1 .99	0 1.00	75. 60. NONE 1.00	157.5 2.5	337.5 .06 -.03	.00	270.0 .20 -.20	0 37.45	1 .79	4.00	97.9	32.01 2721.32	8.00 480.00
48 F3	49 F4 F2-8 69 30 178 00	7	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	337.5 2.5	157.5 .06 .03	.00	270.0 .20 -.20	0 37.45	0 1.00	5.23	97.9	41.87 2763.19	8.00 488.00
48 F3	49 F4 F2-8 69 30 178 00	8	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	247.5 7.5	67.5 .19 .16	.00	270.0 .20 -.20	0 37.45	1 .56	3.00	97.9	24.00 2787.19	8.00 496.00
48 F3	49 F4 F2-8 69 30 178 00	9	0 1.00	0 1.00	1 .95	75. 60. NONE 1.00	22.5 12.5	202.5 .31 -.08	.00	270.0 .20 -.20	0 37.45	1 .56	2.76	97.9	22.08 2809.27	8.00 504.00
48 F3	49 F4 F2-8 69 30 178 00	10	0 1.00	0 1.00	0 1.00	75. 60. NONE 1.00	22.5 17.5	202.5 .44 -.11	.00	270.0 .20 -.20	0 37.45	0 1.00	5.09	97.9	30.97 2840.24	6.08 510.08
49 F4	14 8 Berin 66 41 189 03	1	0 1.00	0 1.00	0 1.00	0. 0. NONE 1.00	22.5 7.5	202.5 .19 .02	2.50	45.0 .50 .14	0 37.45	0 1.00	14.66	119.1	28.10 2868.34	1.92 512.00
49 F4	14 8 Berin 66 41 189 03	2	0 1.00	0 1.00	0 1.00	0. 0. NONE 1.00	67.5 7.5	247.5 .19 -.12	.50	45.0 .50 .14	0 37.45	1 .72	10.40	119.1	83.21 2951.55	8.00 520.00
49 F4	14 8 Berin 66 41 189 03	3	0 1.00	1 .99	0 1.00	0. 0. NONE 1.00	112.5 12.5	292.5 .31 -.31	.50	45.0 .50 .14	0 37.45	1 .72	9.38	119.1	75.03 3026.57	8.00 528.00
49 F4	14 8 Berin 66 41 189 03	4	0 1.00	1 .87	1 .78	0. 0. NONE 1.00	337.5 7.5	157.5 .19 .15	.50	45.0 .50 .14	0 37.45	0 1.00	10.06	119.1	80.50 3107.07	8.00 536.00
49 F4	14 8 Berin 66 41 189 03	5	0 1.00	0 1.00	0 1.00	0. 0. NONE 1.00	67.5 12.5	247.5 .31 -.19	1.50	45.0 .50 .14	0 37.45	1 .54	7.73	119.1	31.52 3138.59	4.08 540.08

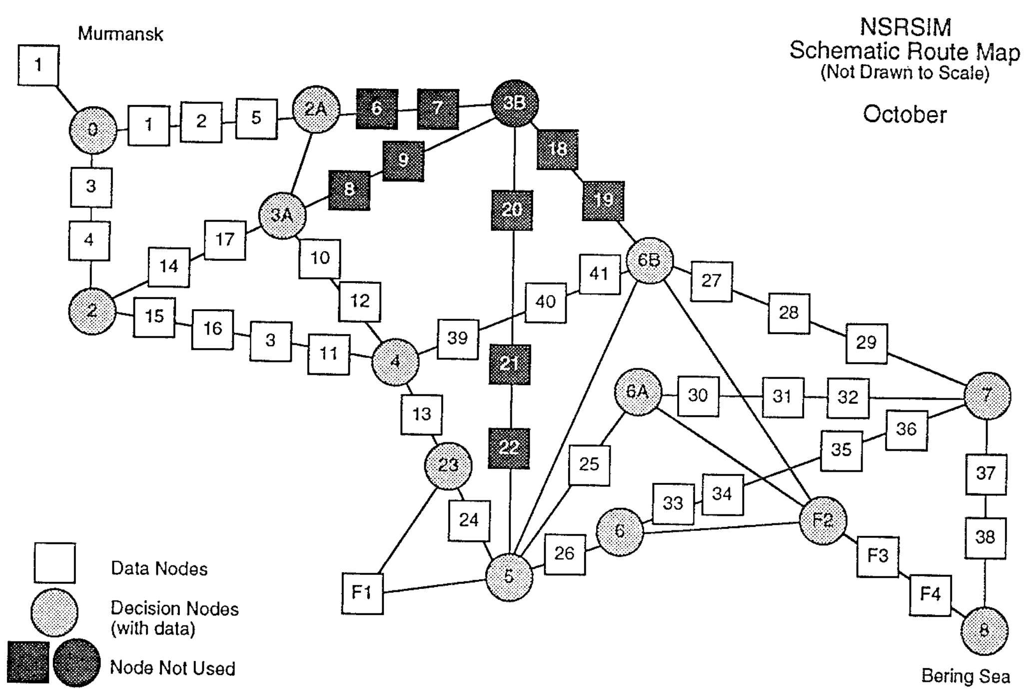
APPENDIX D: NODAL SCHEMES FOR EACH MONTH OF TRANSIT







NSRSIM
Schematic Route Map
(Not Drawn to Scale)
August
Murmansk
Bering Sea
Data Nodes
Decision Nodes
(with data)
Node Not Used



NSRSIM
Schematic Route Map
(Not Drawn to Scale)
October
Murmansk
Bering Sea
Data Nodes
Decision Nodes
(with data)
Node Not Used

APPENDIX E: INFORMATION ABOUT THE NUCLEAR ICEBREAKER *YAMAL*

(From R. Headland, unpublished)

The ship is one of three *Rossiya*-class icebreakers leased to the Murmansk Shipping Company by the Russian Government (her sisters are *Rossiya* [launched in 1985] and *Sovietskiy Soyuz* [1990]).

The name is derived from a Nenets word meaning "End of the Earth," also applied to the Yamal Peninsula.

Her keel was laid on 5 May 1986 in St. Petersburg and she was launched on 28 October 1992. Registered number M 43048 and International Call Sign UPIL.

Length overall 150 m, at waterline 136 m. Breadth overall 30 m, at waterline 28 m. Draft 11.8 m. Height: keel-to-masthead: 55 m on 12 decks (four below water).

The ice knife, a 2-m-thick steel casting, is situated about 22 m aft of the prow. Displacement: 23,455 tonnes; capacity 20,646 gross registered tons.

The cast steel prow is 50 cm thick at its strongest point.

The hull is double with water ballast between them. The outer hull is 48 mm thick armour steel where ice is met and 25 mm elsewhere.

Eight bulkheads allow the ship to be divided into nine watertight compartments.

Icebreaking is assisted by an air bubbling system (delivering 24 m^3/s from jets 9 m below the surface), polymer coatings, specialized hull design, and capability of rapid movement of ballast water. Ice may be broken while moving ahead or astern.

An MI-2 or KA-32 helicopter is carried for observing ice conditions ahead of the ship. The ship is equipped to undertake short tow operations when assisting other vessels through ice.

Search lights and other high intensity illumination are available for work during winter darkness.

Complement: 131 (49 officers and 82 other ranks).

Power is supplied by two pressurized water nuclear reactors using enriched uranium fuel rods. Each reactor weighs 160 tonnes; both are contained in a closed compartment under reduced pressure. Fuel consumption is approximately 200 g a day of heavy isotopes when breaking thick ice. Five hundred kg of uranium isotopes are contained in each reactor when fully fueled. This allows about 4 years between changes of the reactor cores. Shielding of the reactor is by steel, high-density concrete, and water. The chain reaction can be stopped in 0–6 seconds by full insertion of the safety rods. Used cores are extracted and new ones installed in Murmansk, spent fuel is reprocessed, and waste is disposed of at a nuclear waste plant. Ambient radiation is monitored by 86 sensors distributed throughout the vessel. In accommodation areas this is 10 to 12 mRoentgen/h, within the reactor compartment at 50% power, 800 mRoentgen/h. The primary cooling fluid is water that passes directly to 4 boilers for each reactor; steam is produced at 30 kg/cm^2.

Main propulsion system: each set of boilers drives two steam turbines which turn three dynamos (thus six dynamos may operate). One kV DC is delivered to three double-wound motors connected directly to the propellers.

Electricity for other purposes is provided by five steam turbines turning dynamos that develop a total of 10 MW.

There are three propellers: the starboard and midship ones turn clockwise, port turns counterclockwise. Shafts are 20 m long. Screw velocity is between 120 and 180 rpm. Propellers are fixed, 5–7-m diameter and weigh 50 tonnes, each has four 7-tonne blades fixed by 9 bolts (16-tonne torque applied); inspection wells allow them to be examined while in operation. Four spare blades are carried; diving and other equipment is aboard so a blade may be replaced at sea, each operation takes from 1 to 4 days (three such changes have been necessary on *Rossiya* icebreakers since 1985). A propulsive effort of 480 tonnes can be delivered with 18–43 MW (25,000 shaft horsepower) from each screw (total 55.3 MW [75,000 shaft horsepower]). Power can be controlled at a rate of 1% per second.

Maximum speed is 22 knots (40 km/h); full speed in open water is 19.5 knots (35 km/h); breaking ice 2–3 m thick can be done at 3 knots (5.5 km/h) continuously. Maximum ice thickness that can be penetrated while navigating is estimated as 5 m; individual ridges estimated at 9-m thick have been broken through.

The helm controls one rudder, which turns 35° either way, operated by four hydraulic cylinders powered by one of two pumps. It is protected by an ice horn for moving astern. Steering may also be provided by directing air jets of the bubbling system (comparable to use of bow thrusters).

Auxiliary power is available from three diesel generating sets; one MW and two 250 kW.

Anchors: two 7-tonne anchors with 300 m of chain each, and four ice anchors.

Four deck cranes are aboard, the largest pair can lift 16 tonnes each.

Sea water distillation: two vacuum stills can supply 5 m^3 of fresh water per hour each (240 m^3 per day).

Differential ballast tanks are situated fore and aft, and athwart the ship; the pumps are capable of moving 1 m^3 of water per second.

Ship has 1280 compartments (cabins, storage areas, machine rooms, etc.).

Sufficient provisions and supplies can be carried to operate for 7 months.

Safety equipment includes: one launch, two fully enclosed lifeboats, and 18 inflatable life rafts.

APPENDIX F: CARGO SHIP AND ICEBREAKER CLASSIFICATION EQUIVALENCIES. (FROM TORRENS, 1994.)

Cargo ship classes:

		Ice class				
Organization	*Class symbol*	*High*		*Medium*		*Low*
Det norske Veritas (post-1971)	1A1	1A*	1A	1B	1C	
Finnish/Swedish rules (toll classes as per 1985)		IA Super	IA	IB	IC	II
American Bureau of Shipping (post-1971)	A1 (E)	IAA	IA	IB	IC	
Bureau Veritas (pre-1971)	I 3/3 E	I-Super	I	II	III	
Bureau Veritas (post-1971)	I 3/3 E	IA-Super	IA	IB	IC	
Bulgarian Register of Shipping	KM	ULA, UA	L1	L2	L3	L4
DDR Schiffs-Rev. und Klassif.	DSRK KM	Eis Arktis, Eis Super	Eis 1	Eis 2	Eis 3	Eis 4
Germanischer Lloyd	100 A4	E4	E3	E2	E1	
Lloyd's Register of Shipping (post-1971)	100 A1	1AS	1A	1B	1C	1D
Polski Register Statkow	KM	L1A, UL	L1	L2	L3	L4
Nippon Kaiji Kyokai	NS	IA Super	IA	IB	IC	
Register of Shipping People's Republic of China	ZCA	B1*	B1	B2	B3	
Register of Shipping of the USSR*	KM	ULA, UL	L1	L2	L3	L4
Registro Italiano Navale	100A-1.1	RG 1*	RG 1	RG 2	RG 3	
Registrul Naval Roman	RNR+M CM O	G 60, G 50	G40	G 30	G 20	G10
Canadian ASPPR rules/zones		A	B	C	D	E

Icebreaker classes:

	Ice class					
Organization	*High*					*Low*
Register of Shipping of the USSR	LL1	LL2	LL3	LL4		
Det norske Veritas (includes "Sealer" class)	Polar-30	Polar-20	Polar-10 Ice-15	Ice-10	Ice-05	
Lloyd's Register of Shipping	AC3	AC2	AAC1.5	AC1		
Canadian ASPPR rules/zones	Classes not available.					

*For Russian classes: L = ice; U = reinforced, A = Arctic.

APPENDIX G: TRANSLATION OF RUSSIAN MINISTRY OF TRANSPORT'S*

Preliminary Tariffs for Services Rendered to Ships at Commercial Sea Ports of the Russian Federation

Translated from Russian by Backbone Publishing Co.
Lenox Hill Station, PO Box 111, New York, NY 10021
Tel: (212) 535-0321; Fax: (212)535-5255

Contract DACA89-95-M-0707
May 30, 1995

Ministry of Transport of Russia
Department of Marine Transport
ORDER
Moscow No. 60 August 30, 1994

Contents: On the effectiveness of the "Interim regulation on the charges and fees for services rendered to ships at commercial sea ports of the Russian Federation"

1. To approve and make effective from October 1, 1994 the "Interim Regulation on the charges and fees for services rendered to ships at commercial sea ports of the Russian Federation.'
2. To annul as of October 1, 199 the order of the Ministry of the Merchant Marine of USSR dated November 30, 1987. N 186, including subsequent revisions and addenda.
3. Those fees for services rendered to Russian and foreign ships that are not covered by this "Interim Regulation" will be set by the commercial sea ports (Marine Administrations of the ports, AO "Port")
   Director [signed] N.P. Tsakh

ADDENDUM
to the order of the Director of the Marine Transport Department.
Effective August 30, 1994. N60

INTERIM REGULATION
Interim Regulation on the charges and fees for services rendered to ships at commercial sea ports of the Russian Federation.

[Seal]

Moscow, 1994

*Note: "?" indicates that the text from which translation was made was not legible.

1. GENERAL CONDITIONS

1.1. Charges and fees, established by the Department of Sea Transport of the Russian Ministry of Transport, will be collected from Russian and foreign ships and floating objects listed in Table 1.1 in commercial sea ports of the Russian Federation

Table 1.1. Ship Grouping

Ships, floating objects	Group
Cargo ships calling on a port during a Russian-owned or combined-ownership international voyage on an established line	A
Cargo ships on a foreign voyage Ferries on a port-to-port domestic voyage;	B
Icebreakers which are not owned or leased by the port Ferries on a port-to-port international voyage;	C
Passenger ships on a foreign voyage	D
Passenger ships on a domestic voyage	E
Tankers on a domestic voyage	F
Cargo ships and objects (except groups C and E) on a domestic voyage Lighters on-board a lighter container carrier; Military ships;	G
Hospital ships Transit ships*;	H
Ships compelled to call on a port for reasons of repair, supply, or quarantine Government ships; Educational, Industrial-Education, or Education and Training ships; Science and research ships;	I
Hydrographic ships Sports ships, private yachts; Technical ships conducting dredging works in the port; Ships owned by the local port fleet, docks, or ship repair yards;	J
Icebreakers owned or leased by the port. Fishing ships;	K
Non-self-propelled ships	L

* Note: "Transit ships" refers to ships that pass through the water space of the port without mooring to a pier, buoy, or pile, without bringing the ship to an anchor, and without other means of tying to ground with the water space of the port.

1.2. Mandatory charges, as well as charges for all services rendered to the ship and its crew, must be paid by the ship before leaving port. The captain of the port may refuse the ship a permission to leave port in case of non-payment of the established charges and fees.

1.3. Charges and fees are calculated on the basis of a conditional volume of the ship, in cubic meters, defined as a product of three dimensions specified in the ship's documents: maximum length, maximum breadth, and maximum depth.

For ships that transport cargo on the upper deck, or those with two or more decks, the depth used in the calculation of volume will not be less than half of the breadth. The volume of barge-tug trains, caravans, and other compounded floating objects is defined as the sum of volumes of the individual components.

1.4. In addition to rates indicated in this Regulation for the cost of work and services rendered to the anchored ships, a charge for the services of tugs and boats will be assessed on the basis of effective rates charged by the port.

1.5. Charges from lighter carriers which are conducting cargo operations on the internal or external roadstead, are assessed on the volume of the lighters unloaded upon entry into, and loaded before exit from the port.

1.6. The rates for piloting and mooring fees, tug service fees during mooring, fees for the use of tugs and other self-propelled and non-self-propelled water vehicles, as well as fees for additional services rendered to ships by agents and agencies, except for supervisors' services, will be increased:

a) on weekdays
from 16:00 to 24:00, from 00:00 to 08:00 — by 25%

b) on Saturdays, Sundays, and holidays
from 08:00 to 16:00 — by 50%
from 16:00 to 24:00, from 00:00 to 08:00 — by 100%

Holidays are defined as official holidays of the Russian Federation.

The above surcharges apply only to that portion of services which are actually performed during the overtime hours above.

The invoices presented to the ship owners will contain an obligatory detailed itemization of the cost of services rendered and the rates, applicable surcharges, and a calculation of time billed, both regular and overtime.

1.7. If several surcharges apply to a ship, each will be assessed on the base cost.

1.8. If several discounts apply to a ship, only the largest one will be applied.

1.9. In calculating the charges and fees, time will be rounded to the nearest 0.5 hours. Duration's less than 30 min. long will be assessed as 30 min.; those that are over 30 min. will be assessed as 1 hour.

1.10. The monetary unit of fees is ruble or U.S. dollar, equal to 100 cents (US$1.00 = 100¢).

1.11. The ships of the Northern (1190), Murmansk (1190), North-Kaspian, Far-Eastern (1545.6), Primorsk

(1391), Sakhalin (2153.8), Kamchatka (2163.8), and Arctic shipping companies while in domestic navigation will pay port charges and service fees according to the rates of the given Time Belt in rubles, using the limit coefficient effective at the time of services rendered with respect to custom rates of the appropriate shipping company.

Ships belonging to other Russian ship owners in domestic navigation will pay port charges and service fees using the limiting coefficient of the port collecting the payment.

1.12. Russian-flag ships in foreign navigation, and foreign ships (under foreign flag) will pay charges and service fees based on rates in U.S. dollars. In doing so, the Russian-flag shipswill make the payment in rubles by converting U.S. dollars into rubles according to the conversion rates set by the Central Bank of Russia as of the date of invoice submitted before the exit of the ship from port.

1.13. The currency for the payment of charges and fees for services rendered to ships of the CIS is set by agreement with respective countries.

2. OBLIGATORY CHARGES AND FEES

2.1. Ship Charges

2.1.1. Charges for ships of groups A, B, C, D, E, F, G, and L are calculated on the basis of rates given in Table 2.1, separately for each entrance into and exit from a port.

Ships in groups H, I, J, K are exempt from charges if they do not conduct commercial cargo operations in the port.

2.1.2. Charges collected from ships under the Russian flag in foreign navigation, and from ships flying flags of other countries with which Russia does not have an agreement granting their ships a national rate or a favored-nation rate, will be calculated according to "Foreign Navigation" rate.

Charges collected from foreign ships navigating under the flag of countries with which Russia does not have agreements described in the paragraph above, will be calculated according to "Regular" rate.

Charges collected from Russian ships in domestic navigation will be calculated according to "Domestic Navigation" rates.

2.1.3. For ships in groups A, B, F, and G which load or unload in several ports within Russia as part of one run, the ship charges are collected at 100% in the first port of call and with a 50% discount in the subsequent ports.

2.1.4. Ships in group A will be given a 20% discount.

2.1.5. Ships in groups C and E will be charged once during a calendar year in each port of call — on the first entrance into and first exit from the port, unless agreed upon otherwise.

2.1.6. Ships in group D will be charged at 100% in the first port of call and at a discount of 50% in subsequent ports upon first entry into Russian ports and exit from them, once during a calendar year, unless agreed upon otherwise.

Table 2.1. Rates of ship charges.

Port	Regular US$	Foreign US$/$m^3$	Domestic Rubles/m^3	Port	Regular	Foregin	Domestic
			Black Sea — Azov Sea Basin				
Novorossijsk	0.310	0.097	0.029	Taganrog	0.277	0.094	0.0
Sochi	0.333	0.103	0.050	Tuapse	0.254	0.090	0.0
				Other	0.184	0.063	0.0
			Baltic Basin				
Vyborg	0.252	0.024	0.029	Kaliningrad	0.247	0.099	
St. Petersburg	0.308	0.092	0.034	Other	0.247	0.072	
			Northern Basin				
Arkhangelsk	0.268	0.101	0.030	Narjan-Mar	0.268	0.099	
Amderma	0.218	0.081	0.043	Onega	0.216	0.081	
Dikson	0.216	0.081	0.043	Tiksi	0.216	0.081	
Kandalaksha	0.216	0.081	0.043	Khatanga	0.216	0.081	
Mezen	0.216	0.081	0.043	Other	0.216	0.081	
Murmansk	0.268	0.101	0.028				
			Far Eastern Basin				
Anadyr	0.175	0.063	0.034	Providenija	0.265	0.094	0.050
Aleksandrovsk-na-Sakhaline	0.229	0.086	0.029	Pevek	0.125	0.065	0.035
Beringovskii	0.125	0.063	0.034	Posiet	0.225	0.026	0.015
Bozhniakovo	0.234	0.085	0.040	Petr.-Kamchatsk	0.125	0.065	0.017
Vladivostok	0.240	0.103	0.020	Poronajsk	0.248	0.026	0.034
Vostochnyi	0.240	0.103	0.043	Ust-Kamchatsk	0.125	0.065	0.034
Vanino	0.240	0.103	0.034	Uglegorsk	0.234	0.085	0.040
Korsakov	0.317	0.092	0.040	Kholmsk	0.328	0.106	0.022
Krasnogorsk	0.225	0.025	0.040	Shakhtersk	0.234	0.085	0.040
Magadan	0.125	0.065	0.020	Egvekinot	0.265	0.094	0.050
Nakhodka	0.240	0.103	0.038	Others	0.125	0.068	0.034
Nakhodka (Petrol)	0.274	0.101	0.046				
Nikolaevsk-na-Amureh	0.225	0.026	0.040				
			Caspian Basin				
Astrakhan	0.112	0.029	0.006	Others	0.112	0.029	0.006
Makhachkala	0.112	0.029	0.006				

2.2. Lighthouse Charges

2.2.1. For ships in groups A, B, D, F, G, I, and L, the lighthouse charges will be assessed at a rate of 1.016 rubles for ships on domestic voyage or US$0.029 for foreign ships or ships on foreign voyage per 1 cubic meter of volume upon each entrance or transit through the port.

2.2.2. Ships in groups C, E, H, J, and K are exempt from lighthouse charges.

2.3. Canal Collection

2.3.1. Canal charges are assessed on the basis of the ship's volume in cubic meters upon each pass each way through the canal, whether the ship has called on the port or not.

2.3.2. For ships in groups C and E, charges based on the rates in the table are collected in each of the ports of call upon first entering the port, and upon exiting the port, once in a calendar year, unless otherwise specified in a separate agreement.

2.3.3. For ships in group D, the charges based on the rates in Table 2.2. are collected in the first port of call in their entirety (100%), and in the subsequent ports at a discount of 50% upon first entrance into Russian ports and exit from port, once in a calendar year, unless otherwise specified in a separate agreement.

2.3.4. Ships in groups H, J, K are exempt from canal charges if they are not conducting commercial cargo operation in the port.

Table 2.2. Canal charge rates, in rubles from ships in domestic navigation; in U.S. dollars from foreign ships and Russian ships on foreign voyage, per cubic meter.

Port	*Rate Rubles*	*Rate US$*	*Port*	*Rate Rubles*	*Rate US$*
			Black Sea—Azov Sea Basin		
Taganrog	0.057	0.103	Tuapse	0.005	?
Baltic Basin					
Kaliningrad	0.042	0.025	Saint Petersburg	0.039	0.07?
Vyborg	0.034	0.061			
			Northern Basin		
Arkhangelsk	0.109	0.196	Naryan-Mar	0.166	0.295
Mezen'	0.088	0.158	Onega	0.166	0.295
			Far Eastern Basin		
Vostochnyi	0.006	0.011	Nikolayevsk-na-Amure	0.0.028	0.050
Mezen'	0.088	0.158	Onega	0.166	0.295
			Caspian Basin		
Volgo-Kaspiiski Kanal	0.450	0.810	Makhachkala	0.009	0.016

2.4. Pier Charges

2.4.1. Pier charges are collected from ships berthed at the pier.

2.4.2. For all groups of ships, rates in Table 2.3. are used.

Table 2.3. Rates for pier charges (in rubles from ships on domestic voyage, and in U.S. dollars from foreign ships and ships on foreign voyage).

	For berthing with cargo operations conducted by and with with the means of the port (per m^3 per ship entrance) Ships of groups				*In other cases (per m^3 per day) Ships of groups C, E, F,*	
	A, B, D		*G, H, I, J, K, L*			
Basin	*Rubles*	*US$*	*Rubles*	*US$*	*Rubles*	*US$*
Black-Azov, Baltic, Caspian	0.012	0.022	0.002	0.004	0.004	0.007
Northern	0.014	0.025	0.003	0.005	0.005	0.009
Far Eastern	0.019	0.034	0.004	0.007	0.006	0.011

2.4.3. Ships moored beam-on to another ship that is moored to the pier, or ship moored to the pier by their bow or stern will be charged 50% of the pier charges.

2.4.4. Ships in groups H, I, J, K which are not conducting commercial cargo operations in the port, and passenger ships used as hotels, are exempt from pier charges.

2.4.5. Ships in groups A, B, C, D, F, and G that have completed their cargo operations and are staying idle at the pier for reasons dependent on the ships or the ship owner will be charged at a rate of 0.006 rubles for ships on domestic voyage or 0.011 US$ for foreign ships and ships on foreign voyage, per 1 cubic meter per hour, starting from the moment of completion of loading/unloading and fixing the cargo.

2.5. Anchoring charges

2.5.1. Ships in all groups will be charged for berthing in the port for over 12 hours at a daily rate of 0.0015 rubles for ships on domestic voyage or 0.0027 US$ for foreign ships and ships on foreign voyage, per 1 cubic meter over the entire duration of berthing.

3. SERVICE CHARGES

3.1. Sanitation Charges

3.1.1. Sanitation charges include:

— Port's obligation to receive all forms of pollutants to be discharged from the ship without limitations (except ballast water, which will be submitted to purification stations separately, according to rates in Table 3.7.) during the entire stay of the ship at the port, as well as to conduct these receiving operations with the port's means and at its own expense (launch and withdrawal of utility boats, use of containers and other vessels for the collection of refuse, reloading operations, piping etc.;

— Ship's obligation to submit all pollutants aboard in order to prevent their release into the sea. Submittal of pollutants is certified by an appropriate receipt by the port.

3.1.2. Ships in groups A, B, C, G, I, and J will pay charge on the basis of the volume of the ship or the self-propelled component of a compound object according to rates in Table 3.1.

3.1.3. Ships equipped with environmental protection equipment for full utilization of all forms of ship refuse and pollutants, and in possession of international certificates as to the prevention of sea pollution with oil, run-off water, and refuse (ecologically clean), will be given a 50% discount on sanitation charges.

3.1.4. Ships in groups C, D, E, F, H, K, and L (except fishing ships) are exempt from sanitation charges. Their pollutants will be received upon captain's request according to rates in Table 3.7.

3.1.5. No sanitation charges will be assessed in ports that are not equipped to receive all pollutants. In such ports, the charges are assessed on the actual received amount of pollutants according to rates in Table 3.7.

Table 3.1. Rates for sanitation charges (in rubles from ships on domestic voyage, and in U.S. dollars from foreign ships and ships on foreign voyage, per cubic meter).

	Duration of stay in the port, days			
	Less than 10		*10 to 30*	
Basin, Port	*Rubles*	*US$*	*Rubles*	*US$*
Black-Azov				
Novorossiisk, Tuapse	0.008	0.014	0.013	0.023
Taganrog	0.012	0.022	0.022	0.040
Baltic				
Vyborg	0.018	0.032	0.024	0.043
St. Petersburg	0.015	0.027	0.021	0.038
Kaliningrad	0.021	0.038	0.028	0.050
Far Eastern				
Nakhodka (Petroleum Port)	0.008	0.014	0.013	0.023

Note: After 30 days of stay in the port, pollutants are received upon captain's request according to rates in Table 3.7.

3.2. Harbor Pilot Charges

3.2.1. Harbor Pilot Charges are collected from all ships calling on the sea ports of Russia.

3.2.2. Harbor Pilot Charges are assessed based on the volume of the ship in cubic meters. Ship volumes smaller than 5,000 cubic meters will be counted as 5,000 cubic meters.

3.2.3. Harbor Pilot Charges includes the vessels used for transporting the harbor pilot to and from the entering/exiting ship.

3.2.4. Ships in groups A, B, C, D, E, F, G, I, J, and L, will be charged on the basis of the ship's volume according to Table 3.2. for piloting on the approach canals and fairways, for piloting between ports and points outside of the water space of the port (external piloting), and for relocations between the roadstead and port piers, in the absence of approach canals and fairways, or on the water space of the port (internal piloting).

3.2.5. For piloting of all ships and objects (except foreign sport ships) along the Longitudinal fairway, the Vysotsk-Vyborg canal, and the approach fairway of the Saimen canal, charges for harbor piloting will be collected on the volume of the ship at a rate of 0.003 rubles from ships on domestic voyage or 0.0054 US$ from foreign ships and ships on foreign voyage per 1 cubic meter per each mile of piloting each way.

For ships that pass the canal more than five times in a calendar year, a discount of 25% will be applied to the harbor pilot charges, starting with the sixth run.

For piloting foreign sport ships on the longitudinal fairway or between the Vikhrevoi Island Pilot Station and Brusnichnoye lock, the following charges will be collected per ship (US$):

Up to 20 m long	19.80
Up to 20 m long in a group of 4 ships or fewer	11.70
Over 20 m long	37.80

Table 3.2. Rates for harbor pilot charges (in rubles for ships on domestic voyage, or in U.S. dollars for foreign ships and ships on foreign voyage.)

Basin, Port	External piloting per m^3 <1 mi Rubles/US$	1.1–5.0 mi Rubles/US$	5.1–30.0 mi Rubles/US$	>30.0 mi Rubles/US$	Internal piloting per m^3 Rubles/US$
Black-Azov, Baltic, Caspian					
St. Petersburg, Novorossiisk	0.0014/0.0025	0.0006/0.0011	0.0005/0.0009	0.0003/0.0005	0.0032/0.0058
Kaliningrad	0.0016/0.0029	0.0007/0.0013	0.0004/0.0007	0.0003/0.0005	0.0038/0.0068
Sochi	0.0018/0.0032	0.0008/0.0014	0.0004/0.0007	0.0003/0.0005	0.0044/0.0079
Tuapse	0.0020/0.0036	0.0009/0.0016	0.0005/0.0009	0.0003/0.0005	0.0049/0.0088
Astrakhan, Makhachkala, Taganrog, all others	0.0033/0.0059	0.0029/0.0052	00.0021/0.0038	0.0006/0.0011	0.0036/0.0065
Baltic Sea	—	—	0.0002/0.0004	—	—
Northern					
Murmansk	0.0050/0.0090	0.0026/0.0047	0.0009/0.0016	0.0005/0.0009	0.0044/0.0079
Kandalaksha	0.0086/0.0155	0.0038/0.0068	0.0016/0.0029	0.0011/0.0020	0.0054/0.0097
Arkhangelsk	0.0099/0.0178	0.0042/0.0076	0.0018/0.0032	0.0013/0.0023	0.0062/0.0112
Mezen, Naryan-Mar, Onega	0.0123/0.0221	0.0054/0.0097	0.0037/0.0067	0.0016/0.0029	0.0044/0.0079
All other ports	0.1113/0.0203	0.0049/0.0088	0.0021/0.0038	0.0014/0.0025	0.0039/0.0070
Far Eastern					
Vladivostok	0.0041/0.0074	0.0021/0.0038	0.0006/0.0011	0.0004/0.0007	0.0035/0.0063
Vostochnyi, Nakhodka	0.0047/0.0085	0.0026/0.0047	0.0008/0.0014	0.0005/0.0009	0.0042/0.0076
Nakhodka (Petroil)	0.0051/0.0092	0.0028/0.0050	0.0008/0.0014	0.0005/0.0009	0.0046/0.0083
Vanino, Magadan, Nikolaevsk-Na-Amure	0.0058/0.0104	0.0032/0.0058	0.0008/0.0014	0.0007/0.0013	0.0039/0.0020
Yenisei R. (line piloting)	—	—	—	0.0003/0.0005	—
Petropavlovsk-Kamchatskii	0.0086/0.0155	0.0038/0.0068	0.0016/0.0029	0.0011/0.0020	0.0054/0.0097
All other ports	0.0115/0.0207	0.0050/0.0090	0.0022/0.0040	0.0014/0.0025	0.0041/0.0024

3.2.7. For ships in groups A and E, a discount of 20% is given.

3.2.8. Ships in groups H and K are exempt from harbor pilot charges if they are not conducting commercial cargo operations in the port.

3.2.9. A Captain who provides incorrect information about the draft, length, breadth and capacity of the ship will be liable for a punitive charge of twice the harbor pilot charges due, independently of any liability for the consequences of the misleading information provided.

3.2.10. A partial mile of piloting will be counted as a full mile.

In conducting several ships simultaneously, piloting charges will be collected from each ships at the full rate.

Piloting charges will be assessed based on the pilot's receipt, issued and signed by the pilot, or a confirmation from the ship, transmitted over the radio-telegraph.

3.2.11. Piloting during deviation operations is charged according to the rates for internal piloting independently of the location of such operations.

3.2.12. Charges for refusal of pilot's services ordered by the ship, and for the delay of the pilot on the ship are assessed on the basis of the rates in Table 3.3.

Table 3.3. Charges assessed for delays.

Cause of delay	*Charges and terms*
Call for pilot with a subsequent cancellation of his services	100% of pilot's charges due for the conduct for which he was called
1 hour of delay of the pilot due to ambiguous information	20 rubles from domestic and US$36 from foreign ships and Russian ships on foreign voyage
Delay of the pilot for more than 2 hours but no more than for one full day (24 hrs) due to causes that are not insurmountable in nature	50 Rubles from domestic and US$90 from foreign ships and Russian ships on foreign voyage
Same, but for more than one full day, per each subsequent day	100 rubles from domestic and US$180 from foreign ships and Russian ships on foreign voyage

Note: No delay charges will be assessed for pilot's delay on the ship for more than 2 hours as part of a piloting process itself that takes more than 2 hours.

3.3. STC (Ship Traffic Control) Service Charges

3.3.1. Charges for STC services are collected in ports which provide the services of shore-based radio locator systems of traffic control. For ships of all groups except H and K the charges of STC services are assessed upon each entrance into the port, exit from the port, passage through a transit canal according to following rates (in rubles for ships in domestic navigation or U.S. dollars for foreign ships and ships on foreign voyage):

In Russian ports of Black-Azov and Northern Basins .... 0.0031 Rubles/ US$0.0056/$m^3$/ship

In ports of Nakhodka Bay .... 0.0102 Rubles/ US$0.0184/$m^3$/ship

In other ports .... 0.0072 Rubles/ US$0.0130/$m^3$/ship

3.3.2. Ships in groups H and K are exempt from the STC service charges if they are not conducting commercial cargo operations in the port.

3.3.3. Charges for foreign ships (under a foreign flag) for the services of Vladivostok's and Nakhodoka's STC services are assessed at a rate of US$0.025 per cubic meter upon each entrance and exit of the ship.

3.3.4. Depending on the type of STC system, the following coefficients will be applied to rates listed in 3.3.1. and 3.3.3.:

I 1.4

II 1.2

III 1.0

3.4. Mooring Charges

3.4.1. The service of mooring help, mooring line work, cast-off, tie-off, and tie-over of ships of all groups, except H and K, will be charged according to rates in Table 3.4.

Table 3.4.. Mooring charge rates (for each operation, in rubles for ships on domestic voyage, or U.S. dollars for foreign ships and Russian ships on foreign voyage)

Volume of the ship, m^3	Basin: Black-Azov and Caspian		Basin: Baltic and Far Eastern excluding northern extremity and Sakhalin Island		Basin: Northern, including Kamchatka region and Arctic Basin	
	Rubles	*US$*	*Rubles*	*US$*	*Rubles*	*US$*
<1,000	10	18.00	12	21.60	15	27.00
1,001-5,000	20	36.00	24	43.20	30	54.00
5,001-10,000	30	54.00	36	64.80	45	81.00
10,001-20,000	40	72.00	48	86.40	60	108.00
20,001-40,000	60	108.00	72	129.00	90	162.00
40,001-80,000	80	144.00	90	162.00	120	216.00
>80,000	100	180.00	120	216.00	150	270.00
Hydrofoil Ships	1	1.80	2	3.60	2	3.60

3.4.2. Tie-over of a ship along the pier for more than one length of the ship is counted as two operations; less than one length— as one operation.

3.4.3. Relocation of a ship from one pier to another is counted as two operations.

3.5. Tug Boat Charges During Mooring Operations

3.5. 1. Combined charges for the work of all tugs during mooring, cast-off, and relocation in the absence of ice conditions, with wind speeds under 14(?) m/s for ships of all groups except D, E, K, L will be assessed on the volume of the ship according to rates in Table 3.5.

Table 3.5. Rates for the work of tug boats during mooring operations (for each operation, in rubles for ships on domestic voyage, or U.S. dollars for foreign ships and Russian ships on foreign voyage) per cubic meter.

Basin, Port	*Mooring/Cast-off*		*Relocation*	
	Rubles	*US$*	*Rubles*	*US$*
Black-Azov and Caspian				
Sochi	0.026	0.047	0.045	0.081
Novorossiisk, Tuapse	0.029	0.052	0.050	0.090
All other ports	0.021	0.038	0.030	0.054
Baltic				
Kaliningrad	0.020	0.036	0.028	0.050
Vyborg	0.030	0.054	0.052	0.094
All other ports	0.026	0.047	0.040	0.072
Northern				
All ports	0.032	0.058	0.052	0.094
Far Eastern				
Vladivostok	0.027	0.049	0.046	0.083
Vostochnyi, Nakhodka	0.030	0.054	0.051	0.092
All other ports	0.033	0.059	0.054	0.097

3.5.2. The number and power of tugs needed for the mooring operations is regulated by the "Obligatory Regulation of Ports," or is determined by the Harbor Piloting Service in agreement with the captain of the ship.

3.5.3. Ships in group A are give a discount of 20%.

Ships that are more than 250,000 cubic meters in volume will be charged for the tug services as 250,000 cubic meters in volume.

3.5.4. Ships with a faulty, non-operational main engine will be charged for mooring as non-self-propelled ships of group L.

3.5.5. Charges for the work of tugs during mooring, cast-off and relocation of ships in groups D, E, K, and L will be set by the sea commercial ports.

3.6. Charges for Combined Lighter Carrier Service

3.6.1. Lighter containers, from the moment of their transfer from the lighter carrier (sea or river line tug) to the moment of their transfer to the lighter carrier (line tug), excluding services rendered by the crew on duty (substitute crew), are charged according to rates in Table 3.6.

Table 3.6. Rates for the servicing of lighter containers (per entrance, in rubles for ships on domestic voyage, or in U.S. dollars for foreign ships or ships on foreign voyage).

Type of lighter container	*Basins*								
	Black-Azov and Baltic			*Far Eastern*			*Northern, ports of Kamchatka*		
	Rate category								
	I Rubles/US$	*II Rubles/US$*	*III Rubles/US$*	*I Rubles/US$*	*II Rubles/US$*	*III Rubles/US$*	*I Rubles/US$*	*II Rubles/US$*	*III Rubles/US$*
LEW(?)	On internal roadstead								
	420/756	315/567	165/297	505/909	380/684	200/360	630/1134	470/846	250/450
	On external roadstead								
	375/675	270/486	120/216	450/810	325/585	145/261	560/1008	405/729	180/324
DM(?)	On internal roadstead								
	520/936	420/756	265/477	625/1125	505/909	320/576	780/1404	630/1134	400/720
	On external roadstead								
	440/792	335/603	185/333	530/954	400/220	220/396	660/1188	500/900	280/504

3.6.2. The charges listed include the following obligatory services rendered by the port:

Category I charges (servicing of the lighter container with loading and unloading in the port) includes the cost of port services in receiving the lighter container from the lighter carrier (line tug), towing to the accumulation basin (AB) and back, from AB to the cargo pier of the port and back, two operations of opening and closing of the lids, one relocation in the process of cargo operations, provision for gangway for two days with two operations (installation and removal);

Category II charges (servicing with unloading or loading of the lighter container in the port) include the cost of services listed in Category I, without the inclusion of one lid opening and one closing operations, relocation, installation, removal, and use of the gangway during two days;

Category III charges (servicing without cargo operations) include the cost of port services of receiving the lighter container from the lighter carrier (line tug), towing to AB and back.

3.6.3. Charges for the services rendered by the on-duty (substitute) crew are assessed on the actual time of service to the lighter carrier independent of the type of lighter container, starting from the moment of receiving it from the carrier (sea or river line tug) to the moment of its transfer to the carrier (sea or river line tug) according to the following rates for one lighter per day (counting partial day as a full day), in rubles, from ships on domestic voyage or in U.S. dollars from foreign ships and ships on foreign voyage:

For the ports of Black-Azov and Baltic Basin	10 Rubles/US$18
For the ports of Northern and Far Eastern Basins:	
during summer navigation:	12 Rubles/US$21.60
during winter inter-navigation period	6 Rubles/US$10.80

3.6.4. The responsibilities of the on-duty (substitute) crew include:

24-hour reception and return of lighters, equipment, seals, deck cargo, and cargo and ship documents pertaining to the cargo transfer operations;

Providing security for the safety and wholeness of the lighter, including the turning on (off) of signal lights.

Installation of light ladders, gangways, portable handrails, and the catching and transfer of lines during the movement of the lighter;

Control over the process of loading and unloading of the lighter, over the full use of the capacity and lift limits, correct arrangement of the cargo, and appropriate separation of bill-of-lading parts of the cargo;

Control over the presence and safety of seals, the making of requests for opening and inspection of the contents of the lighter in case of the violation of seals and the discovery of means of access to the load;

Control over the heave and pitch of the lighter, the measuring of water level in bilgeways no less than twice each day, the making of requests to the port for water pumping and ventilation of the lighter;

Control over the technical condition of the hull, equipment and mechanisms, including the mooring and anchor devices;

Participation, in conjunction with a representative of the port and an agent, in dealing with accidents, the composition of certificates of damages to the hull, equipment, and mechanisms; the making of requests for lighter repair, control over the process of repair;

Preparation of the lighter for voyage, receiving of supplies and lubricating and other materials necessary for proper operation of the lighter's mechanisms and devices.

3.6.5. Services not included into the combined charges and the duties of on-duty crew are paid according to local tariffs or by agreement between the ship owner and the port.

3.7. Charges for Fire Protection

3.7.1. Fire protection by the shore security service onboard the ship or near its side during the entire time of its berthing will be charged at 5 rubles per hour for ships on domestic voyage, or US$9 per hour for foreign ships or ships on foreign voyage. This charge is assessed when fire protection onboard or near the side of the ship is required by port regulations.

3.7.2. The presence of one fire boat and a fire truck near the side of the ship will be charged for on the basis of the nominal cost of services, with a profit surcharge of 45% added to the cost.

When a fire protection charge for the service of a fire boat or fire truck is collected, charges for fire protection onboard the ship or by its side are waived.

3.8. Receiving of Utility Refuse, Food Refuse, Ballast, Bilgeway and Run-off Water.

3.8.1. Charges for the collection by the port of utility and food refuse, ballast and bilge waters, including tug services, are assessed according to rates in Table 3.7.

Table 3.7. Rates for the reception of utility and food refuse, ballast, bilge and run-off waters (in rubles for ships on domestic voyage, or U.S. dollars for foreign ships and ships on foreign voyage).

	Black-Azov, Caspian, and Baltic basins		*Northern and Far Eastern basins*	
Name of services rendered	*Domestic, US$*	*Foreign, Rubles*	*Domestic, US$*	*Foreign, Rubles*
Food refuse and utility trash (per 1 bag up to 100 kg each, or 1 container 0.75 cub.m.	8	29	10	36
Ballast, bilge, and run-off waters:				
— by the port's floating utility vehicles	10	36	12	43
— by shore-based sanitation station	0.25	0.30		

Note: Minimum charge for the use of floating vehicles of the port per operation is 350 rubles for ships on domestic voyage, or 630 U.S. dollars for foreign ships and ships on foreign voyage.

3.8.2. In ports which collect sanitation charges in accordance with sub-item 3.1. of this regulation, the reception from ships of utility refuse, food refuse, bilge and run-off waters is done at no charge, except for ships listed in paragraph 3.1.4.

In the remaining ports, the reception of specified pollutants from ships is paid on general terms according to rates indicated above.

4. CHARGES FOR AGENTING AND ADDITIONAL SERVICES RENDERED TO RUSSIAN SHIP OWNERS.

4.1. Charges for agenting of Russian self-propelled and non-self-propelled ships (independently of the type of navigation) will be assessed according to rates in Table 4.1.

Table 4.1. Agent's fee (in rubles for ships on domestic voyage, or U.S . dollars for foreign ships and ships on foreign voyage).

Volume, m^3	*Purpose of call on a port*					
	For loading/unloading of passengers, bunkering, water refilling etc., without cargo operations; per passing of the Saimen Canal		*For cargo operations*			
			Loading OR Unloading		*Loading AND Unloading*	
	Rubles	*US$*	*Rubles*	*US$*	*Rubles*	*US$*
<1,800	15	27	20	36	30	54
1,801–3,500	25	45	30	54	50	90
3,501–5,300	35	63	50	90	80	144
5,301–7,100	45	81	60	108	90	162
7,101–11,000	60	108	80	144	120	216
11,001–14,000	70	126	96	183(?)	140	252
14,001–18,000	90	162	110	198	170	308
18,001–21,000	100	180	125	225	190	342
21,001–28,000	115	207	150	270	220	396
28,001–35,000	130	234	170	306	240	432
35,001–53,000	165	297	205	369	280	504
53,001–71,000	190	342	230	414	310	558
71,001–90,000	210	378	250	450	330	594
For each subsequent full or partial 100,000 m^3	6	?	?	9(?)	?	14

4.2. a) For the servicing of passenger ships navigating on a domestic voyage, the ship owners will pay additional fee in the amount of 5% of the sum of transit fees for the transport of cargo, passengers and luggage sent from the given port; the amount thus received will be distributed between the agenting organization, the Sea Administration of the port, and A/O "Port" in accordance with the actual work performed by each of the sides.

b) for the organization of sea excursion, including the sale of tickets, a 10% fee will be assessed on the sum of tickets sold, for the benefit of that side which performed the said organization work

c) For the servicing of dry cargo ships in Arctic ports on the Northern Sea Route, the ship owners will pay additional fees in the amount of 0.3% of the tonnage charges, covering the work of icebreakers.

4.3. The services of a manufacturing type performed with the participation of auto vehicles and labor of the agenting organization, Sea Administration of the A/O "Port," will be paid for according to local tariffs or on the basis of an agreement.

4.4. Services of a personal type, rendered to seamen and the members of their families, will be paid for by them on a cash basis in accordance with the local tariffs.

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For a Corps of Engineers reconnaissance study, we developed a numerical model to estimate the time needed for various ship types to transit the Russian Northern Sea Route. We simulated liquid bulk, dry bulk, and container ship transits during the months of April, June, August, and October. In the model, probability distributions for various ice, ocean and atmospheric inputs are exercised by a Monte Carlo algorithm to generate combinations of conditions that affect ship speed. The speed, dependent on the established environment during each time and distance segment, is read from empirically derived lookup tables. Daily ship rates and Russian passage fees were applied to calculate the relative total costs for moving the various cargoes over the route. The model's development, limiting assumptions, simulation logic, data inputs, and resulting output are discussed.

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17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
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