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NSRSIM2A: A Time and Cost Prediction Model for

Northern Sea Route Shipping

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FOREWORD - INSROP WORKING PAPER

INSROP is a five-year multidisciplinary and multilateral research programme, the main phase of which commenced in June 1993. The three principal cooperating partners are Central Marine Research & Design Institute (CNIIMF), St. Petersburg, Russia; Ship and Ocean Foundation (SOF), Tokyo, Japan; and Fridtjof Nansen Institute (FNI), Lysaker, Norway. The INSROP Secretariat is shared between CNIIMF and FNI and is located at FNI.

INSROP is split into four main projects: 1) Natural Conditions and Ice Navigation; 2) Environmental Factors; 3) Trade and Commercial Shipping Aspects of the NSR; and 4) Political, Legal and Strategic Factors. The aim of INSROP is to build up a knowledge base adequate to provide a foundation for long-term planning and decision-making by state agencies as well as private companies etc., for purposes of promoting rational decisionmaking concerning the use of the Northern Sea Route for transit and regional development.

INSROP is a direct result of the normalization of the international situation and the Murmansk initiatives of the former Soviet Union in 1987, when the readiness of the USSR to open the NSR for international shipping was officially declared. The Murmansk Initiatives enabled the continuation, expansion and intensification of traditional collaboration between the states in the Arctic, including safety and efficiency of shipping. Russia, being the successor state to the USSR, supports the Murmansk Initiatives. The initiatives stimulated contact and cooperation between CNIIMF and FNI in 1988 and resulted in a pilot study of the NSR in 1991. In 1992 SOF entered INSROP as a third partner on an equal basis with CNIIMF and FNI.

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NSRSIM2A: A TIME AND COST PREDICTION MODEL FOR NORTHERN SEA ROUTE SHIPPING

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ABSTRACT

In an earlier study, we created a Monte-Carlo based numerical model that calculated the time and cost required for shipping by way of the Northern Sea Route for three cargo ship types during the four seasons of the year. The model used historical probabilities of occurrence for sea-ice cover, meteorological, and oceanographic conditions to establish the physical environment at each transit way point in the model. It then set the speed of the ship for the upcoming trip segment or the need for icebreaker escort according to a series of decisions related to the physical conditions. Shipping costs were related to the type of ship, the time of year, how long the transit takes, and how much of the time an icebreaker escort is needed.

For this study, we conducted an extensive sensitivity analysis of the transit model to reveal the most significant parameters determining the shipping time and cost. We provided this information to other researchers to help them decide which variables to include and their degree of resolution in their creation of an improved transit model. We then modified the CRREL model, further segmenting its spatial grid by a factor of ten and adding the necessary environmental data files that were provided to us from another INSROP project. Obtaining and incorporating more recent cost data or ship performance criteria were outside the scope of work for this project. The cost data used herein were those that were available as of 1993. The cost calculations therefore are useful only in a relative sense. Our new model results indicate that better information in these two areas is needed.

In this report, we compare the structure, the data, and the logic used in the old and the improved CRREL models. We describe our sensitivity analyses and identify those variables having the greatest influence on time and cost. We present and discuss the new model results and compare them with results from the original CRREL model.

Whereas our earlier model results agreed reasonably well with historical experience, those from our new model, at least for August transits, were significantly different. In fact, the new August time and cost results were not much different from those calculated for April. This was contrary to historical experience, which indicates that shipping in August requires half the time as shipping in April. This discrepancy was narrowed with subsequent modifications that indicate that greater definition in the ship speed versus specific ice and wave conditions is needed.

CONTENTS

1.	INT	RODUC	CTION	1				
	1.1	About	this report	2				
	1.2	Backgr	round	2				
2.	OR	IGINAL	MODEL NSRSIM01 DESCRIPTION	4				
	2.1	Assum	Assumptions					
		2.1.1	Icebreaker escort	6				
		2.1.2	Transit routes	6				
		2.1.3	Simulated conditions	6				
	2.2	Mesh d	lescription	7				
	2.3	Logic p	progression	7				
	2.4	Input v	variablès	8				
		2.4.1	Meteorological variables	9				
			Wind	9				
			Icing	9				
			Visibility	9				
		2.4.2	Oceanographic variables	10				
			Waves	10				
			Ocean currents	10				
		2.4.3	Ice condition variables	11				
			Ice concentration	11				
			Ice thickness	11				
			Ice pressure	12				
		2.4.4	Cost variables	13				
			Cargo ship operating and ownership costs	13				
			Icebreaker escort fees					
			Miscellaneous passage fees	15				
	2.5	Detaile	ed simulation logic	15				
		2.5.1	Set initial speed for ice conditions (Step 1)	16				
		2.5.2	Adjust speed for wind and waves (Steps 2 and 3)	17				
		2.5.3	Adjust speed for visibility and maneuverability factors (Step 4	18				
			Fog	19				
			Superstructure icing	19				
			Snowstorms	19				
			Darkness	19				

		2.5.4	Adjust speed for ocean currents (Step 5)	19
٠			Wind-induced currents	19
			Permanent currents	20
		2.5.5	Update time and distance traveled (Step 6)	20
		2.5.6	Save segment statistics (Step 7)	
	2.6	Sensiti	vity mode	20
3.	NSF	RSIM01	SENSITIVITY STUDY	21
	3.1	Previo	us sensitivity simulations	21
		3.1.1	Model repeatability	21
		3.1.2	Number of voyages per simulation	21
		3.1.3	Transit directionality	21
		3.1.4	Sensitivity of cost components	21
			Cargo ship rate	21
			Icebreaker escort rate	22
			Miscellaneous fees	22
	3.2	New se	ensitivity simulations	23
	٠	3.2.1	Code modification	23
		3.2.2	Cost inputs	25
		3.2.3	Tests for sensitivity	25
		3.2.4	NSRSIM01 sensitivity results	26
		3.2.5	Summary of final NSRSIM01 sensitivity results	29
4.	NSI	RSIM2A	: THE MODIFIED CRREL MODEL	30
	4.1	New ro	outing scheme	30
		4.1.1.	The Hamburg-to-Barents Sea section	33
		4.1.2	The Barents Sea section	33
		4.1.3	The Northern Sea Route section	34
		4.1.4	Bering Strait-to-Yokohama transit route	34
	4.2	New e	nvironmental data	34
		4.2.1	Ice concentration	34
		4.2.2	Wind	35
		4.2.3	Waves	35
	4.3	Logic	changes	36
	4.4	Runnir	ng the NSRSIM2A model	36
		4.4.1	Input file structure	36
		4.4.2	Starting a simulation	37
		4.4.3	Output files and print options	39
			Print Option 0 (Simulation summary)	39
			Print Option 1 (Individual voyage summaries)	39
			Print Option 2 (Listing of variables at each change for all	voyages)40
		4.4.4	NSRSIM2A Sensitivity analysis mode	40

5.	SIM	ULATIO	ON RESULTS FROM NSRSIM2A	41
	5.1	New se	ensitivity analyses	41
		5.1.1	Repeatability	
		5.1.2	Length of time step	
	5.2	Final N	ISRSIM2A results	44
		5.2.1	Simulation results for all transit legs	44
		5.2.2	Simulation results for specific scenarios	46
		5.2.3	Comparison of NSRSIM01 and NSRSIM2A results	46
			The quality and quantity of our new environmental data	48
			Parameter interactions	49
			Inaccurate ship-speed algorithms	49
		5.2.4	Experiments with the ship-speed algorithms	49
6.	COI	NCLUSI	ONS	51
7.	LIT	ERATUI	RE CITED	52
8.	AU	THORS'	RESPONSE TO REVIEW COMMENTS	54
	APF	ENDIX	A	A-1
			В	
	API	PENDIX	C	C-1
	API	PENDIX	D	D-1
	API	PENDIX	E	E-1
			F	
	APF	ENDIX	G	G-1
	APF	ENDIX	H – REVIEW COMMENTS OF THE REPORT	
FIG	URES	S		
]	l. Sele	ection of	ice thickness values from a hypothetical probability density	
	f	unction u	using Monte Carlo methods	5
2	2. Me	shing sch	neme used in first transit model, NSRSIM01	7
3	3. Sin	plified f	lowchart of steps performed during each simulation segment	15
4	4. Rel	ationship	between wind direction, ship heading, and seas	18
4	5. Roi	iting sch	eme for new transit model, NSRSIM2A	31
(5. The	high- ar	nd low-latitude routes between Murmansk and the Bering Strait	
	t)	hat we m	odeled for this study to compare results to those from our original	
	Ŋ	ISRSIM(01 modeling	47
TAE	BLES			
	1. Sur	nmary of	environmental variables	8
2	2. Bas	e ship sp	beed initialized as a function of sea-ice thickness and concentration	16
	3. Ma	neuverin	g factors applied to initial base speed to compensate for deviations	
			aight-line track between data points	
2	4. Slo	wing fac	tors applied to base ship speed to account for ice pressure	17

5. Ship speeds under different ice, wave, and wind conditions	18
6. Sensitivity study of model repeatability using the following set of conditions:	
Noril'sk multipurpose cargo ship, 500-voyage transits, daily cargo ship	
cost = \$23,000, daily escort cost = \$7,500, fixed passage fees = \$0	24
7. Ratios of ship speeds and costs for which the environmental parameter shown	
has been turned off to those calculated by a "normal" run in which all parame	eters
are MC-selected	27
8. Ratios of ship speeds and costs for which one environmental parameter's	
probability of occurrence has been reduced by the amount shown to those	
calculated by a "normal" run	28
9. Ratios of ship speeds and costs for which one environmental parameter's	
probability of occurrence has been enhanced by the amount shown to those	
calculated by a "normal" run	28
10. Ratios of ship speeds and costs for which all environmental parameters	
except the one shown have been turned off to those calculated by	
a "normal" run	29
11. Parameter values that show the new model's repeatability	42
12. Parameter values to show the effect of varying the time-step length in	
the model	43
13. Fog statistics for all legs of NSRSIM2A	45
14. Comparison of simulation results from both CRREL models, NSRSIM01	
and NSRSIM2A, with historical data from Wergeland (1991)	47
15. Ship-speed and ice-condition relationships used in final simulations	50
16. Simulated August transit times and mean ship speeds using modified	
ship-speed algorithms for ice and wave conditions	50

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, research consultant and co-founder of Bronson Hills Associates; and Devinder S. Sodhi, Senior Research Engineer, Ice Engineering Division, Research and Engineering Directorate, CRREL. This project was sponsored by the International Northern Sea Route Programme (INSROP), whose cooperating partners are the Central Marine Research & Design Institute, St. Petersburg, Russia; the Ship and Ocean Foundation, Tokyo, Japan; and the Fridtjof Nansen Institute, Lysaker, Norway.

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ABBREVIATIONS AND ACRONYMS

°C degrees Celsius

deg degrees azimuth

m meters

km kilometers

nm nautical miles

m/s meters per second

PDF probability distribution function

kn knots

s seconds

ANSR Administration of the Northern Sea Route

BHA Bronson Hills Associates

CRREL U.S. Army Cold Regions Research and Engineering Laboratory

FESCO Far Eastern Shipping Company

INSROP International Northern Sea Route Programme

MSC Murmansk Shipping Company

NCAR National Center for Atmospheric Research

NSR Northern Sea Route

UAF University of Alaska Fairbanks

USAED U.S. Army Corps of Engineers - Alaska District
USNOCD U.S. Naval Oceanography Command Detachment

NSRSIM2A: A TIME AND COST PREDICTION MODEL FOR NORTHERN SEA ROUTE SHIPPING

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1. INTRODUCTION

The Northern Sea Route is legally defined by its Russian proprietors as extending from the islands of Novaya Zemlya at its western end to the Bering Strait at its eastern end. However, it is generally regarded as any and all possible shipping routes between the Atlantic and the Pacific oceans through the many straits, passages, open seas, and island groups along the Eurasian coastline. It has been important for commerce since the 16th century, especially for bringing to market the abundant raw materials of Siberia and for supplying the region's inhabitants with food, fuel, and finished goods. Foreign use of the route was carefully guarded and generally prohibited by the Soviet Union until its political demise in 1991. It was then that the new Russian Federation opened the NSR and actively promoted its use as a way of attracting foreign investment and capital and to busy an underutilized fleet of cargo and icebreaking ships.

Other northern European and Asian nations were not long in recognizing the potential benefits for their own economies, and significant research was begun to analyze the benefit/cost relationship. A pilot project with this emphasis was undertaken at the Fridtjof Nansen Institute in Norway, and its positive findings were highly influential in spurring a major international collaboration for further study. An overview of the pilot study was published as Østreng and Jørgensen-Dahl (1991). As a result of this work, a consortium known as the International Northern Sea Route Programme (INSROP) was formed in 1993. It was a partnership formed by the Central Marine Research and Design Institute of Russia, the Fridtjof Nansen Institute of Norway, and the Ship and Ocean Foundation of Japan. During its initial phase of activity, INSROP sponsored research designed to help potential shippers evaluate whether the NSR provided advantages over the regular Suez and Panama Canal routes. INSROP has published a wide array of reports that discuss the route's physical conditions, the navigation issues, the ecological and commercial aspects, and the legal and political considerations of NSR marine trade.

In 1997, a second phase of work was sponsored by INSROP (hereinafter referred to as INSROP2) to conduct additional research and to integrate more thoroughly the vast amount of new information into more definitive documentation of the route's utility and actual tools that would aid in user decision-making.

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The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) became an INSROP2 participant to help in creating a numerical model for users to estimate the time and cost required for shipping between various points along the route. Already having a working transit model for the NSR that was based on the limited information that was available to us in 1994, we were tasked with helping to create a similar but more comprehensive model. This new model would be the culmination of an INSROP2 project entitled WP8 Simulation Based on Yearround and Seasonal Operation Scenarios. It was planned to be the most comprehensive transit model possible, incorporating the multitude of new knowledge available. The responsibility for completing the WP8 project fell to Japan's Ship and Ocean Foundation, but our existing model was needed to provide early guidance for creating the WP8 model. The purpose of our work, titled Support Project 1.1.6, Numerical Simulation Model for Ship Transit, and its relationship to the many other INSROP2 projects is described in a project catalogue published by the INSROP Secretariat (1997).

1.1 About this report

This report describes the results of our support project for the INSROP2 work, which we conducted in three phases. During our first phase we performed a sensitivity analysis of the existing CRREL model to learn which input variables were most influential in determining shipping time and cost. This work identified the most important types of data to include in the WP8 model.

During our second phase of work, we expanded the CRREL model with new routing way points, the same ones to be used in the WP8 model. These additional way points increased our model's numerical mesh of routing nodes by approximately a factor of ten and required the enlargement of our associated data files. The additional data were compiled and made available to us as WP8 Support Project I.5.8, Environmental Conditions Affecting Commercial Shipping.

Our third phase required us to perform transit simulations with our modified model and to make those results available for comparison with similar ones generated at the Ship and Ocean Foundation using the WP8 model.

Section 2 of this report briefly describes the structure, underlying assumptions, and the logic of our original model, NSRSIM01, and the input data for it. Section 3 describes the results of our sensitivity analysis of NSRSIM01 (our Phase 1). Section 4 describes the modifications we made to NSRSIM01 in constructing our new model version, NSRSIM2A (Phase 2). It details the new input data, logic changes, how the new model is run, and its output. Section 5 describes new sensitivity studies we performed and the results of our new simulations (Phase 3).

1.2 Background

A Northern Sea Route shipping model was developed at the Cold Regions Research and Engineering Laboratory (CRREL) as part of a reconnaissance study by the Alaska District of the U.S. Army Corps of Engineers (published as USAED 1995 and summarized in Smith 1995). The purpose of the reconnaissance study was to assess the need for and benefit of infrastructural improvements that would facilitate Alaskan maritime commerce by way of the NSR. Our model estimated the time and cost of commercial ship transits in order to compare the efficacy of shipping

via the NSR with that of the conventional Suez and Panama Canal routes. The modeling effort generated time and cost estimates for three different cargo ship types for each of the four seasons of the year. A full description of its underlying assumptions, input parameters, the available data, output formats, and the final simulation results were presented in Mulherin et al. (1996). A summary of the reconnaissance study's analysis of NSR shipping versus the canal routes appeared as Mulherin et al. (1995).

NSRSIM01 is a computer model that uses extensive historical data and a Monte Carlo selection technique to establish at each node point along the route a set of environmental conditions. These, in turn, determine the speed of certain cargo vessels for that segment of the voyage. The number of hours required for transit multiplied by the hourly ownership and operating cost for the vessel provided one of three components that we summed for a total transit cost. When heavy ice-cover conditions were Monte Carlo (MC)-selected for a certain segment, the need for Russian icebreaker assistance, with its own hourly cost, was triggered and added as the second component. Miscellaneous Costs, the third cost component, was added as a fixed amount at the end of the voyage regardless of the amount of time required for transit.

Northern Sea Route environmental data, such as ice conditions, sea state, conditions that degrade visibility, and meteorology, came primarily from Soviet and Russian observations acquired over long time periods. The nature of these data allowed probability density functions (PDFs) that reflect the probability of encountering specific environments to be constructed, given that future conditions do not depart significantly from those observed in the past. MC 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 necessary for calculating the cost of transit but are inherently more unpredictable. Simulation of these variable types using MC methods is not reliable because a PDF of past observations cannot be formulated to describe the probability of future patterns. In other words, past events do not necessarily predict future events. Data such as these must be input in other ways. Either random samples can be selected from a range of discrete values with equal probability of occurrence, a single fixed estimate can be established for all simulations, or a series of simulations can be run to produce estimates of transit cost at each of several discrete values.

We selected values for most parameters in the model using an MC approach. MC methods make random drawings from pools of possible values. We weight each drawing by *a priori* knowledge of the frequency with which each value has previously occurred 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 that city's 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; drawing five through ten means it is sunny. Because, 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 in New York City.

In principle, our NSRSIM01 model works in this manner. The likelihood that a particular variable will assume a given value is described by a PDF that is based in most cases on observational data acquired over long time periods. A variable is initialized by making a random drawing, which is weighted by the PDF, from the range of possible values that 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 1**. MC sampling of this distribution as implemented in our algorithm involves

- Converting this raw PDF to a cumulative probability distribution, also illustrated in Figure 1
- Generating a random number, R, drawn from a uniform distribution such that $0.0 \le R \le 1.0$
- Choosing an ice thickness value on the basis of the value of R taken with respect to the cumulative probability distribution.

Figure 1 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.

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. 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.

Thus, to the extent that raw PDFs reflect environmental parameters accurately, the MC method simulates the frequency with which real-world conditions occur. The more times that this algorithm is repeated, the more the distribution of simulated values will replicate the PDF in **Figure 1**. The greater the number of voyages per transit, the more accurately the mean values for time and cost are predicted based on the input PDFs.

2. ORIGINAL MODEL NSRSIM01 DESCRIPTION

The model was constructed so that both westward and eastward transits by various cargo ship types could be modeled. The environmental data for four different months (April, June, August,

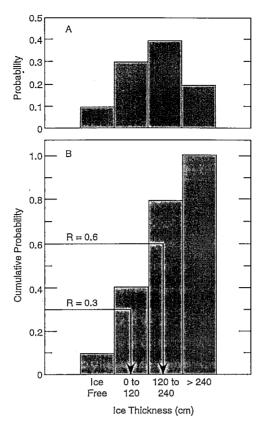


Figure 1. Selection of ice thickness values from a hypothetical probability density function (PDF) using Monte Carlo methods.

and October) were stored in companion input files enabling simulation of ship transits in any of the four seasons. The model's output included various statistical measures of the time and cost required for a chosen transit. A choice of three different amounts of output allowed an increasingly more detailed record of the calculations performed by the model.

NSRSIM01 was written in FORTRAN77, and its main program consisted of approximately 1100 lines of code, which controlled 21 different subroutines. We assembled and stored our data in companion files and lookup tables. The program allowed the user to 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 performed 500 repetitions of one set of voyage parameters in approximately 2 minutes if the short output format was selected. Before doing the sensitivity analysis of NSRSIM01 (Part 1 of this project), we upgraded to a 166-MHz, Pentium desktop computer with math coprocessor, which allowed us to do those same 500 repetitions in less than 5 s.

2.1 Assumptions

The following assumptions concerning icebreaker escort, transit routes, and the simulation of real-world conditions are inherent in the model.

2.1.1 Icebreaker escort

- a. In practice, icebreaker escort is required by Russian regulations in some NSR locations where navigation is usually difficult. However, in our model, we triggered the need for escort only when the MC-selected environmental conditions were of certain combinations of severity.
- b. We assumed that escort is instantaneously available when needed. In actual practice, delays in a voyage may occur while waiting for an icebreaker to arrive or to form up convoys of ships.
- c. 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 algorithms, which are currently unknown, would have to be incorporated.
- d. Our model progresses in 8-hr time steps with ice conditions being reexamined at the start of each transit segment. This can result in escort being required for isolated 8-hr time periods of the transit rather than for consecutive days, which is probably more realistic. Therefore, at the end of a complete transit simulation, we round the number of icebreaker escort hours up to the next greater whole day before costs are calculated.

2.1.2 Transit routes

- a. The transit routes that we selected for simulation covered a 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.
- b. We assumed that transit from Murmansk to the Bering Strait is nonstop; that is, the model did not allow for intermediate ports of call to pick up or discharge cargo.
- c. The calculation of ship's heading that is 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, currents, and ice conditions.
- d. Transit distances are calculated along great circle routes, one consequence of which is that, except for due north—south and due east—west travel, compass headings change continuously en route.

2.1.3 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, though highly improbable, that an 8-hr time period 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. Conditions generated in a few segments of a few voyages may not necessarily reflect real-world conditions accurately because of the chance that low-probability conditions will occur. However, the more voyages used to simu-

late a transit, the more that the range of simulated conditions and their frequency of occurrence will reflect the real world. 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.

2.2 Mesh description

Figure 2 shows a map of the Russian Arctic and the set of route alternatives that we modeled. We segmented the various route choices with a mesh of data nodes (filled circles), which are generally spaced 250 nautical miles (nm) apart. These nodes were mesh points where the navigation conditions were set for an upcoming trip segment. Decision nodes, shown as circled numbers, were similar to data nodes in that there we updated the environmental conditions of the voyage, but they had the additional feature of marking where a choice was made to follow either the coastal route or a more northerly variant. For example, from decision node 0 at the mouth of Kolskiy Gulf (43 nm seaward from Murmansk), we could choose to skirt Novaya Zemlya either to the south (to node 2) or to the north (to node 2A). Route options were selected using MC methods, with the probabilities that a particular leg would be chosen being derived from historical environmental data obtained from ANSR (1996). In the absence of such historical data, we assumed that each leg leading away from a decision node had an equal probability of being selected.

2.3 Logic progression

- 1) The program first read the user-supplied command line arguments that input the parameters of month of transit, ship class, level of detail desired in the printed output, and number of voyages the simulated transit was based on.
- 2) The data files containing the required PDFs were loaded into the program's working arrays.

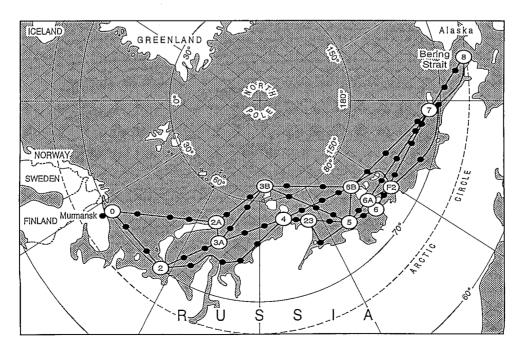


Figure 2. Meshing scheme used in first transit model, NSRSIM01.

- 3) The program initialized the ship's position at either Murmansk or the Bering Strait, depending on the direction of travel chosen, and selected the first leg of the voyage.
- 4) Using the MC method, the environmental conditions and the ship's speed were established for the next 8 hours or until the next data node was reached.
- 5) Based on ship speed and sailing time, the ship's position was updated along the transit path and checked to determine whether the next data point had been reached. At the end of that time or distance segment, the voyage statistics were updated.
- 6) If the voyage was complete, the summary statistics were compiled and either another voyage was begun (back to step 3) or the final statistics were compiled for the completed transit simulation.

2.4 Input variables

Table 1 shows the environmental parameters that we considered for the model. Shaded cells indicate those variables that we eventually decided to build into the model, and the notes explain why others were not. These are briefly discussed in the following subsections.

Table 1. Summary of environmental variables. Shaded cells indicate the variables that were used in the NSRSIM01 model.

		Apr	Jun	Aug	Oct
	Concentration	112 (116)	1947 4 17 T	Bally Est.	
	Thickness	0.000			
Sea Ice	Pressure	数据数据	7.79.75	351.3	114
Bea Ice	Salinity	2	2	2	. 2
	Strength	2	2	2	2
Ridges	Distribution	1	1	1	1
Riuges	Spacing	1	1	1	1
Fog		274	are first	No. of the last of	
Icing		1	1	44.44	120
Snowstorms	Snowstorms		1,4	1,4	
Currents	Permanent Ocean	September 200	t.		e disense
Currents	Wind Induced	is Distant	Figure 1866	<i>(1)</i>	
Waves	Height	and Mark		Jan die	
VY A V CS	Frequency	1	1	1	1
Winds		managaran i		The street	10.00
Temperature		2	2	2	2
Tides	Diumal	4	4	4	4
1100	Storm Surge	2,4	2,4	2,4	2,4
Darkness			3		a (SASSATE

2.4.1 Meteorological variables

Three meteorological phenomena that can impede commercial navigation were addressed in the model. These were wind (as it affects ocean current speed and wave height), ship structure icing, and visibility (as affected by fog, snowstorm, and darkness).

Wind ·

The speed and direction of the wind affect vessel speed through the direct force it exerts on the ship and indirectly by the magnitude of wind-induced currents and waves. These indirect forces are considered *oceanographic variables* and are discussed in Section 2.4.2. Because the available wind regime information was not adequate to make a statistical description of the wind speed and direction, we used a geostrophic wind model for the Arctic Ocean with a spatial resolution of 50 km (Gill 1982). Simulations of wind were initialized and started from rest on 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). This wind model required daily atmospheric pressure input to generate estimates of the wind conditions along our routes. We used these calculated values for estimating the statistical probability of wind speed and direction at each node point on our spatial grid. We compared our simulated wind statistics with those in a limited data set of observed values at meteorological stations along the NSR and found reasonable agreement. In the model, we first MC-selected the wind direction and followed that with an independent MC selection of the wind speed.

Icing

Vessel icing may occur throughout the year from either atmospheric (rime icing, freezing rain, and the like) or marine sources (freezing sea spray). Strong winds, cold air, and water contribute to icing of vessels. To avoid icing, ships must reduce their speed, change course, or seek shelter, thus increasing their time of transit. Icing along the Northern Sea Route is generally not a serious problem for large cargo ships, but along some routes icing can be dangerous, especially near the end of autumn when there is no ice cover and air temperatures are below zero. Both atmospheric and marine icing have lower probabilities of occurrence from December through June because there is usually an extensive ice cover that limits sea-to-air moisture exchange. In the model, we used PDFs that we constructed from data out of ANSR (1996) to MC-select the occurrence of icing. The data showed that icing is highly unlikely during the month of April, so we assigned a zero probability for its occurrence in our model for April transits.

Visibility

Visibility, or lack of it, is cause for slowing a vessel, especially when operating in ice concentrations of 30% and greater. As the percentage of ice cover increases, especially under conditions of limited visibility, so does the chance of vessel collision with ice. Therefore, to reduce the frequency of damaging ice encounters, vessel speed should be reduced. Diminished visibility more commonly occurs during the autumn—winter period because of fog and snowstorms combined with longer nights. In conditions of limited visibility, ships can also lose a channel or become

icebound in the channel, interrupting convoy progress. 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. In the model, a simulation clock keeps track of the time of day and therefore the occurrence of darkness. We assumed 8 hr of daylight in October, 20 hr in both April and August, and 24 hr in June.

The model also treats snowstorm and fog as MC variables, but neither one has subcategories for their severity. They are simply either occurring or not. Only their presence is MC-selected. The snowstorm and fog PDFs were digitized from maps presented in Proshutinsky et al. (1994). These data showed no snowstorms occurring in August (unlike the other three months), so for all nodes we set our probability of occurrence for snowstorms during that month to zero.

2.4.2 Oceanographic variables

We considered the effects of three oceanographic variables in our model: waves, permanent currents, and wind-induced currents.

Waves

Waves were assumed to have an effect on navigation, and the larger the wave, the greater its influence. 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. We constructed wave height PDFs from data on wind speed probability and maximum waves found in *The Soviet Arctic* (1970). First, we assumed the wave height to be zero if the ice concentration was greater than 30%. However, at every point where it was 30% or less, the model selected one of six different wave heights in the PDF. The height categories were 0–1 m, 1–2 m, 2–3 m, 3–5 m, 5–7 m, and 7–9 m. In retrospect, we realized that the wind and wave variables were treated independently in the model. More correctly, we should simply have assigned corresponding wave height values after establishing the wind speed. This mistake was corrected in the modified model version (NSRSIM2A). However, as will be made clear in Section 3.2.4, our error in selecting the wave height has only a minor effect on the total time and cost conclusions arrived at using NSRSIM01.

Ocean currents

Ocean currents were assumed to have an effect on speed of transit in the model. Currents, in effect, represent a bias that is present in the medium through which the ship moves. That is to say, underlying currents move the water and ice through which the ship sails regardless of ice characteristics and visibility conditions. Summary currents in the Arctic seas are composed of tidal, permanent, and wind-induced currents. We did not take into account tidal currents but considered them to be semidiurnal and primarily reversing in nature. We assumed that their cumulative influence on transit navigation was essentially nullified. Therefore, only two types of currents contributed to our modeled ship speed: 1) permanent marine currents that arise from local-and basin-scale patterns of ocean circulation and 2) currents induced by wind in either the marine surface layer or, in the case of ice-covered seas, the pack ice cover itself. In general, permanent

currents remain quite constant with regard to both speed and direction throughout the year and thus were modeled as fixed values that depended on the ship's location.

The wind-induced currents are generally in the same direction as the wind and equal to 2.5—3.0% of the wind speed (Zubov 1945). Under ice-free conditions, we assumed that the wind induced a current moving in the same direction as the wind. Likewise, for ice-covered seas, we assumed that the wind forced the ice and, to a certain degree, the ship to move in the same direction. In the model, we always assumed the wind-induced current to be independent of ice conditions and equal to 2.5% of the wind speed. We calculate the magnitude of the current vector in the direction that the ship is traveling and add it to the ship speed after the speed adjustments for all other environmental factors have been made.

2.4.3 Ice condition variables

Sea ice greatly affects navigation in the Arctic, but its presence is highly variable in terms of both space and time. Certain regions and key straits have a high probability for difficult ice conditions even during the summer season and thus may require an icebreaker escort for passage. Heavy ice accumulations, known as ice massifs, sometimes hundreds of square kilometers in area, are found in roughly the same locations each summer. Apart from these vast perennial accumulations, the interannual extent of the ice cover is markedly variable. In summer, much of the coastal route may be totally ice-free, or nearly so. In other summers, there may be very little melting of ice, requiring nearly continuous icebreaker escort. Three parameters related to sea ice cover that have the greatest effect on ship speed are considered in the model: concentration, thickness, and pressure. The first two are unrelated in that one does not determine the other. In other words, the concentration can be either high or low at the same time that the thickness is either high or low. The existence of ice pressure, on the other hand, requires an ice concentration of virtually 100%.

Ice concentration

The measure of water surface area that has floating ice is referred to as ice concentration. It is expressed as the percentage ratio of ice-covered surface area to the total area in question. Regardless of their thickness, the closer together the floes are that comprise the ice cover, the higher its concentration. We took our April and August ice concentration data from Romanov (1993) to make up PDFs with five concentration categories: ice free, <30%, 31–60%, 61–80%, and 81–100% ice cover. Our June and October thickness values were digitized from the *Sea Ice Climatic Atlas* (USNOCD 1986a, b) and from *Arctic and Antarctic Sea Ice, 1978–1987* (Gloerson et al. 1992). In the Chukchi Sea region, the ice concentration data were derived from the above-named sources and revised using information from *Alaska Marine Ice Atlas* (LaBelle et al. 1983).

Ice thickness

The vertical thickness measurement can apply to either unconsolidated ice floes, to a level and unbroken ice sheet, or to rubbled (broken) and hummocked (piled up) ice. Ice thickness values

for April and August are also from Romanov (1993). We interpolated or extrapolated these for June using April and August observations from coastal and island stations. We computed our ice thickness data for October using the equation of Zubov (1945):

$$I^2 + 501 - 8R = 0 \tag{1}$$

where I = ice thickness (cm)

R = cumulative freezing degree-days (°C).

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

Ice pressure

Ice pressure, or ice compression, refers to how tightly compressed the ice cover is due primarily to the force of the wind. It is one of the most important factors that can slow ship speed or even stop an icebreaker. We simulated ice compression and its probability along the NSR on the basis of atmospheric pressure data obtained from NCAR (1990). We assumed the divergence of the ice drift velocity to be proportional to divergence of the surface wind, W, after Doronin and Kheisin (1977). The ice pressure then is a function of the divergence of the ice drift velocity. That is

$$P_i = A_p[div(V_i)] \tag{2}$$

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

$$A_p = 0$$
, if $div(V_i) > 0$

and

$$A_p = 10^7$$
, if $div(V_i) < 0$.

The surface wind was determined from geostrophic relationships with consideration of the transitional coefficient, C, and angle of deviation of surface wind from the geostrophic direction, α . Implemented in the model calculations is the algorithm in which

$$C = 0.7$$
 and $\alpha = 30^{\circ}$, if $W < 15$ m/s

or

$$C = 0.8$$
 and $\alpha = 20^{\circ}$, if $W > 15$ m/s.

The surface wind transitional coefficients and turning angles are based on prognostic and diagnostic simulations of the ice drift and storm surges in the Kara, Laptev, East Siberian, and Chukchi Seas (Proshutinsky 1978, 1986, 1993). In the model, we calculated divergence of the surface winds and assumed that the ice pressure was proportional to this divergence. We then categorized ice pressure into four levels of severity: no pressure (when $div[V_i] > 0$), low, medium, and high ice pressure.

2.4.4 Cost variables

In this section we discuss the rationale used to formulate the cost factors used in the model. The model allowed 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 were both applied as daily rates in the model. In the case of cargo ship costs, the model calculated the total number of hours required for transit, divided that number by 24, and multiplied by the daily rate. Icebreaker fees were applied only as complete days of service. That is, an odd number of escort hours was rounded up to the next whole day. The miscellaneous passage fees, on the other hand, were applied as a fixed cost regardless of how long the transit took. Each cost component is further described below.

Cargo ship operating and ownership costs

Actual NSR ship ownership and operating costs could not be determined for application in the previous reconnaissance study. Instead, we adjusted Corps of Engineers estimates for average ship costs (USACE 1995) to reflect higher costs for owning and operating ice-strengthened cargo ships for Arctic service. The Corps' 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 7.75% per year interest)

Crew wages, benefits, and subsistence

Stores and supplies

Maintenance and repair

Insurance

Other costs

Administrative

• Operational costs, considered as variable amounts, depending on the length of service

Fuel at sea

Fuel in port.

In USACE (1995), 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 nondouble-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 dead-weight tonnage, container capacity, length, beam, loaded draft, horse-power, and fuel consumption rates of main and auxiliary power plants at sea and in port.

Russian regulations require that ships using the NSR have ice-strengthened hulls and other features so as to be classified by the Russian Registry as LI, UL, or ULA (ANSR 1991). We selected three vessel classes from the *Inventory of Icebreaking Ships for Navigation on the Northern Sea Route* (Tunik 1994) as the more modern of the Russian fleet and that most likely would be used for dry bulk, liquid bulk, container, and general cargo deliveries via the NSR. These were the *Mikhail Strekalovsky*, the *Uikku*, and the *Noril'sk* classes, respectively. We chose classes of ships from the Corps' estimates that most closely matched the length, power, and cargo service of each of the NSR vessel classes and adjusted their ownership and operating costs to account for the more difficult service expected from NSR ships. The age of the existing fleet of Russian container ships and dry bulk carriers was taken into account by assuming a reduced capital book value by a standard 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 appeared 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.

These Russian vessels will inevitably be replaced with new ships. Designers will presumably apply the full benefit of modern commercial ship design and building methods to the 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.

Icebreaker escort fees

The Murmansk Shipping Company (MSC) or the Far Eastern Shipping Company (FESCO), depending on sailing 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 had been relatively few commercial NSR voyages involving foreign vessels at the time we conducted our simulations for the reconnaissance study. Financial information from those few voyages was very difficult to obtain, because it was not covered in much detail in the open literature. We based our icebreaker fees for summer and winter transits for various ship classes on then-recent information provided by Ramsland.³ We used the figures that he obtained from a preliminary schedule issued by the Russian Ministry of Transport and applied these rates to displacement tonnage in the fashion of Wergeland (1993). The fees used were fixed rates per voyage. Because we had little information about the average duration of voyages outside the summer season, we chose to apply these icebreaker rates in the model as fixed miscellaneous fees, which are discussed below.

³T. Ramsland, Foundation for Research in Economics and Business Administration, Bergen-Sandviken, Norway, personal communication, 1995.

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 that were reported by Wergeland (1991) included fees for pilotage, an ice helmsman, maps, guide books, guidance by reconnaissance aircraft, hydrographic and meteorological forecasting services, the use of communication systems, and so forth. He listed many other miscellaneous fees that could add substantially to the total cost of passage. Such additional fees include, for example, bunker filling, water delivery, special required vessel guidance in or near ports along the way, emergency services, local taxes, and tariffs.

2.5 Detailed simulation logic

Following the stepwise logic used in the model, this section describes how the simulated ship's base speed is first established and then adjusted for the current environmental conditions. Figure 3 shows a generalized flow chart of steps completed at the start of each segment of the simulation procedure. We defined a simulation segment as any portion of a transit during which all variables remained constant. Variables were reevaluated according to steps in the shaded box every 8 transit hours, which was the longest period of time spanned by a single segment. Segments may be shorter if, for instance, the simulation clock indicated that the sun rose or set within the 8-hr period, or if the ship reached a data point or decision node before the full 8-hr

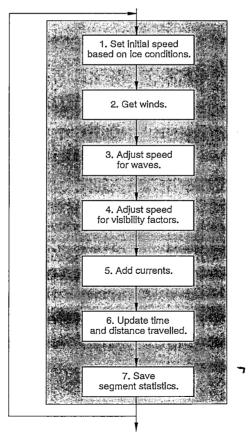


Figure 3. Simplified flowchart of steps performed during each simulation segment.

time step was completed. The simulation algorithm (Figure 3) first established the headway speed that the ship would maintain for the upcoming transit segment. It then tracked the ship's position and the distance traveled so that the environmental parameters (heading, ice, wind, fog, currents, etc.) were properly updated when the ship reached the next data or decision node.

Ship speed was a function of four groups of variables: 1) ice conditions, 2) sea state, 3) ocean currents, and 4) visibility and maneuvering factors (fog, snowstorms, icing, and darkness). Ice conditions determined the initial speed, and that was subsequently adjusted downward, if warranted, by other factors. The following subsections give more detailed explanations of the various steps followed in the algorithm.

2.5.1 Set initial speed for ice conditions (Step 1)

We established an initial speed for the cargo vessel depending on the sea ice conditions. Ice conditions not only determined the maximum forward speed that the vessel could maintain, but also whether escort by an *Arktika*-class icebreaker was needed. The initial speed was established by MC-selecting the sea-ice concentration first, followed by the selection of ice thickness. **Table 2** gives our initial speeds as a function of ice conditions, which we derived from Buzuyev and Gordienko (1976) and Brigham.⁴ Icebreaker support was deemed necessary whenever ice concentration exceeded 80%, or when the ice concentration was in the 60% and 80% category at the same time that the ice was 120 cm thick or greater. We chose these levels as needing icebreaker assistance based on our interpretation of Arikaynen and Chubakov (1987) and Brigham.⁴

After ship speed was initialized, we adjusted it by two factors. The first compensated for lengthening of the transit distance due to in-ice maneuvering for easier passage by using leads and avoiding massive ridges and hummocks. Instead of increasing the distance traveled, though, we addressed this issue by reducing the ship's speed according to the values shown in **Table 3**.

The second factor compensated for the occurrence of ice pressure. We assigned probabilities of occurrence for each of three ice pressure categories at each data node: low, medium, and high. Ice pressure was selected using the MC algorithm, but only if ice concentration was at its highest level (80–100%). When the pack was exerting pressure, speed was multiplied by the corresponding reduction factor shown in **Table 4**. Low pressure resulted in a 25% reduction in speed;

Table 2. 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	121–180	181–240	>240	
	Ice free			Full s	peed*		
Ice	<30	Full speed*	8	8	7	6	
concentration	31–60		8	8	7	6	
(%)	61–80	speed*	6	10	10	10	
	81–100		8	6	6	4	

⁴L.W. Brigham, former commanding officer of the U.S Coast Guard icebreaker *Polar Sea*, personal communication, 1995.

Table 3. 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.

		,	Ice thickness (cm)				
		Ice free	<120	120–180	181–240	>240	
	Ice free			100	<u>, , , , , , , , , , , , , , , , , , , </u>		
Ice	<30	0.97					
concentration	30–60			0.9	94		
(%)	61–80		0.90		0.95		
	81–100						

medium pressure, a 50% reduction; and high pressure stopped the ship for the remainder of that 8-hr time step. Ship speed was always multiplied by this factor regardless of the slowing factor imposed later by snowstorms, topside icing, fog, or darkness. In the case of high pressure, the ship was considered to be dead in the water and the only ship motion then was that due to wind-induced and permanent currents. Under such circumstances, negative speeds resulted if the direction of the currents was counter to forward motion of the ship. In this case the ship, locked in the ice, was drifting backward with the ice pack along the transit track in response to the summary ocean current.

2.5.2 Adjust speed for wind and waves (Steps 2 and 3)

We used the MC-selected wave height in conjunction with ice concentration to determine whether conditions existed that required the forward speed of the ship to be further adjusted downward. Table 5 shows how we adjusted ship 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 concentration was 30% or greater, insufficient fetch was present for a slowing sea to develop, and the speed established in Step 1 was maintained. If ice concentration was less than 30%, then we assumed that sufficient wave action could develop to slow the ship. The relationship of the wind direction to the ship's course then determined whether head seas, following seas, or beam seas were present (Figure 4), and we slowed the ship according to the values shown in Table 5. Larger waves in the presence of a partial ice cover (<30%) was cause for greater slowing than waves in open water, because of the increased risk of damage from collision with ice.

Table 4. 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			

Table 5. Ship speeds under different ice, wave, and wind conditions.

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

2.5.3 Adjust speed for visibility and maneuverability factors (Step 4)

Ship speed may have been further slowed by any of the four variables that cause degraded visibility or maneuverability. These are fog, topside icing, snowstorms, and darkness. Fog, icing, and snow were selected by applying the MC algorithm to PDFs that described the likelihood that each condition was present. Darkness, however, was set by the simulation clock that kept track of the time of day throughout the simulation. We assumed daylight to be 20 hr long in April and August, 8 hr long in October, and the full 24 hr during June. These visibility and maneuverability reduction factors came into play only if the cargo vessel was not under icebreaker escort. In addition, only that factor having the greatest impact on speed was actually applied to slow the ship. The extent to which a cargo ship is slowed by these factors is not well documented in the literature, so our reduction factors were fixed by trial-and-error experimentation with the program's logic and code. We increased some factors after earlier test runs indicated that the extent of slowing was too great. Discussions with Brigham led us to believe that our final reduction factors were not unrealistic. Specific points about each of these factors are discussed below.

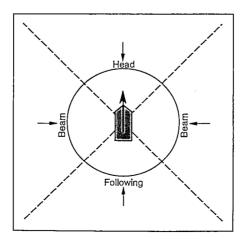


Figure 4. Relationship between wind direction, ship heading, and seas.

Fog

If fog was present and the cargo vessel was not under icebreaker escort, then a slowing factor between 0.50 and 1.0 was randomly chosen. This reduction was applied only if it was the largest one selected among all the visibility factors. If the cargo ship was under icebreaker escort, then no slowing was imposed due to any of the visibility factors, regardless of their magnitudes (i.e., the slowing factor was set to 1.0).

Superstructure icing

If topside icing was occurring and the cargo vessel was not under icebreaker escort, then a slowing factor between 0.85 and 1.0 was chosen at random to account for decreased maneuverability and visibility. If icing was not occurring, or if the cargo ship was under escort, then this slowing factor was set to 1.0.

Snowstorms

We considered decreased visibility to be the primary effect of falling snow. If a snowstorm was raging and the cargo vessel was not being escorted, then a slowing factor between 0.50 and 1.0 was chosen at random. Ship speed would then be reduced due to snowstorm only when it produced the largest of the visibility factors.

Darkness

The simulation clock kept track of the time of day, and for those segments traversed in darkness, a randomly selected reduction factor between 0.5 and 1.0 was applied to the ship's speed. Again, we applied this reduction factor only if it was the largest of all those affecting visibility and the ship was not under escort.

2.5.4 Adjust speed for ocean currents (Step 5)

Effects of wind-induced and permanent currents were largely independent of and superimposed on all other factors that influenced speed. The contribution that currents made to ship speed, therefore, was added after all other speed-related factors were accounted for. These factors are discussed in more detail below.

Wind-induced currents

We assumed the wind current velocity to be independent of ice conditions. For NSRSIM2A, we made it a simple calculation from the wind speed and wind direction that were chosen in Step 2 above. Under ice-free conditions, winds induce a current in the surface mixed layer of the open ocean that moves parallel to the wind direction. We assumed the velocity of the wind-induced current to be 2.5% of the wind speed. For ice-covered seas we assumed that the wind pushes the pack ice in the same direction the wind is blowing. Our modeled ship speed was adjusted by calculating the component of the velocity vector acting in the direction the ship was traveling and adding it to the ship speed (or subtracted it, in the case of a head wind).

Permanent currents

Permanent ocean currents were assumed to remain constant with regard to both speed and direction throughout the year. Ship speed was adjusted for the permanent current by calculating the current's vector component that acted in the direction of travel and adding it to the ship's speed. This vector and that of the wind-induced current were recalculated at each data node.

2.5.5 Update time and distance traveled (Step 6)

Once the ship speed was established for the transit segment ahead, the length of the segment in distance and the travel time were calculated in one of two ways. The algorithm first checked to see if the time remaining to the next sunrise or sunset was less than 8 hr. If so, then the time-length of the segment was set to whatever length of time remained until the next sunrise/sunset; otherwise the time length was set to 8 hr. Next, distance traveled was calculated by multiplying the ship speed by the segment time. This distance was compared with the distance from the ship's position at the start of the segment to the next data point or decision node. If that distance fell short of the next point, then the calculated time and distance were accepted. If the calculated distance to travel was greater than the distance to the next point, then distance was changed to the distance to the next node, time was adjusted downward, and calculations for the segment length were complete.

2.5.6 Save segment statistics (Step 7)

With all parameters set, they were saved to a data structure such that summary statistics could be calculated at the end of each voyage and when the entire transit simulation was completed. If detailed output of segment parameters was requested, values assigned to virtually all variables were written to the print file at this point in the algorithm. Finally a check was made to determine whether the transit end point had been reached. If not, control in the loop transferred back to Step 1, and the procedure repeated.

2.6 Sensitivity mode

During a typical run, the model assigned 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 one or more 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 was run in sensitivity mode, the program prompted the user with regard to what values were assigned to each variable. Fixed values for one or more parameters could be entered from the keyboard while others continued to be selected randomly. This feature allowed us to study the effect that modifying any one or several parameters together had on the output. It was especially useful for looking at the contribution that each individual parameter had on transit time and cost. By comparing the output for a "normal" run (one with no user-specified parameter values) with a run where all but one of the parameters were turned off, we obtained a quantitative measure of that parameter's contribution to the result.

3. NSRSIM01 SENSITIVITY STUDY

3.1 Previous sensitivity simulations

Some features of the original version of the CRREL model, NSRSIM01, were analyzed in terms of their sensitivity to systematic variation during the COE—AK reconnaissance study, and results were presented in Mulherin et al. (1996). Those results will only be summarized here; the reader is referred to this earlier report for more complete discussion of those results.

3.1.1 Model repeatability

Previously, we reported on the model's repeatability from run to run given the same set of input parameters. Any difference in output was due solely to the chance variation allowed by the MC nature of the data; that is, environmental data in the form of probability distributions. We demonstrated model repeatability by running the same set of conditions five times and showing that the standard and relative deviations were acceptably small. The relative deviations for transit time, cost, and average ship speed were all less than 2% of their mean values.

3.1.2 Number of voyages per simulation

Varying the number of voyages between 100, 200, 300, 400, and 500 had even less effect on time and cost than on repeatability. The relative time and cost deviations for this exercise each varied by less than 1% of their mean values. It was clear that 100-voyage runs, requiring considerably less computing time, allowed for the chance variation to be exercised adequately in our model. The computing time for a 100-voyage simulation was 21 s vs. 129 s for 500 voyages, so to save the time that we would expend for negligible improvement, we generated all of our results thereafter by running 100-voyage simulations.

3.1.3 Transit directionality

We tested identical scenarios in both directions for the months of April and August for the three different ship types. The time and cost calculations for eastward vs. westward transits also differed by less than 2%. We concluded that with the environmental data we had, there was no significant difference in time and cost between eastward and westward transits. Based on this information, we thereafter simulated only eastward transits. By simulating only one direction we reduced our number of runs by a factor of two.

3.1.4 Sensitivity of cost components

The model allowed the input of shipping costs in three separate categories: cargo ship operating and ownership costs in the form of a daily rate, icebreaker escort fees in the form of a daily rate, and miscellaneous passage fees. Each cost component is further described below.

Cargo ship rate

The cargo ship rate (CSR) was made up of the operating and ownership costs associated with the ship being used to transport the cargo. Operating costs included fuel used at sea and fuel used.

in port. Fixed annual ownership costs included a depreciated replacement cost; crew wages, benefits, and subsistence; stores and supplies; maintenance and repair; insurance; and administration. We did not include a business profit component. We applied these operating and ownership costs as a single daily rate (US\$/day). That is, the model calculated the total number of hours required for transit, divided that number by 24, and multiplied by the daily cargo ship rate stored in the COST.DAT data file (which can be easily modified between runs by the user, if desired).

Icebreaker escort rate

The icebreaker escort rate (IBR) was made up of fees that are paid for icebreaking services along the route. IBR was also applied as a daily rate (US\$/day) but only in increments of complete days of service. That is, at the end of each voyage, the number of escort hours was divided by 24 and any remainder was added to the quotient as another complete day.

Miscellaneous fees

Miscellaneous fees (MF) were the third component of total cost (TC). These included, for example, administrative, permitting, and harbor fees; fees for maps, communications, pilotage, weather and ice forecasts, bunker filling, water delivery, emergency services, and local taxes and tariffs. The miscellaneous passage fees were applied as a single fixed cost at the end of a voyage regardless of its duration (US\$/voyage). The icebreaker escort rate and miscellaneous fees are also stored in the COST.DAT file and are easily modified between runs.

In our model, TC was calculated using the above-described cost components in the following equation:

$$TC = (CSR * TT) + (IBR * ET) + MF$$
(3)

where TT = total transit time (days)

ET = escort time (rounded up to the next full day).

We previously determined the effects of each cost component on total cost by systematically varying each one while holding the other two constant. Using linear regression, we developed equations of total cost for a *Noril'sk* vessel during both April and August. First, CSR was varied while holding IBR at zero and MF at \$137,000 (for April) and \$116,000 (for August). The least-squares linear fits for TC with respect to CSR were

$$TC_{Apr} = 23.402 CSR + $146,448$$

 $TC_{Aug} = 14.173 CSR + $113,827.$

In other words, the change in total costs was 23.4 and 14.2 times the cargo ship rate for April and August, respectively.

IBR was then varied while holding CSR and MF constant. MF was held at zero and CSR was

held at \$16,450/day. The least-squares linear fits for TC with respect to IBR were

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

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

Finally, MF was varied while holding CSR and IBR constant. CSR was held at \$16,450/day while IBR was held at zero. The least-squares linear fits for TC with respect to MF were

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

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

3.2 New sensitivity simulations

After the Alaska reconnaissance study and before the present study, we upgraded to a faster computer, a 166-MHz Pentium personal computer. This allowed us to reduce the run time needed to complete a 500-voyage simulation from 129 s to less than 5 s. Because we were no longer limited by computing time, all of the present work is based on 500-voyage simulations, the maximum capability of our current model. Running the model five times using the same 500-voyage scenario, we found that the variation in the output was slightly less than that resulting from the five 100-voyage runs reported in Mulherin et al. (1996). The 500-voyage results and their deviation statistics are shown in **Table 6**.

3.2.1 Code modification

The one modification that we made to the model for this work enabled the user to shift upward or downward the PDF of individual parameters by any percentage amount at all data nodes. This option permitted the user to shift PDFs that describe environmental conditions (sea ice, fog, winds, etc.) left or right by a user-specified percentage at run time. This allowed one to assess how transit time was affected by an incremental change in the data for each parameter. It effectively provided a quantitative measure of how the resolution of the data affected the model calculations. For example, we direct the model to use a PDF that raises the probability for thicker ice by 20% at every data node over what our current data actually are. Comparing the longer transit time required for this hypothetically harsher condition with that of the "normal" run showed how influential this much uncertainty in ice thickness was on the final time and cost results. This provided insight as to how accurate the ice thickness data needed to be so as not to exceed a specific level of uncertainty in transit time. When this option was selected, the user was prompted to enter a percentage that is applied to the PDF in the following way: positive percentages shift the PDF toward the right (more severe conditions); negative percentages shift the PDF toward the left (milder conditions). Using ice thickness as an example, if +20% was entered, then the probability in each ice thickness category was first reduced by 20%. Further, the 20% by which one category was reduced was added to the probability in the next greater category (the category to the right). This procedure is demonstrated below.

Ice thickness category (cm)	Ice free	<120	120-180	181-240	>240
Beginning probability	0.05	0.25	0.30	0.35	0.05
Subtract 20%	-0.01	-0.05	-0.06	-0.07	
Add to next greater category	_	+0.01	+0.05	+0.06	+0.07
Enhanced severity probability	0.04	0.21	0.29	0.34	0.12

If a shift of -20% was entered, the same procedure was followed, except that greater probability was shifted to the next lower category:

Ice thickness category (cm)	Ice free	<120	120-180	181-240	>240
Beginning probability	0.05	0.25	0.30	0.35	0.05
Subtract 20%	_	-0.05	-0.06	-0.07	-0.01
Add to next greater category	+0.05	+0.06	+0.07	+0.01	
Reduced severity probability	0.10	0.26	0.31	0.29	0.04

The two examples above apply to variables characterized by an increase in severity as one moves from the left to the right, and vice versa. In the above example, categories progress from thinnest ice at the left to thickest ice at the right. Data that describe directional components of winds or currents, in effect, wrap around from the rightmost category to the leftmost category and so must be treated differently. Specifically, if a shift of +20% was applied, then 20% of the probability in the leftmost category was transferred around to the rightmost category, as shown below.

Table 6. Sensitivity study of model repeatability using the following set of conditions: Noril'sk multipurpose cargo ship, 500-voyage transits, daily cargo ship cost = \$23,000, daily escort cost = \$7,500, fixed passage fees = \$0. All sensitivity parameters are MC-selected by the model.

Run no.	Time (hr)	Speed (kn)	Icebreaker escort (hr)	Total cost (US\$)	Cost/ hour (US\$)	Cost/ mile (US\$)
April Transits:		·				
April Halistis.	560.0	£ £0	E1E /	712 262	1272.00	226 40
1	560.8	5.58	515.4	713,263	1272.00	228.40
2	566.0	5.57	516.3	717,732	1270.50	, 228.80
3	566.2	5.56	520.1	720,396	1272.60	229.60
. 4	562.7	5.59	517.3	715,991	1272.60	228.40
5	567.1	5.55	520.5	721,598	1272.40	229.90
Mean	564.6	5.57	517.9	717,796	1272.00	229.00
Standard deviation	2.68	0.02	2.28	3,355	0.88	0.69
S.D. relative to the mean (%)	0.47	0.28	0.44	0.47	0.07	0.30
August Transits:						
1	324.8	9.70	73.4	349,928	1077.20	111.90
2	325.0	9.69	76.5	351,070	1080.10	112.40
3	323.0	9.73	74.8	348,787	1079.20	111.90
4	322.5	9.76	72.2	347,447	1077.50	111.30
5	326.2	9.66	75.7	351,737	1078.10	112.60
Mean	324.3	9.71	74.5	349,794	1078.10	112.00
Standard deviation				•		
	1.52	, 0.04	1.73	1,728	1.21	0.51
S.D. relative to the mean (%)	0.47	0.39	2.33	0.49_	0.11	0.45

Wind direction category (deg)	1–90	91–180	181-270	271-360
Beginning probability	0.15	0.20	0.25	0.40
Subtract 20%	-0.03	-0.04	-0.05	-0.08
Add to next greater category	+0.08	+0.03	+0.04	+0.05
Resulting probability	0.20	0.19	0.24	0.37

If a shift of -20% was applied, 20% of the probability in the leftmost category is transferred to the rightmost category, as shown here.

Wind direction category (deg)	1–90	91–180	181-270	_271-360
Beginning probability	0.15	0.20	0.25	0.40
Subtract 20%	-0.03	-0.04	-0.05	-0.08
Add to next greater category	+0.04	+0.05	+0.08	+0.03
Resulting probability	0.16	0.21	0.28	0.35

The presence of fog, snow, or icing are examples of environmental data that were not described by a PDF, but by a single probability of whether or not they will occur. Although only one probability was given, in effect, these binary variables had a PDF consisting of two categories: yes and no. In these cases the probability of occurrence was increased (or decreased) by the percentage specified by the user.

Finally, there was the way that we applied the error to the permanent current velocity and direction. Rather than PDFs, these were single fixed values at each data node. In the case of velocity the percent error was simply converted to a numerical factor. For example, if the user inputs an error of -50.0, then the velocity is reduced by 50%. For current direction, the input value was the number of degrees to be added or subtracted from the datum at each node. Therefore, a -50.0 input resulted in a current that was 50° more counterclockwise than the actual data.

3.2.2 Cost inputs

For the present sensitivity simulations, we used the following costs:

Noril'sk cargo ship costs \$16,450/d
Icebreaking escort \$7,500/d
Miscellaneous fees \$0

Although the *Noril'sk* ship costs are those that we used earlier for the reconnaissance study, the icebreaking escort fee is an arbitrary figure that we chose for demonstration purposes only. To simplify these analyses, no miscellaneous fees were applied.

3.2.3 Tests for sensitivity

Each environmental parameter was exercised in a number of different ways, and those complete results are shown in **Appendices A.1 through A.7**. On each page of **Appendix A** the first table shows the mean April values for elapsed time, ship speed, hours of icebreaker escort, and total cost for several different run scenarios. The second table shows these same values for

August transits. The numbered run scenarios are described as follows.

- Run 1 All variables were switched off (their probabilities of occurrence were made equal to zero) for the entire simulation so that they could not affect the outcome. The outcome was therefore due solely to factors in the model that could not be altered by the user.

 Note that the April results were essentially identical to those for August because there was no difference in the sailing environment between these two runs.
- Run 2 Only one variable was turned off during the entire simulation. All other variables were chosen in the normal way by the model.
- Run 3 One variable was first MC-selected and then *reduced* in magnitude by a user-selected percentage amount, and all others were chosen in the normal way by the model.
- Run 6 The "normal" run, where all variables were chosen in the normal way.
- Run 7 One variable of interest was first MC-selected and then *enhanced* in magnitude by a user-selected percentage amount, and all others were chosen in the normal way.
- Run 10 All variables were switched off except the one variable of interest.

Runs 4 and 5 were similar to Run 3 in cases where more than one environmental parameter was exercised (see **Appendix A.1**). For example, the ice-conditions parameter had the three variables of concentration, thickness, and pressure and the PDF for each one was reduced in its own separate run. Runs 8 and 9 were similar to Run 7, but the PDF for each variable was enhanced

In each of the tables for April and August, we normalized each run with respect to Run 6, the "normal" run. Dividing by the mean values of the normal run showed the relative change that resulted from the exercise of each variable. For example, in **Appendix A.1**, we show that the time required for a transit in April during which the ice conditions were switched off (Run 2) is only 37% of that for the normal run, Run 6. This shows that ice conditions alone accounted for 63% of the time needed for a normal transit in April. In other words, if ice was never encountered (all other things being equal) then the mean ship speed would be 63% faster. Similarly, in August, ice conditions are less severe but they still account for 36% of transit time. These ratios then show the relative importance of each parameter in the model, given the data that we then had.

3.2.4 NSRSIM01 sensitivity results

Table 7 lists all the time and cost ratios for both April and August transits when one parameter is turned off while allowing all others to be MC-selected (Run 2). For April transits, we saw that ice conditions is the only parameter that affects time and cost when it alone is turned off. For August transits, ice conditions was again the most sensitive parameter, accounting for 36 and 40% of transit time and cost, respectively. When ice pressure was turned off while concentration and thickness were allowed to be MC-selected along with all the other variables in April, there was a 9% improvement in both time and cost. The improvement amounted to only 3% for August transits, owing to the lower probability of encountering pressure and ice in general at that

Table 7. Ratios of ship speeds and costs for which the environmental parameter shown has been turned off to those calculated by a "normal" run in which all parameters are MC-selected.

	<u>Month</u>							
	A	pril	Aus	gust				
Principal parameter	Time	Cost	Time	Cost				
Ice conditions Concentration Thickness	0.37	0.29	0.64	0.60				
Pressure	0.91	0.91	0.97	0.97				
Wind conditions Direction Speed	1.00	1.00	0.99	0.99				
Waves	1.00	1.00	0.97	0.98				
Fog	1.00	1.00	0.95	0.95				
Icing	1.00	1.00	0.99	1.00				
Snow	1.00	1.00	0.99	0.99				
Permanent currents Direction Speed	1.00	1.00	0.99	0.99				

year. Each of the other parameters had a much less significant effect, the most sensitive of these being fog. Turning off fog resulted in a 5% decrease in both time and cost with respect to a normal run. This showed that it is not worthwhile to obtain more accurate PDFs for the other variables without making improvements to our ship performance algorithms or our understanding of the interactions between the environmental parameters.

Table 8 shows the result of simulations in which the principal parameter's probability of occurrence was reduced by the amount shown with respect to a normal run (Runs 3, 4, 5). For each of the variables except direction and speed of permanent currents (these were fixed values rather than PDFs), 25% reductions were simulated. We reduced direction and speed for permanent currents by 90° and 50%, respectively. Again, the greatest changes in time, and to a lesser degree cost, were due to ice conditions. Each of the remaining variables affected time and cost by less than 2%.

Table 9 shows the result of simulations in which the principal parameter was enhanced by the amount shown with respect to a normal run (Runs 7, 8, 9). Again, 25% enhancements were simulated for each of the variables except for the direction and speed of permanent currents. We enhanced those by 90° and 100%, respectively. Here again, the greatest changes in time and cost were due to ice conditions. Each of the remaining variables again affected time and cost by less than 2%.

Table 10 lists the ratios for time and cost for April and August transits when the principal parameter was MC-selected while all the others were turned off (Run 10). This exercise showed the relative importance of the principal parameter in conjunction with factors in the model that could not be turned off, such as the occurrence of darkness and the choice of route. Again we see

Table 8. Ratios of ship speeds and costs for which one environmental parameter's probability of occurrence has been reduced by the amount shown to those calculated by a "normal" run.

	Month							
	A	pril	Aug	rust				
Principal								
parameter	Time	Cost	Time	<u>Cost</u>				
Ice conditions								
Concentration (-25%)	0.92	0.91	0.97	0.96				
Thickness (-25%)	0.95	0.95	0.98	0.96				
Pressure (-25%)	0.98	0.98	0.99	0.99				
Wind conditions								
Direction (-25%)	1.00	1.00	0.99	0.99				
Speed (-25%)	1.00	1.00	0.99	0.99				
Waves (-25%)	1.00	1.00	0:99	1.00				
Fog (-25%)	1.00	1.00	0.98	0.98				
Icing (-25%)	1.01	1.01	0.98	0.98				
Snow (-25%)	1.00	1.00	0.99	0.99				
Permanent currents								
Direction (-90°)	1.00	1.00	0.99	0.99				
Speed (-50%)	1.01	1.01	0.99	0.99				

Table 9. Ratios of ship speeds and costs for which one environmental parameter's probability of occurrence has been enhanced by the amount shown to those calculated by a "normal" run.

		M	onth	
	A	pril	Aug	gust
Principal				
<u>parameter</u>	Time_	Cost	Time	Cost
Ice conditions				
Concentration (+25%)	1.01	1.01	1.10	1.10
Thickness (+25%)	1.02	1.02	1.00	1.01
Pressure (+25%)	1.06	1.06	1.00	1.01
Wind conditions				
Direction (+25%)	1.00	1.00	0.99	0.99
Speed (+25%)	1.00	1.00	0.98	0.99
Waves (+25%)	1.00	1.00	1.00	1.00
Fog (+25%)	1.00	1.00	1.00	1.00
Icing (+25%)	1.01	1.01	0.99	0.99
Snow (+25%)	1.00	1.01	0.99	0.99
Permanent currents				
Direction (+90°)	1.00	1.00	0.99	0.99
Speed (+100%)	1.00	1.00	0.99	0.99

Table 10. Ratios of ship speeds and costs for which all environmental parameters except the one shown have been turned off to those calculated by a "normal" run.

	Month								
	A	pril	Aus	gust					
Principal									
<u>parameter</u>	Time	Cost	Time	<u>Cost</u>					
Ice conditions	0.98	0.99	0.92	0.94					
Conc. and thick.	0.89	0.90	0.90	0.90					
Pressure									
Wind conditions	0.34	0.27	0.59	0.56					
Direction									
Speed									
Waves	0.35	0.28	0.59	0.56					
Fog	0.35	0.28	0.63	0.59					
Icing	0.34	0.27	0.59	0.56					
Snow	0.35	0.28	0.59	0.56					
Permanent currents	0.34	0.27	0.59	0.55					
Direction									
Speed									

that ice condition is the main parameter controlling time and cost. For April transits, the differences in time and cost between these and normal runs were 2% or less, and for August they were 8% or less. Fog during August had the next greatest effect, albeit a relatively minor one, as it had an effect 3–4% larger than any remaining variables.

These exercises, however, did not exercise all the different combinations of variables that were possible. Conceivably, there might be certain combinations of variables that could significantly affect time and cost; however, exercising all combinations was beyond the scope of this study.

3.2.5 Summary of final NSRSIM01 sensitivity results

We conducted a sensitivity analysis of the CRREL NSR transit model to learn the relative importance of each model variable in calculating transit time and cost.

We systematically exercised each environmental variable four different ways:

- One variable of interest was switched off while all others were MC-selected.
- One variable of interest had its probability of occurrence reduced by a specified amount at every data node.
- One variable of interest had its probability of occurrence enhanced by a specified amount at every data node.
- One variable of interest was MC-selected while all others were switched off.

We normalized the results of each exercise with respect to those calculated when the model was

allowed to MC-select all the variables, i.e., the "normal" run. These ratios illustrated the relative contribution of each variable to time and cost.

The four exercises all showed that, given our current data, ice concentration, thickness, and pressure were the major determinants of time and cost. All other variables individually had very little, if any, effect. Therefore improvements in the resolution and accuracy of the ice conditions data would yield the greatest improvement in the accuracy of our model. What we have not tested, and it is beyond the scope of this work, is the effect that the many combinations of variables might have on the outcome.

We knew little about the current shipping rates and fees, but we showed their relative effect on our hypothetical cost results and provided the underlying equations in which more accurate data could be used. In addition, we believed that our estimates of vessel speed were reasonable for the conditions we modeled. However, our results would likely be substantially improved by more accurate cost and ship speed factors. Both are being compiled or developed under various INSROP2 work projects concurrent with this study and presumably will be incorporated into the WP8 transit model.

4. NSRSIM2A: THE MODIFIED CRREL MODEL

After we completed the NSRSIM01 sensitivity analysis we created NSRSIM2A, a new version of the CRREL model, so that its output could be compared more directly with results from the transit model developed in WP8. The modifications consisted of 1) replacing our routes and data nodes with those used in the WP8 model, 2) constructing the environmental data tables corresponding to the new data points, and 3) some code and logic changes.

4.1 New routing scheme

Our NSRSIM2A model uses the shipping routes that were formulated under the INSROP2 Work Project entitled WP1 Routes and Associated Operational Infrastructure (Baskin et al. 1998). Whereas our earlier model was limited to simulating complete voyages between Murmansk and the Bering Strait, NSRSIM2A allows voyages from Hamburg, Germany, to the Bering Strait, and to and from specific locations in between. Figure 5 shows the routing scheme employed in both the WP8 and NSRSIM2A models. We divided the available routes into a total of 33 different transit "legs." These legs are generally sets of consecutive transit segments lying between certain decision nodes. Each of the 33 legs is labeled with a circled numeral. Except for the leg endpoints, the data nodes are shown as black dots. The nodes marking the leg endpoints are shown as open circles. Appendix B contains a complete listing of the transit legs, their endpoints and intermediate data nodes, their locations by latitude and longitude, and the distance and heading to the next data node in the leg.

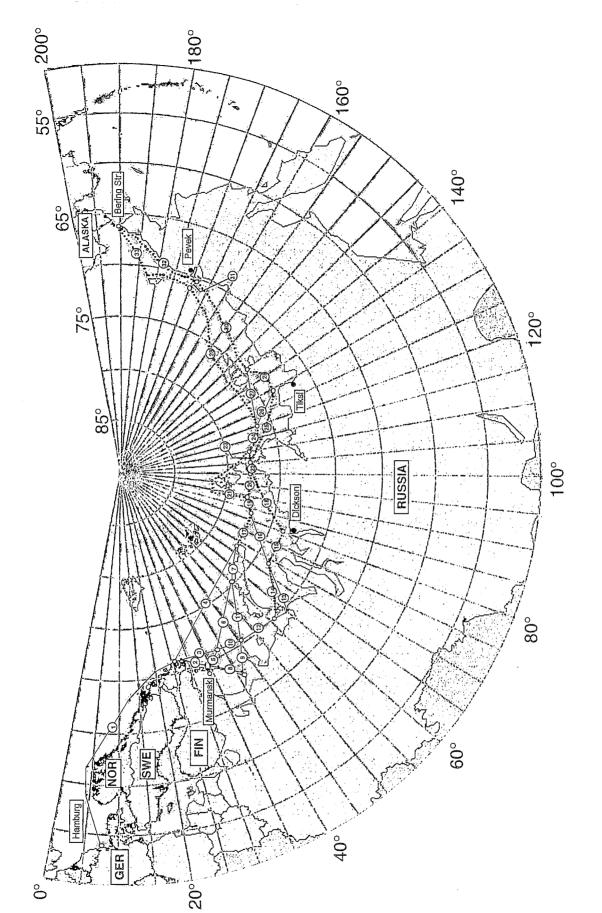


Figure 5. Routing scheme for new transit model, NSRSIM2A. The various routes were broken into 33 different legs, labeled with circled numerals. The leg endpoints are shown as open circles. The black dots and leg endpoints are node points for which the environmental data is available for the model to call upon.

Whereas the spacing between the 59 data nodes in our earlier model was approximately 250 nm, our new model has much finer spacing of the way points. This new routing scheme is composed of 335 data nodes, each where the environmental conditions are updated during simulation. Outside the legal bounds of the NSR, the node spacing is still wide and highly variable. West of the NSR, from Hamburg to the Barents Sea, the spacing ranges from 442 to 119 nm. The route segments (defined as the spaces between data nodes) across the Barents Sea range from 6 to 732 nm long, with the shorter segments occurring in the various straits and port approaches where navigation must be more precise for safety considerations. However, in general, across the actual NSR portion (i.e., between Novaya Zemlya and the Bering Strait) the majority of nodes are now spaced only 20 nm apart.

NSRSIM2A is more versatile in terms of voyage origin and destination than our earlier version. The user has the choice of generating time and cost statistics for all-33 segments or for a select combination of segments to piece together a particular voyage of choice. The model can simulate full-transit passages or shipping only between specific ports, straits, or islands. For example, if the user wants to know the time required to sail from Murmansk to Dikson, he might input, for example, leg numbers 5, 10, 12, 14, and 15 at the user prompt. Another combination of legs available for travel between those two ports is 8-9-12-13-15. Unlike NSRSIM01, though, the new version is not currently programmed to simulate east-to-west transits. This feature could easily be added in the future if the need presents itself.

4.1.1. The Hamburg-to-Barents Sea section

This section of the model comprises a single transit leg with five segments representing the distance between Hamburg, Germany, and North Cape, Norway. The total distance is 1260 nm; it is Leg 1 in our model. The endpoints of Leg 1 are 1.00 and 1.05 (H-01 and B1-01 in the WP8 model).

4.1.2 The Barents Sea section

This section of the model is divided into 11 legs (Legs 2 through 12). These represent the possible route choices available in the Barents Sea area, between North Cape in the west and Novaya Zemlya in the east. The user can select any one of three different courses to proceed from North Cape: a southern route along the coast to the ports of Murmansk and Arkhangel'sk, a direct route to the southern end of Novaya Zemlya, or the high-latitude choice directly to Mys Zhelaniya (the northern tip of Novaya Zemlya). Many different route variations are also available. Leg 2, from North Cape to Murmansk, is 211 nm in length, and Arkhangel'sk, near the mouth of the White Sea, is another 231 miles farther, by way of Leg 8. The direct route from North Cape to southern Novaya Zemlya is composed of three legs—3, 10, and 12, with a total length of 604 nm. Leg 4, extending from North Cape to northern Novaya Zemlya, is 732 nm long.

4.1.3 The Northern Sea Route section

The section between Novaya Zemlya and the Bering Strait has basically a northern route and a southern route, with many crossover legs to allow transition between the two. In addition, many combinations of legs can be selected to simulate travel to a variety of destinations within the NSR, namely the ports of Dikson (at the east endpoint of Leg 15), Tiksi (at the east end of Leg 25), and Pevek (at the east end of Leg 30). The transition legs between the northern and southern routes are Legs 16, 20, 23, 26, 27, and 31. Legs 13 and 14 are different ways through the southern Novaya Zemlya straits. Note that Leg 13 has a long stretch with no data nodes. The length of the Murmansk-to-Bering Strait coastal route is either 2741 nm or 2795 nm, depending on whether Leg 13 or Leg 14 is chosen. The high-latitude route is either 2922 nm or 3181 nm in length, depending on whether one chooses to follow the shallow route through Vil'kitskogo Strait using Legs 20 and 22, or to skirt Severnaya Zemlya to the north via Leg 21.

4.1.4 Bering Strait-to-Yokohama transit route

Our model doesn't have a Bering Strait-to-Yokohama leg, which is included in the WP8 model. The environmental data that was required for MC-modeling this transit section was not provided to us. We can only assume that the *Noril'sk* ship, traveling at its full, open-water speed of 17 kn, will transit this 2721-nm section in 160 hr. The user should include this additional time requirement for any transit of interest that includes the Bering Strait-to-Yokohama leg.

4.2 New environmental data

The environmental data (meteorological, oceanographic, and sea ice conditions) for our new routing scheme were compiled under a separate INSROP2 project entitled *Project I.5.8 - Environmental Conditions Affecting Commercial Shipping*. For complete discussion of the derivation of these data, we refer the reader to Proshutinsky et al. (1998). These data, no doubt, differ from those used in the WP8 model because they originate from different sources. The INSROP2 environmental data were compiled under work package WP2 - Natural Conditions Along the Selected Routes and are discussed in a report of the same title (Aschik et al. 1998).

The following subsections briefly describe the sources for our data when they differ from those used in our original model. Most parameters were changed only in the fact that the data were interpolated to fill the new scheme of 333 data nodes. Those changed only in this way include ice thickness and pressure, permanent and wind-induced currents, fog, icing, and snow-storms. Our data sources for, and the new ways in which we treated, ice concentration, wind, and waves in NSRSIM2A are described below.

4.2.1 Ice concentration

Our new ice concentration data were developed from 10-day Arctic Ocean EASE-Grid sea ice observations that were available from the National Snow and Ice Data Center⁵ (NSIDC). These data of Arctic sea-ice concentration and its stage of development were originally digitized

⁵NSIDC is located at the University of Colorado, Boulder, Colorado, U.S.A

by scientists at Russia's Arctic and Antarctic Research Institute (AARI) from original paper source charts that were developed for shipping purposes from aircraft and satellite observations. NSIDC has issued the digitized Russian ice charts in the Equal Area SSM/I Earth (EASE) Grid format for 1953 through 1990. The data in the EASE-Grid North azimuthal projection for both Western (24°W to 110°E) and Eastern (105°E to 130°W) sectors have a resolution of 12.5 km².

4.2.2 Wind

Our new wind speed and direction PDFs were developed by Proshutinsky et al. (1998), who used the geostrophic wind model of Gill (1982) in the same way they did for NSRSIM01 (see Section 2.4.1). However, they derived the atmospheric pressure data that they used in the Gill model for calculating wind direction and speed from two sources:

- Actual observations spanning 1946 to 1978 from the National Center for Atmospheric Research (NCAR 1990), and
- The combined result of numerical modeling and actual observations dating from 1973 to 1997 from the National Centers for Environmental Prediction⁶ (NCEP) on-line database.

4.2.3 Waves

In the original model version, we MC-selected the wave height for each data node independent of the wind speed. In reality, wave height is directly related to wind speed. For NSRSIM2A, we still assumed a wave height equal to zero if ice concentration was greater than 30%. Otherwise, we calculated the wave height in the ways described by Tucker (1991), which depend primarily on water depth. The algorithm we used for locations where the water depth was greater than 40 m was

$$H = 0.0317 \ W(X^{0.5}) \tag{4}$$

in which H is the wave height in meters, W is the wind speed (kn), and X equals wind fetch (km). In general, this equation applies for the deep Barents Sea and the central Kara Sea.

For shallower seas, i.e., less than 40 m (mainly the Laptev, East Siberian, and Chukchi Seas), water depth is more important than fetch, and it is related to the wave height as follows:

$$H = 0.21 (W^{0.5}) (h^{0.75}) (g^{0.25})$$
 (5)

in which h is the depth in meters and g is acceleration due to gravity (9.8 m/s²).

In the Arctic, fetch is the distance from the upwind ice edge, and we assumed it was equal to either 100 or 200 km, depending on the month of transit. We used the smaller value for transits occurring in April and the higher value for those in June.

⁶The NCEP Central Operations is located at the World Weather Building, 5200 Auth Rd., Room 800, Washington, D.C., U.S.A.

4.3 Logic changes

A detailed flow chart of NSRSIM2A is shown in **Appendix C**. The model no longer selects the choice of route between origin and destination by the MC method, as was the case with NSRSIM01. As was stated earlier, the user can now input which legs are to be followed during simulation. This allows the user to define a route of his choosing between any origin and destination as long as they are leg endpoints. Alternatively, he can also choose to generate the time and cost statistics for all 33 legs at once. The results for all legs then are output to a table from which the user can select any combination of two or more to observe their individual contributions to the total transit.

Another change allows the user to select a choice of time step employed in the model, that is, the length of time after which the dice are rolled again if the end of the distance segment has not been reached. Although NSRSIM01 always used a time step of 8 hr, NSRSIM2A will function with whatever time step the user inputs in the command line to start the model.

Wave heights are no longer MC-selected. Instead they are now calculated directly using the wind speed, open-water fetch, and sea depth at each data node.

4.4 Running the NSRSIM2A model

NSRSIM2A can simulate a 500-voyage transit of all 33 legs and generate the least detailed choice of output (option 0; see Section 4.4.3) in approximately 40 s. Simulation of a single specified route requires less time. For example, a northern latitude 500-voyage transit between Hamburg and the Bering Strait, that is, one that uses only Legs 1, 4, 17, 19, 21, 24, 28, 33, requires approximately half that time.

4.4.1 Input file structure

NSRSIM2A makes decisions based on probabilities of occurrence that different sets of conditions will occur. These data are stored in separate files that are read into data structures in the program at its initiation. The input files all must be located in the same directory as the executable file (NSRSIM2A.EXE). For most variables, the data for each of the two different months are stored in separate files. Exceptions are the permanent current data and the cost data. The permanent currents are assumed to remain constant year round so the same file, PERMCURR.ALL, is used for either April or August transits.

The cost data used in the model are stored in the file named COST.DAT. Before starting the simulation, the user should check to see that this file contains the correct cost factors for whichever month is to be modeled and if not, the file must be edited and resaved.

File names were constructed to reflect the type of data in the file and the month to which it corresponds. Files with extensions .DAT and .ALL contain the data for both April and August together. The file-naming format is as follows:

```
{type_of_data }.{ month }, or
{type_of_data }.DAT, and
{type_of_file}.ALL for files containing both April and August data together.
```

For example,

- FOG.APR contains the probabilities for the occurrence of fog during April for all data nodes.
 - ICEPRES.AUG contains the ice pressure PDFs for August.
- WATER_DPTH.DAT contains the water depth values, which we have assumed are the same for both months.
 - ICECONC.ALL contains the ice concentration PDFs for both April and August.
 - NDESWE.DAT contains the routing gridpoints and geographic data.

Appendix D contains information concerning the various input data files. Table D.1 provides the input file names and identifies the table that corresponds to each input parameter (Tables D.2 through D.12). For example, Table D.2 describes the input file format specifications for the ice concentration PDFs. A portion of the actual data file is also shown following each table.

When the model is invoked, only files that contain data for the month specified in the command line are loaded. For example, if the model is run to simulate transits in April, only the .DAT files, the .ALL files, and files with extensions that end .APR need be present in the directory for the program to run properly. PDFs for the different environmental conditions are automatically loaded from these input files. The order in which data are listed for a specific node point is critical. NSRSIM2A identifies a given node 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 because the PDFs will be assigned to the wrong nodes.

4.4.2 Starting a simulation

The program is invoked by typing at the DOS prompt the name of the executable program file NSRSIM2A in either upper or lower case, followed by the command line arguments. The arguments are numbers separated by spaces and specify certain run conditions. The general form of the initial command line is as follows:

NSRSIM2A a b c d e f

where the argument options are

```
a = the month of transit (4 = April or 8 = August)
```

b = ship type (1 = Noril'sk or 4 = user-defined ship)

c = output option (0 = short, 1 = medium, 2 = long)

d = the number of voyages for the simulation (500 or fewer)

e = sensitivity mode (0 = off or 1 = on)

f = length of the time step (in hours).

All the arguments should be entered as positive whole numbers except f, which can be entered as

a real number indicating decimal hours. For example, to run the model for April, using a *Noril'sk*-class ship, printing only the overall summary statistics for a 500-voyage simulation in the non-sensitivity mode, and using 4-hr time steps, enter

NSRSIM2A 4 1 0 500 0 4.0 or nsrsim2a 4 1 0 500 0 4

To restate, the command line arguments are delimited by spaces, not commas.

To run the model for August, using a user-defined cargo ship, providing detailed output for only five voyages, each with a 2-hr time step, enter

NSRSIM2A 8 4 2 5 0 2.0

When a user-defined ship is selected, the user is then prompted to enter the maximum open water speed of the new ship. Enter the speed in knots. Note that this changes only the ship's speed for ice-free sailing and does not make any changes to the modified speeds that are stored in the various lookup tables (Tables 2, 3, and 5).

The choice of output determines the level of detail the user wishes to see after the run. The size of the output files varies quite dramatically. A short output option saves only the summary statistics for the overall run, the medium option saves the same tables produced by the short option plus similar statistics for each voyage comprising the run. The long output file saves the information produced by the short and medium options plus a record of all parameter values at each data node for every voyage comprising the run.

The number of voyages refers to how many times the user wants to repeat the voyage. A simulation can consist of a single voyage or as many as 500 voyages. The more voyages selected, the more times the dice are rolled at each node and the more likely one is to achieve the average environmental conditions for any chosen transit simulation.

The user must enter a 1 instead of 0 for the next-to-last argument in the command line to run the model in sensitivity mode (discussed in Section 3.2). When the user selects the sensitivity option, the model steps through each variable and allows the user to select whether each (or all) will be MC-selected or fixed at a constant value, or if its PDFs should be changed by a user-specified amount (see Section 4.4.4).

As previously stated, the time step can be entered as hours either as a whole or a real number. Any time step length can be chosen, but one that is something other than a whole hour must be entered as a decimal hour. For example, a time step of 2 hr and 30 min should be entered as 2.5.

Once the command line is entered, the model reads in the appropriate data and then instructs the user to select the route desired for simulation. The user can respond by entering specific leg numbers (Figure 5) that he wishes to follow. These are each entered separately, followed by a carriage return. For example, to simulate only a transit between Murmansk and Dikson, the user might input the route composed of Legs 5, 10, 12, 14, and 15. When all the desired legs have been entered, a final user entry of 999 followed by a final carriage return signals the model to begin the simulation. A different route from Murmansk to Dikson can be specified by selecting

Legs 5, 10, 13, 14, 15, and 999. Alternatively, an entry of 99 followed by a carriage return instructs the model to simulate the transit and generate the output for all 33 legs.

4.4.3 Output files and print options

Each time the model is run, simulation results are written to an ASCII print file named NSRSIM2A.PRN. If the file already exists, previous results are overwritten; if it does not exist, then it is created. To preserve the results from each run, print a hard copy of NSRSIM2A.PRN or save an electronic version of it under a different name before another simulation is run.

NSRSIM2A allows for three levels of detail in output written to the print file. At the most basic level (print option = 0), the program prints only the overall statistics for the complete transit simulation. At the intermediate level (print option = 1), the output file includes additional statistics that summarize the parameter values for 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 for each transit, listing all parameter values each time they are reset.

Appendix E shows examples of the three different print options.

Print Option 0 (simulation summary)

The output consists of eight separate tables. The first table summarizes the overall statistical information, including the min, the max, the mean, the variance, and the standard deviation for each of the following:

- Elapsed time, mean speed, distance traveled, and total time while under escort
- Total time and percentage of time that each environmental condition was in effect
- Permanent current and wind-induced current velocities
- Total hours and distance over which open, ice-free ocean was encountered
- Total cost and mean cost per hour and per mile.

The next five tables give statistics that summarize the time and distance over which each environmental parameter was in effect for each leg of the transit. These tables include one each for fog, icing, snowstorms, darkness, and the general occurrence of sea ice.

Next are seven tables that provide more detailed information about sea-ice concentration, thickness, and pressure. They show the elapsed time and distance traveled for each category of ice severity at every transit leg. One of these is a table that shows how often each combination of ice concentration and thickness occurs at each leg during the simulation. The ice tables are followed by a summary table for the amount of time and distance traveled under icebreaker escort. A final table shows the summary statistics for overall elapsed time for each leg of the simulation.

Print Option 1 (individual voyage summaries)

Printed output for Option 1 includes all that was provided under Option 0 plus three additional tables for each voyage comprising the simulation. The first new table shows the minimum, maximum, mean, variance, and standard and average deviation statistics for

• The speed-reduction factor for each visibility parameter (fog, icing, snow storms, and dark-

ness)

- The magnitude of the permanent and wind-induced current vectors
- Ship speed
- · Wave height
- Wind speed.

The second table provides the following for each of the environmental parameters:

- The total and percentage amount of time that condition was present during the voyage
- The total and percentage distance over which it was occurring
- The total and percentage number of transit segments where it was occurring.

The third table presents the amount of each cost component (cargo ship, icebreaker escort, and miscellaneous fees), the total cost, and the costs per mile and per hour for that one voyage.

Print Option 2 (listing of variables at each change for all voyages)

Printed output for Option 2 includes all the tables provided under Options 0 and 1 plus a table for each voyage listing the actual values assigned to each variable at every segment. Print Option 2 is useful for debugging and for very detailed analysis of a voyage. In general, it should not be used for more than a few repetitions. Otherwise, the amount of output can be voluminous and unmanageable.

4.4.4 NSRSIM2A sensitivity analysis mode

When NSRSIM2A is run in sensitivity mode, it prompts the user as to how values will be assigned to each variable. In the sensitivity run mode, parameter values to be held constant throughout the run can be entered from the keyboard at the same time that others are left to random selection. In addition, the PDFs for single or multiple parameters can be increased or decreased by user-specified percentages. To run the second example shown in **Section 4.4.2** in sensitivity mode, change the next-to-last digit from 0 to 1, as shown:

NSRSIM2A 8 4 2 5 1 2.0

This will produce an August transit of a user-defined ship and provide detailed output for a five-voyage simulation. If sensitivity mode is turned on, after the user enters the command line arguments and selects the route segments, he then is prompted for a series of responses that describe how the various environmental parameters will be used throughout the simulation. Such a prompt, using fog as an example, reads as follows:

ENTER OPTION FOR FOG:

- 0 = NO FOG for Entire Run
- 1 = CONSTANT FOG and CONSTANT FOG FACTOR Defined by User
- 2 = CONSTANT FOG and RANDOM FOG FACTOR

- 3 = RANDOM FOG and CONSTANT FOG FACTOR Defined by User
- 4 = RANDOM FOG and RANDOM FOG FACTOR
- 5 = ADD ERROR TO FOG PDF
- 9 = QUIT Program Now

When the user selects 0, the probability of encountering fog will automatically be zero for the entire simulation. Selections 1, 2, 3, or 4 allow the user to choose either a random (drawing from the normal PDF) or fixed presence of fog at every node and to choose a random or fixed speed reduction factor. If 1 or 3 is selected, then the user is prompted to enter a constant speed reduction factor that will be used whenever fog is encountered. The user should input a value between 0.00 and 1.00, which becomes the factor multiplied by the ship's speed at every node where fog occurs. Note that any input value other than 1.00 reduces ship speed.

Selection 5 should be chosen if the user desires to change the PDF at every node by a set amount, as discussed in Section 3.2.1. When 5 is selected, the user is then prompted to enter a percentage amount in the form of a real number between –99.99 and +99.99. A 10% increase, for example, should be entered as 10.0, and a 10% decrease should be entered as –10.0. Return to Section 3.2.1 for discussion on how this option changes the PDFs for each variable.

5. SIMULATION RESULTS FROM NSRSIM2A

5.2 New sensitivity analyses

5.1.1 Repeatability

We tested the overall repeatability of NSRSIM2A by running identical scenarios several times and comparing the output from each. We ran 500-voyage simulations each for both April and August and for both high- and low-latitude routes between Murmansk and the Bering Strait. We found that the repeatability from run to run was excellent. As an example, in **Table 11** we present the results from an April high-latitude transit that was repeated five times. For this simulation, the route consisted of Legs 5, 6, 7, 17, 19, 21, 24, 28, and 33. Each Min, Max, Mean, and Within-Run Standard Deviation value shown in the table is the mean of the five individual values that were obtained. For example, the minimum value for Total Time shown in the first row, first column of **Table 11** (526.1) is the mean of the five minimum values, one from each run. The minimum and maximum values show the average range in the various parameters within each run. The range and the within-run standard and relative deviations indicate the cumulative variability produced by the model during a single run (transit simulation). These values indicate that 500-voyage simulations reproduce fairly well the mean values for each parameter. Wide excursions about the mean values can occur within every simulation, but their occurrence is of relatively low probability.

The between-run parameter deviations show how very repeatable the model is when the same conditions are modeled during successive simulations. The relative deviations for nearly all parameters were less than 1%. April transits produced several exceptions but only one that was

Table 11. Parameter values that show the new model's repeatability. The model was run five times each for April and August for a high-latitude route between Murmansk and the Bering Strait (Legs 5, 6, 7, 17, 19, 21, 24, 28, and 33). Shown here are the mean values calculated from the corresponding values obtained from the five runs. For example, the Min value for Total Time shown here was the mean of five mins, one from each run. Relative deviation values are the standard deviations as a percentage of the means.

			Within	run		Betw	veen runs	
	Min	Max	Mean	Std Dev	Rel Dev (%)	Std Dev	Rel Dev (%)	
April high-latitude transi	ts				-			
Total time (hr)	526.1	642.5	590.7	21.3	3.6	1.1	0.2	
Speed (kn)	-0.71	18.10	5.40	0.2	3.7	0.0	0.2	
Icebreaker escort (hr)	478.3	637.5	574.0	32.4	5.6	1.6	0.3	
Total cost (US\$)	497,596	577,403	541,861	14,576	2.7	723	0.1	
Fog (% of total time)	2.2	17.6	10.0	2.7	26.9	0.1	0.6	
Icing (% of total time)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Snow (% of total time)	4.4	19.8	11.3	2.6	22.9	0.1	1.2	
Waves (% of total time)	0.3	13.5	2.2	2.2	97.2	0.1	5.7	
Wave height	0.21	15.09	0.7	0.9	126.8	0.4	47.4	
Ice-free (% of total time)	0.0	7.9	1.7	1.4	81.2	0.0	2.7	
Ice-free (% of total distance	0.0	16.5	4.3	3.3	75.8	0.1	2.2	
August high-latitude tran	sits							
Total time (hr)	440.9	545.9	486.0	17.8	3.7	0.5	0.1	
Speed (kn)	-0.13	18.26	6.56	0.2	3.6	0.0	0.1	
Icebreaker escort (hr)	131.8	268.3	190.4	23.1	12.1	0.9	0.5	
Total cost (US\$)	418,212	490,154	449,144	12,227	2.7	317	0.1	
Fog (% of total time)	15.0	38.6	26.1	4.0	15.3	0.1	0.4	
Icing (% of total time)	23.7	45.2	34.4	3.9	11.2	0.1	0.2	
Snow (% of total time)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Waves (% of total time)	30.2	56.1	42.2	4.2	10.0	0.1	0.3	
Wave height	0.3	30.71	3.6	0.6	16.0	0.0	0.5	
Ice-free (% of total time)	6.2	12.1	9.3	1.2	13.5	0.0	0.4	
Ice-free (% of total distance	e) 16.5	23.1	21.5	2.1	9.9	0.0	0.3	

notable. The mean wave height in winter varied significantly over the chosen route. However, its effect on mean time and cost is insignificant due to the 2.2 mean percentage of time that waves even occur in winter and their 0.7-m mean height when they do occur. Similar testing was done for April and August low-latitude transits between Murmansk and the Bering Strait (Legs 5, 10, 12, 14, 15, 18, 22, 25, 29, 30, and 32), and the results were equally reproducible.

5.1.2 Length of time step

In response to a reviewer's comment concerning the length of time step used in an earlier version of the model, we reprogrammed NSRSIM2A to accept a user-defined time step of any length. Remember that we intended time-step updating to be a way of reshuffling the environmental conditions during long stretches between nodes to account for temporal changes in the weather, ice, and ocean conditions. We had chosen to use a time step of 8 hr for default updating. The reviewer felt that 8 hr was an excessive amount of time between updating, given the frequency with which ice conditions can change dramatically. It was suggested that we try shorter

voyage simulations in April between Murmansk and the Bering Strait along a high-latitude route (Legs 5, 6, 7, 17, 19, 21, 24, 28, and 33) with the following conditions: Daily cost of cargo ship = US\$16,450; daily cost of escort Table 12. Parameter values to show the effect of varying the time-step length in the model. Runs are for 500vessel = US\$0; total cost of fees and tariffs = US\$137,000.

	2	19.27 0.2 31.68	11.6	0 0	9.9	3.4	12.7 2.3 0.74 0	7.4 1.4 102.6 3.2	13,209 8.00 4.15
viations	4	21.62 0.2 33.19	15.1 2.4	0 0	14.4 2.5	3.7	12.8 2.3 0.87 0.01 0.01	8.5 1.6 119.4 3.8	14,819 8.93 4.65
Standard deviations	9	22.57 0.2 34.85	15.7	0 0	14.6 2.4	3.8	14.7 2.6 0.8 0.01	8.6 1.6 121.2 3.8	15,471 9.24 4.86
,	8	20.71 0.2 31.82	16.7	00	14.6	3.6	11.3 2.0 0.84 0.01 0.01	7.3 1.3 101.8 3.2	14,195 8.28 4.46
	2	586.2 5.44 569.2	58.4 9.9	0 0	66.3 11.3	96.0 16.4	13.3 2.3 0.83 0.07	9.9 1.7 · 139.9 4.4	538,722 919.40 169.18
Means	4	586.1 5.44 569.2	58.0	00	67.0 11.5	96.0 16.4	13.5 2.4 0.9 0.07 -0.03	10.4 1.8 147.4 4.6	538,688 919.51 169.15
M	9	588.2 5.42 570.1	57.7 9.8	00	66.8	96.4	14.3 2.5 0.84 0.07 -0.03	10.4 1.8 146.7 4.6	540,168 918.68 169.62
	8	592.3 5.38 576.2	59.7 10.0	00	65.8	97.0 16.4	2.1 2.1 0.86 0.07 -0.03	9.6 1.7 134.0 4.2	542,958 917.02 170.49
•	Time step (hr)	Total time (hr) Mean speed (kn) Icebreaker escort (hr)	Fog (hr) Fog (% of total time)	Icing (hr) Icing (% of total time)	Snow (hr) Snow (% of total time)	Darkness (hr) Darkness (% of total time)	Waves (hr) Waves (% of total time) Mean wave height (m) Permanent current vector (kn) Wind-induced current vector (kn)	Ice-free time (% of total time) Ice-free distance (nm) Ice-free distance (nm) Ice-free distance (% of total time)	Total cost (US\$) Cost per hour (US\$) Cost per mile (US\$)

time steps. We theorized that this variable was probably of greater importance in NSRSIM01 where our data nodes were spaced so widely. In NSRSIM2A, the data nodes are very close together in those areas where ice conditions are more severe, where ice is more a determining factor in the speed of the ship. With the variable time-step capability programmed into NSRSIM2A, we ran a series of runs to see if shortening the time-step length would make a noticeable difference in results. We shortened the time step in progressive runs from 8 hr, to 6, to 4, and finally to 2 hr. These results (**Table 12**) show that there was no significant change in output when the time-step length was varied. Note that the difference between shortest and longest transit times was just 6 hr, or only about 1%. Similarly, the range in transit cost was less than 1%.

There also was little difference in the parameter variations as revealed by the standard deviations shown in the table. Before the analysis, we had theorized that shortening the time step might result in smaller variation in parameter values within each run, but because the variations were already very small, the gain would be negligible. Our reasoning was based on the fact that a time-step-related change in PDFs occurs only if a distance segment requires more time to traverse than the time step allows. If the time segment has expired before the ship reaches the next data node, then another "roll of the dice" occurs to select values from the same PDFs that were drawn from previously. The longer the distance segment, the more often this happens. Some of the variability in the final result is therefore eliminated, because the more times a PDF is randomly drawn from, the more likely we are to approximate the mean of the distribution. In the limit this would result in a ship speed corresponding more and more closely to the "average" environmental conditions for that distance segment. Similarly, shortening the time segment has the effect of potentially rolling the dice more often to select from the same PDF. In reality, however, a reduction in parameter variations cannot be discerned from their already low levels. This shows that varying the length of the time step in 2-hr increments from 2.0 to 8.0 hr has no discernible effect.

5.2 Final NSRSIM2A results

This section discusses the results of our NSR simulations using the NSRSIM2A model. We first discuss summarized output data that contain information for all legs of the model, using those for sea ice as an example. Keep in mind that similar output is easily generated for nearly all other variables in the model. We then show our summary results from four different transit scenarios—that is, high-latitude transits in each of April and August, and low-latitude transits for the same. Finally, we compare those with similar output from our earlier model, NSRSIM01.

5.2.1 Simulation results for all transit legs

Given the three available options, the user can choose a wide range of output data to analyze, from simple summaries to extreme detail. The reader will recall that the user can choose which legs will be followed or to follow all legs during any one simulation. We ran 500-voyage simulations in both April and August for all transit legs in the model, and from the simplest output option we generated the type of information to be discussed in this section. As an example, we present here summary results for fog.

Table 13. Fog statistics for all legs of NSRSIM2A.

				Т	_			_																									_	_	_	7	_	-
	% Total	Transit	Distance	0	0.5	0.7	د .	0,5	1 .0	0.5	9.0	0.8	9,0	6'0	0.7	0.7	0.5	0,3	8.0	0.4	0.4	0,3	0.4	4.	0.1	0.2	0.3	0.7	0.3	9.0	1.5	0.3	1.3	0.4	6.0	1,3	21.2	6
		% Distance	with Fog	ט ט	27.1	31,6	19.8	42.9	27.5	26,9	28.1	43.7	45.4	28.8	34,3	19.8	16.3	18.1	29.6	25.4	11.9	33.2	24.8	28.7	30,2	36.8	26.7	18.8	15.0	20.8	23.2	17.6	23.6	23.3	18.6	19.5	838,1	25.4
	Mean	with Fog	This Leg	2	57.35	77.60	145.21	53,94	109,96	56.46	65.47	88.21	65.67	97.04	73.06	76.71	54.43	35.26	85.52	49.06	47.57	32,02	40.52	153,79	15,32	22.47	38.74	82.09	35,58	66.60	164.45	31.11	139,84	47.94	103,69	150,30	2362,98	71.61
		% Total	ransit Time	So Julia	2 0	4.0	Ţ	0.3	0.5	0.4	0.3	4.0	0.3	0.5	0.4	5.7	7.0	7.0	7	0.5	9.0	0.3	0.4	1.5	0.2	0.2	0.4	4.4	9.0	1.2	2.1	9.0	1.9	8.0	1.7	1.8	24.6	0.7
August Transit		5 Time with	Fog This T	600	34.5	38.1	23.5	63.0	33,3	31.2	34.7	63.8	55.6	35.3	42.2	22.7	21.4	22.0	31.8	29.3	13.5	36.5	26.3	31.1	33.7	41.9	29.9	22.6	18.7	24.3	26.1	21.0	26.8	27.5	21.8	23.1	987.2	29.9
Aug	emi Tue	, a~ ,	This Leg																																		425.0	
	2	Aean Travel		l	(3.6		84.2	8,3	26.3	20.9	15.8	13.3	9.4	22.2	14.6	96,5	55,9	55,8	57.4	31.8	76.1	15.3	25.9	85.4	8.3	8.6	24.6	106.8	56.4	82.7	140.0	41.9	120.9	50.7	131.2	134.3	1729.5	52.4
		-	/oyages]		312		440	248	380	351	394	250	212	361	128	497	492	468	473	484	491	452	479	200	159	320	473	200	386	478	200	473	200	420	200	200	12915	391
				140.	- 2	,	4	2	9	7	æ	6	40	=	12	1 3	4	15	16	17	48	19	20	21	22	23	24	22	26	27	28	29	30	31	32	33	TOTAL	MEAN
			eg Length	4260 44	211.32	245.88	732,34	125.77	399.86	210.13	233.01	201.81	144.65	336.62	213.04	387,05	333,06	195.27	289,01	193,36	399.88	96,34	163.71	535,06	50.65	61.01	144.94	436.45	237.8	320.67	707.81	176.73	591,6	205.64	557.73	771.34	11169.68	338,48
	% Total	Transit	Distance L	╁	3 7	_ : ;:	0.3	0.7	4.8	0.4	1.5		0.8																				0.2	0.2	0.1	0.2	14.5	0.4
		Distance	with Fog	HIS LEY	58.7	51.7	5.0	63.9	49.4	19.0	71.6	57.2	58.3	48.8	15.7	14.2	5.8	8.5	12.0	8.5	4.0	17.3	9.6	3.6	29.2	29.1	10.3	3.7	14.1	8,3	2.7	9.4	3.0	12.7	2.8	2.3	710,4	21.5
	Mean		_	-	124.13	127.16	36.28	80.41	197.54	39,98	166,76	115,50	84,39	164.30	33.42	54.77	19.41	16.61	34.79	16.41	16.03	16.68	15.65	19.01	14.78	17.78	14.95	15.98	33.42	26.77	19.04	16.54	17.78	26,04	15.88	17.74	1615.93	48.97
		% Total	Transit Time Truth	60.00	0.5	9.0	0.4	0.4	1.9	9.0	1.0	0.8	0.4	4.6	0.3	0,5	0.2	0.2	0,3	0,2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0,3	0.3	0,2	0.2	0.2	0.3	0.3	0.2	13.1	0.4
April Transit		_	Fog This Tr		65.4	57.9	5.0	70.2	50.5	24.7	73.5	61.8	64.0	49.9	15.2	13,5	5,8	8,6	12.2	8.3	3.9	17.1	9.5	3.6	29.4	27,5	10,2	3,6	14.1	8.0	2.7	9.1	3.1	13.4	2.9	2.3	747.0	22.6
Ą	Aean Time		This Leg	(11)	10.2	1.1	6.7	7.3	36.6	11.5	19.7	14.9	8.2	31.0	5.8	9,1	3.5	3.0	6.0	2.8	3.0	2.8	3.1	3.4	3,3	2.5	2.6	2,9	6,0	5,5	3.5	2.9	3.5	6.1	4.9	3.7	246.9	7.5
	2	 Mean Travel ∨	•	77 B	15.7	19.2	134.0	10.4	72.5	46.3	26.8	24.1	12.8	62.1	38.4	0.79	59.6	34,3	49.4	34.0	74.8	16.5	32,3	25.7	11.2	9.2	25.0	80.7	42.5	68.1	130.7	31.9	113,3	45.4	166,3	158.6	1886,5	57.2
		-	Voyages		498	453	96	475	497	461	500	481	412	496	61	482	192	82	87	78	114	43	47	158	7	4	53	158	80	47	186	119	161	20	203	212	7016	213
			4	1 NO.	- 2	m	4	6	6	7	ω	o,	우	.	12	1 3	4	ŧ	16	11	48	0	20	21	22	23	24	22	26	27	28	29	30	34	32	33	TOTAL	MEAN

Table 13 shows time and cost relative to the occurrence of fog in both April and August. The second column shows for each leg how many of the 500 voyages encountered fog somewhere along the leg. The average number of encounters over all 33 legs is shown at the bottom of column 2. For example, fog was encountered somewhere along Leg 2 during 498 of the 500 voyages, and the average number of voyages that encountered fog per leg was 213. Similarly, the mean travel time across each leg and the mean for all 33 legs is shown in column 3. The next three columns show mean travel time ("fog-hours") over which fog was present along each leg, followed by its percentage of total time for each leg, ending with fog-hours as a percentage of the complete transit time. The next three columns show similar information for transit miles where fog was encountered ("fog-miles"). Similar tables for the occurrence of icing, snow storm, darkness, sea-ice cover, and icebreaker escort are contained in Appendix F.

In **Table 13**, we see that over all legs fog occurred for a total of 247 of the 1887 total transit hours (13%) in April and for 425 of 1730 hours (25%) in August. In terms of fog-miles, 1616 nm of the 11,170 total (14%) were foggy in April and 2363 nm, or 21%, were foggy in August. The table also shows which legs are particularly high in fog-time and fog-miles so that certain of the legs with higher fog probability may be avoided. Remember though that the occurrence of fog slows the ship only when its speed reduction factor is greater than all others. Thus, the mere occurrence of fog does not absolutely determine ship speed.

5.2.2 Simulation results for specific scenarios

Using the tables in **Appendix F**, one can select the values from certain legs and sum up their individual contributions to any complete transit of choice. This is what we have done in making up both a high-latitude and a low-latitude voyage, and those general results are discussed in the section that follows. Similar to **Appendix F**, parameter summaries for our high- and low-latitude routes are contained in **Appendix G**.

5.2.3 Comparison of NSRSIM01 and NSRSIM2A results

In this section, we compare the NSRSIM2A simulation results with those obtained earlier from our NSRSIM01 model. Our first model simulated only transits between Murmansk and the Bering Strait, and the user was not allowed to specify which legs to follow. You will recall that the actual route selection in NSRSIM01 was done by MC selection from PDFs of route choices based on a set of historical data. The results we presented then pertained to routes that historically were most often selected, those that comprised the most likely choice of travel at that particular season of the year. The actual route that was selected by the model is unknown to us, so a direct comparison of the two models is impossible. For that reason, we chose to compare a high-and a low-latitude route to our previous work. In this model, these are the most direct routes available to us between those same points, and we believed that their combined results might correspond most closely with our earlier work.

We selected Legs 5, 6, 7, 17, 19, 21, 24, 28, and 33 to represent our high-latitude route and Legs 5, 10, 12, 14, 15, 18, 22, 25, 29, 30, and 32 for our low-latitude, coastal route (**Figure 6**). The summary results from both models are shown in **Table 14**.

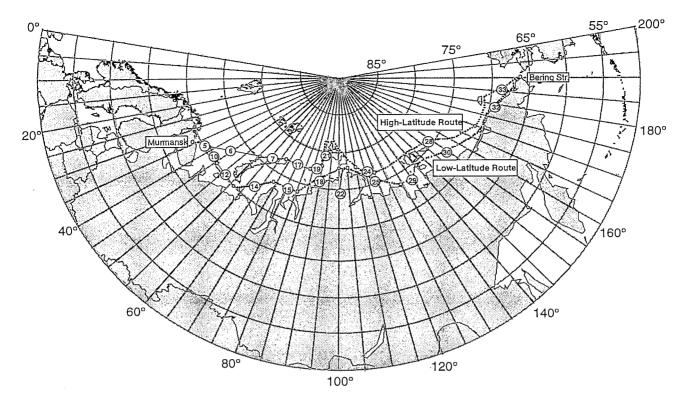


Figure 6. The high- and low-latitude routes between Murmansk and the Bering Strait that we modeled for this study to compare results to those from our original NSRSIM01 modeling.

The data show a number of interesting results. First, the total transit distances are similar in the two models. The mean travel distance for 100 voyages was 3142 nm in April and 3163 nm in August by our earlier model versus a mean of 3205 nm for the new (3185 nm for the northern route, 3225 for the southern one).

Table 14. Comparison of simulation results from both CRREL models, NSRSIM01 and NSRSIM2A, with historical data from Wergeland (1991).

Month	Route	Distance (nm)	Total time (days)	Speed (kn)	Icebreaker escort (hr)	Total cost (US\$)
Historical	data:					
April		3200	22.2	6.0		
August		3200	11.1	12.0		
NSRSIM0	l results:					
April	—	3142	23.6	5.6	519.0	528,850
August		3163	13.6	9.7	77.0	347,945
NSRSIM2.	A results:					
April	North	3185	24.6	5.4	594.8	541,861
-	South	3225	26.4	5.1	601.8	642,400
	Mean	3205	25.5	5.3	598.3	592,131
August	North	3185	20.3	6.5	230.3	449,144
•	South	3225	26.2	5.1	147.5	609,500
	Mean	3205	23.3	5.8	188.9	529,322

Our new April transit times averaged 25.5 days (612 hr) compared with 23.6 days generated by the old model. Both these speeds are in reasonable agreement with the historical data. For example, Wergeland (1991), based on historical data, showed an August mean transit speed of 12.0 kn, which translates to a transit time of 22.2 days.

A major difference in output between our two models lay in our new August transit times and ship speeds. The new times and speeds were not appreciably different regardless of the season of transit. This was in sharp contrast to those calculated by NSRSIM01, which match more closely actual experience. Our new transit time for August (23.3 days) was only 54 hr shorter than that for April, and our mean speed was 5.8 kn (only 0.5 kn faster than for April). Our old model indicated that 13.6 days was needed for an August transit, and the ship maintained a mean speed of 9.7 kn. Wergeland reported a mean ship speed for August of 12.0 kn, which translated to a transit time of 11.1 days. Our old August speed was 73% faster than our April speed, and Wergeland's was 50% faster. Our new August speed of 5.8 kn, however, is only about 9% faster.

Our new times and speeds also do not differ greatly with the route followed. In August, the northern route required 142 fewer hours (5.9 days) less time for transit than the southern route, but in April, the difference was only 44 hr. These results seemed to indicate that ice conditions are more difficult for navigation along the southern route than the northern regardless of the season.

The hours calculated by both models for icebreaker escort were more similar—for NSRSIM2A, a mean of 598 hr during April and 189 hr during August versus 519 and 77 hr, respectively, for NSRSIM01. Interestingly, our new escort times were not radically different from north to south, especially in April, where the northern route actually required 7 fewer hours than the southern route.

Mirroring the transit time results, the total costs calculated in the new model also do not differ as much as those obtained earlier. NSRSIM01 showed that the cost of transit in April was about 52% greater than in August. NSRSIM2A showed only a 12% difference.

In general, our new values are much less different season-to-season and north-to-south than one might expect and than what can be inferred from the literature. Our earlier work was more in keeping with actual experience and reported values. Because the scope of this project did not allow us to reevaluate and recalibrate the ship-speed matrices in our model, we can only offer the following possible explanations for these unexpected results.

The quality and quantity of our new environmental data

The model's node spacing now is finer than the observational data being used for it. Obviously, for the Arctic, continuous and long-term records of weather, ice, and oceanographic observations are relatively rare. The parameter PDFs used in the model were derived from the best available data but from a multitude of sources. In many cases, the data were interpolated from much more widely spaced observations than our system of data nodes represents. It may be that interpolating these data to the 20-nm scale unrealistically increases the severity of shipping conditions. The actual conditions may in fact be less severe than is estimated by our interpolated PDFs.

Parameter interactions

The finer spatial grid may result in parameter interactions that cause unrealistic slowing of the ship, and our decision to apply only the single greatest speed reduction factor may no longer be valid. That is, perhaps the ship speed should be slowed even more when two or more challenging environmental conditions exist. Experimentation in setting ship speeds under various parameter combinations is necessary to test this hypothesis.

Inaccurate ship-speed algorithms

The algorithms that establish ship speed seem to perform adequately for April, but they do not seem to give correct August transit times. Although they seemed to work well in our first model, they may not be accurate for this one. We may need to alter them to perform more realistically with the finer spatial grid, or the finer grid may require that we use a different set of algorithms altogether for summertime environmental conditions. New guidance on icebreaking performance under various NSR ice conditions by Buzuev and Fedyakov (1997), for example, should be incorporated into these algorithms.

5.2.4 Experiments with the ship-speed algorithms

Our NSRSIM2A transit speeds for August were much too low relative to the historical average. In a final effort to reconcile this discrepancy, we modified the model in a way suggested by one of our technical reviewers (see review comment 8 in Section 8). He felt that our speed reduction from [17 kn] in open water to 8 kn when the ice concentration is less than 30% (as shown in Table 2) was too extreme, and suggested that a reduction from 17 to "about 12 kn" would be more reasonable. We modified the model to allow the user to input different ship speeds for the various combinations of ice concentration and thickness for August transits. Until now, we had used one set of ship speeds for both April and August runs. Since the April transit times were not in question, here we experimented with only the August ship speeds. Due to warmer ice temperatures in summer, a different set of speeds for August can be rationalized. The August speeds are input using a new data file named SPEED.AUG. Note that this file contains a list of ship speeds (in knots), one per line, that the program reads into Table 2 whenever an August transit is selected. The top-line value in the file is the ship's full speed. Each successive value thereafter fills in the ice concentration—thickness matrix of Table 2, starting at the top and moving from left to right to fill out each row.

Our first trial with this modification was to increase the speed whenever the ice concentration was less than 30% for the two thinnest ice categories; that is, <120 cm and 120–180 cm thick. These we increased from 8 kn to 12 kn, with no apparent effect noted in the output. The same was true when we increased these two categories to 14 kn. Next, we also increased all other ship speeds, except when under icebreaker escort, by 2 kn (the unshaded values shown in **Table 15**). The resulting transit times decreased only very slightly, as shown in **Table 16** as Trial 1. We then further lowered all the icebreaker-escorted ship speeds by 2 kn (the shaded values shown in **Table 15**). This resulted in only a 2-day decrease in the mean August transit time (Trial 2). Finally, we input the maximum value of 17 kn for all ice concentration and thickness conditions

Table 15. Ship-speed and ice-condition relationships used in final simulations. The shaded values are those that apply when an icebreaker escort is in effect.

		,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	Ice thickness (cm)									
		Ice-free	<120	120–180	181–240	>240						
	Ice-free											
Ice	<30%		14	14	9	8						
concentration	30–60		10	10	9	8						
(%)	61–80		8	12	2	12						
	81–100		10		86	8						

(Trial 3), and even this did not allow the ship to progress at the mean speed needed to achieve the historical transit time. The simulation required a mean transit time that was still more than 5 days longer than the historic target of 11 days. It was obvious that our ship speed under other environmental conditions would have to be altered.

Finally, we investigated a change in the ship speed with respect to wave height. A model change was made to the speed values shown in **Table 5**. Instead of speeds ranging from 8 kn down to 3 kn whenever the ice was of 30% or less concentration, we instituted speeds of 14, 13, 12, 10, 9, 8, and 6 kn for the six possible wave-height categories. Trial 4 involved our running these increased wave-related ship speeds at the same time as the increased ice-related speeds were in effect. This resulted in a northern transit of 14.3 days and a southern transit of 16.5 days. The mean of 15.4 days was still greater than the 11-day historical average that we were seeking, but this shows that such modifications to the ship speed algorithms can significantly change the

Table 16. Simulated August transit times and mean ship speeds using modified ship-speed algorithms for ice and wave conditions.

		From Table 14	1 .	Tria 2	l no.	4	Historic average
	Northern route	20.3	19.7	17.7	13.1	14.3	
Transit time	Southern route	26.2	25.4	23.9	19.8	16.5	_
(days)	Mean	23.2	22.6	20.8	16.4	15.4	11.1
Moon shin	Northern route	6.5	6.7 -	7.5	10.2	9.3	
Mean ship speed	Southern route	5.1	5.3	5.6	6.8	8.2	
(kn)	Mean	5.8	6.0	6.6	8.5	8.8	12.0
Icebreaker	Northern route	230.3	191.9	141.9	71.5	141.9	
escort time	Southern route	147.5	143.8	104.6	52.5	104.9	
(days)	Mean	188.9	167.9	123.2	62.0	123.4	
	Northern route	449,144	440,293	407,475	331,402	351,170	
Total cost (US\$)	Southern route	609,500	533,964	509,284	440,955	387,444	
(354)	Mean	529,322	487,128	458,380	386,178	369,307	

model's output. Further experimentation is needed to better simulate August transits.

6. CONCLUSIONS

This NSR transit modeling work was conducted in three phases for the International Northern Sea Route Programme:

- 1) We conducted an extensive sensitivity analysis of an existing CRREL Arctic navigation model to reveal the most significant parameters determining the time and cost of cargo shipping by way of the Northern Sea Route. We provided this information to help researchers in a separate INSROP-sponsored project determine the important environmental parameters for inclusion in their own NSR transit model. This work also provided guidance on the degree of resolution needed for new input data.
- 2) We then created a new CRREL model version, which employed a spatial grid that was segmented more finely (approximately by a factor of ten) and added the necessary data files that describe the physical environment at each grid point.
- 3) Finally, we ran new shipping simulations and presented these results for future comparison with those generated by the other INSROP transit model.

Both our old and our new models rely on three types of information for their calculations: environmental data, shipping costs, and ship-performance estimates under given Arctic conditions. At any given time, there is always some amount of uncertainty and inaccuracy in each of these variables that can be eliminated through the use of more up-to-date information. With the funding that was available, we were not able to obtain more up-to-date shipping costs or ship performance data than we had used for our earlier modeling work. However, we used new environmental data that was assembled and provided by researchers working under another INSROP supporting project. Our sensitivity analysis of the old CRREL model showed that the sea-ice cover conditions of concentration, thickness, and pressure were the most influential environmental parameters in determining the time and cost of NSR shipping. For example, setting openwater conditions throughout a simulation allowed the ship to transit from Murmansk to the Bering Strait in 37% of the time required when an ice cover was selected in the normal way (by the MC method) at every data point. This indicated that the ice conditions of thickness, concentration, and pressure alone were responsible for about two-thirds of the ship's speed during a normal run, making them most influential in determining the simulation outcome. Therefore, we recommend that, of all the environmental parameters, improving the accuracy of the ice cover data would yield the greatest improvement in the model results.

Our new model produced results that differed significantly in one respect from those obtained with our earlier model: While our earlier results agreed well with historical transit experience, these new results showed little difference between April and August transit times and ship speeds. The new model showed a mean transit time in April of about 25.5 days, but it also showed a quite lengthy August transit time of 23.3 days. The historical average for April was

22.2 days and for August, it was 11.1 days. We experimented with several different, but reasonable, ship speeds with respect to ice and wave scenarios and were able to show that the model could produce more realistic transit times by simple changes in the model's ship-speed algorithms. Ice algorithm changes suggested by a reviewer of this work and our own wave algorithm changes succeeded in generating a mean August transit time of 15.4 days. These trials point out the additional research and experimentation that is still needed to have this transit model, with its, more highly segmented routing scheme, function acceptably.

Unfortunately, the multitude of new research and data to be incorporated into the new WP8 transit model were not available to us for this work. Given the anticipated quantity, quality, and currency of the NSR information that is now being accumulated and published by INSROP, we expect that a numerical transit model can be an even more accurate and useful tool for analyzing the time and cost of Northern Sea Route marine trade.

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8. AUTHORS' RESPONSE TO REVIEW COMMENTS

The authors thank Dr. Joachim Schwarz, Director of the Hamburg Ship Model Basin in Hamburg, Germany, for constructive comments pertaining to our work and draft reports. We have paraphrased his comments in the following paragraphs and follow each with our response. His two letters with review comments are included as Appendix H.

Review comment 1: The sensitivity analysis that was developed for this NSR transit model is a very valuable tool for helping to develop transit models in general, and attempts should be made to generalize the sensitivity analysis for use with other transit models.

Authors' response: Our task was to perform a sensitivity analysis, specific to our model, that would identify which transit parameters were most influential in determining time and cost. To generalize our approach for other models was outside the limited scope of our work. However, we hope that we have explained our methods sufficiently for others to use them in analyzing their own models and comparing their results with ours.

Review comment 2: I do not agree with the authors' statement in their introduction that insurance costs, tariffs, and transit fees are less indicative of future trends (see p. 3 of this report). On the contrary, these parameters most likely will determine the economical competitiveness of the NSR compared with the Suez Canal route.

Authors' response: Our statement intended to convey that the lack of predictability of these parameters is the reason that they cannot be described by a probability distribution function and

handled as Monte Carlo-type variables. We agree that knowledge of these fees is crucial for a realistic transit cost calculation, but they should be used in the model as discrete values instead of a distribution of values (in the form of a PDF), which is what we have done.

Review comment 3: The availability of escorting icebreakers should be variable in the model because it affects the transit calculation significantly. In practice, waiting time costs should be included as a separate item associated with icebreaker fees.

Authors' response: Our model assumes that each time an icebreaker is needed, it would be instantaneously available. While we agree that the length of time required for an icebreaker to show up when needed is an important variable in the time-of-transit calculation, we maintain that in the absence of those data for each node point, we cannot easily account for it. We could program the model to allow the user to define a single time delay value to be used at all nodes each nonconsecutive time that an icebreaker is needed. However, assuming a single value would be no more realistic than not having one at all. Alternatively, enabling the user to set a value at each new time an icebreaker is needed would be too cumbersome, considering the total number of node points where this would be required for any voyage of appreciable length. However, in response to Dr. Schwarz' comment, we'd like to point out that if the user desires to introduce a certain time delay at a particular node, then output option 2 should be requested, which shows each segment where icebreaker escort is in effect. The user can then insert any desired time-delay value for any segment and add the total time increase to the transit time calculated by the model.

Review comment 4: Eight-hour time segmentation for ships in ice seems too large. Ice conditions can change significantly in only 2 hours. I suggest you show the effect that time segments of 2 hours, 4 hours, and 8 hours, respectively, would have on the outcome.

Authors' response: We reprogrammed the model to allow the user to define the time segment used in the simulation. We then performed a sensitivity analysis on this variable. Briefly, we found that varying the time step from 8 hours down to 2 hours produced no significant change in our results. Those sensitivity results and our discussion are detailed in Section 5.1.2.

Review comment 5: Some of the most realistic route combinations are missing from the model, such as the routes from 2A to 4 and from 2 to 2A.

Authors' response: True, the first model was limited in many ways, including the choice of routes. This deficiency is eliminated in the new model.

Review comment 6: Lack of visibility should result in a reduction of ship speed only when ice concentration is greater than 70% (not 30%), because icebreakers can navigate using radar.

Authors' response: Our reasoning for reducing our modeled ship's speed whenever ice concentration was greater than 30% is because we believe that the probability of experiencing a damaging collision with ice was high enough at just 30% concentration to warrant slowing of a cargo ship, especially in low-visibility conditions. We are not aware of any published data that

show otherwise.

Review comment 7: In addition to ocean currents and wind-induced currents, tidal currents need to be considered, because the tidal currents are especially important in changing the ice conditions. Further, ice compression depends not only on atmospheric pressure (and consequently the wind) but also quite significantly on tidal currents. They definitely need to be considered in the sensitivity model.

Authors' response: It is true that we have neglected this potentially significant parameter. In our model, we assumed that the tidal currents reversed themselves every 6 hr and therefore their sum effect on the speed of the ship *in open water* was zero. We did not, however, consider how tidal currents might adversely affect ice conditions, an effect that is not reversed every 6 hr. Since ice conditions play such an important role in trafficability, we agree that this should be considered in future models. Unfortunately, the funding we received for our INSROP2 work did not allow us to research how additional parameters should be programmed into the model or to obtain new data sets for those parameters.

Review comment 8: The crucial point of the new model is that the April transit times during the worst ice conditions and the August times during the easiest ice conditions are nearly the same. This does not coincide with actual experience in Arctic navigation, and the simulation model should be checked for this discrepancy.

The table of ship speeds under various ice conditions seems unrealistic; especially when the ice concentration is less than 30%. The speed reduction from [17 kn] in open water to 8 kn (**Table 2**) is too large, in my experience. I would propose to increase the 8 kn to 12 and adjust the other speeds accordingly.

Authors' response: This suggestion was followed and produced encouraging results, which are discussed in Section 5.2.4.

Review comment 9: One item that is the most governing factor in the transit of Arctic seas is totally missing in the sensitivity analysis: the effect of ice reconnaissance by satellite or other means, which sometimes is also called ice routing. In our experience the progress of ships/ice-breakers in the Arctic depends more on routing than on any other parameters. It is certainly difficult to define the routing in terms of trafficability. This can only mean that transit models have still a long way to go before we can predict the speed and costs of Arctic transportation more accurately, not to mention the political obstacles that are unpredictable in the present situation in Russia.

Authors' response: We agree with Dr. Schwarz' observation that much more knowledge is needed to improve the accuracy of present-day models and that some very significant parameters are not easily modeled. This holds true for ice routing as well. However, transit modeling remains an important tool to help determine the feasibility of more profitable shipping via the NSR versus other route alternatives. We offer the present work as a springboard to this end, recognizing that there remain important issues to resolve. Dr. Schwarz has pointed to some very significant ones to work on in future modeling attempts.

APPENDIX A

NSRSIM01 SENSITIVITY RESULTS

APPENDIX A.1. Sensitivity results of ice conditions during 500-voyage transits of a *Noril'sk* MPC with icebreaker escort MC-selected. Daily ship costs = \$23,000, daily escort fee = \$7,500, fixed passage fee = \$0.

Run	Al	PRIL RUN ICE C	CONDITIONS	Time	Speed	Escort	Total Cost	
No.	Concentration	Thickness	Pressure	All Others	(hr)	(kn)	(hr)	(\$US)
1	OFF	OFF	OFF	OFF	191.7	16.33	0.0	193,853
2	OFF	OFF	OFF	MC	206.9	15.10	0,0	210,358
3	-25% PDF	MC	MC	MC	521.5	6.03	442.1	653,616
4	MC	-25% PDF	MC	MC	536.7	5.84	484.9	681,043
5	MC	MC	-25% PDF	MC	553.9	5.66	504.8	703,631
6	MC	, WC	MC	MC	564.6	5.57	517.9	717,796
7	+25% PDF	· MC	MC	MC	568.7	5.53	524.9	724,127
8	MC	+25% PDF	MC	MC	573.8	5.47	526.2	729,425
9	MC	MC	+25% PDF	MC	599.5	5.22	551.9	762,322
10	MC	MC	MC	OFF	555.5	5.63	513.2	707,959

Effect of turning off ice conditions wrt* normal run (Run 2/Run 6) Reduced CONCENTRATION wrt normal run (3 / 6) Reduced THICKNESS wrt normal run (4/6) Reduced PRESSURE wrt normal run (5/6) Enhanced CONCENTRATION wrt normal run (7/6) Enhanced THICKNESS wrt normal run (8/6) Enhanced PRESSURE wrt normal run (9/6) Effect of only ice conditions wrt normal run (Run 2/Run 6)

0.37	2.71	0.00	0.29
0.92	1.08	0.85	0.91
0.95	1.05	0.94	0.95
0.98	1.02	0.97	0.98
1.01	0.99	1.01	1.01
1.02	0.98	1.02	1.02
1.06	0.94	1.07	1.06
0.98	1.01	0.99	0.99

Run		August Run C	onditions		Time	Speed	Escort	Total Cost
No.	Concentration	Thickness	Pressure	All Others	(hr)	(kn)	(hr)	(\$US)
1	OFF	OFF	OFF	OFF	191.3	16.33	0.0	194,156
2	OFF	OFF	OFF	MC	206.9	15.17	0.0	210,634
3	-25% PDF	MC	MC	MC	315.1	10.00	59.1	335,668
4	MC	-25% PDF	MC	MC	319.0	9.87	73.5	334,133
5	MC	MC	-25% PDF	MC	321.2	9.81	71.9	335,357
6	MC	MC	MC	MC	324.3	9.71	74.5	349,794
7	+25% PDF	MC	MC	MC	358,2	8,80	79.3	383,575
8	MC	+25% PDF	MC	MC	324.6	9.72	82.8	352,207
9	MC	MC	+25% PDF	MC	325.1	9.70	82.6	352,473
10	MC	MC	MC	OFF	299.8	10.49	77.2	327,086

Effect of turning off ice conditions wrt normal run (Run 2/Run 6) Reduced CONCENTRATION wrt normal run (3/6) Reduced THICKNESS wrt normal run (4/6) Reduced PRESSURE wrt normal run (5/6) Enhanced CONCENTRATION wrt normal run (7/6) Enhanced THICKNESS wrt normal run (8/6) Enhanced PRESSURE wrt normal run (9/6) Effect of only ice conditions wrt normal run (Run 2/Run 6)

0.64	1.56	0.00	0.60
0.97	1.03	0.79	0.96
0.99	1.01	1.02	1.00
0.99	1.01	0.97	0,96
1.10	0.91	1.06	1.10
1.00	1.00	1.11	1.01
1.00	1.00	1.11	1.01
0.92	1.08	1.04	0.94

^{*} wrt = "with respect to" ,

APPENDIX A.2. Sensitivity results of wind conditions during 500-voyage transits of a *Noril'sk* MPC with ice-breaker escort MP-selected. Daily ship costs = \$23,000, daily escort fee= \$7,500, fixed passage fee = \$0.

Run		April Run Wind Conditions		Time	Speed	Escort	Total Cost
No.	Direction	Speed	All Others	(hr)	(kn)	(hr)	(US\$)
1	OFF	OFF	OFF	191.7	16.33	0.0	193,853
2	OFF	OFF	MC	*564.2	5.57	517.4	717,729
3	-25% PDF	MC	MC	563.3	5.60	518.7	717,166
4	MC	-25% PDF	MC	566,8	5,50	519.6	721,208
6	MC	MC	MC	564.6	5.57	517.9	717,796
7	+25% PDF	MC	MC	563.0	5.58	517.6	716,176
8	MC	+25% PDF	MC	5.6	5.57	514.3	715,639
		·					
10	MC	MC	OFF	192.4	16.30	0.0	194,488

Effect of turning off wind conditions wrt* normal run (Run 2/Run 6) Reduced DIRECTION wrt normal run (3/6) Reduced SPEED wrt normal run (4/6)

Enhanced DIRECTION wrt normal run (7/6) Enhanced SPEED wrt normal run (8/6)

Effect of only wind conditions wrt normal run (Run 10/Run 6)

1.00	1.00	1.00	1.00
1.00	1.01	1.00	1.00
1.00	0.99	1.00	1.00
1.00	1.00	1.00	1.00
0.01	1.00	0.99	1.00
		·	
0.34	2.93	0.00	0.27

Run		August Run Wind Conditions		Time	Speed	Escort	Total Cost
No.	Direction	Speed	All Others	(hr)	(kn)	(hr)	(US\$)
1	OFF	OFF	OFF	191.3	16.33	0.0	194,157
2	OFF	OFF	MC	321.2	9.80	77.1	347,728
3	-25% PDF	MC	MC	319.9	9.86	73.9	345,218
4	MC	-25% PDF	MC	320.9	9.80	75.0	346,621
6	MC	MC	MC	324.3	9.71	74.5	349,794
7	+25% PDF	MC	MC	320.4	9.86	75.8	346,418
8	MC	+25% PDF	MC	319.2	9.86	75.9	345,217
		,					
10	. MC	MC	OFF	191.8	16.33	0.0	194,764

Effect of turning off wind conditions wrt normal run (Run 2/Run 6) Reduced DIRECTION wrt normal run (3/6) Reduced SPEED wrt normal run (4/6)

Enhanced DIRECTION wrt normal run (7/6) Enhanced SPEED wrt normal run (8/6)

Effect of only wind conditions wrt normal run (Run 10/Run 6)

0.99	1.01	1.03	0.99
0.99	1.02	0.99	0.99
0.99	1.01	1.01	0.99
0.99	1.02	1.02	0.99
0.98	1.02	1.02	0.99
0.59	1.68	0.00	0.56

^{*} wrt = "with respect to"

Appendix A.3. Sensitivity results of fog during 500-voyage transits of a *Noril'sk* MPC with icebreaker escort MC-selected. Daily ship costs = \$23,000, daily escort fee = \$7,500, fixed daily costs = \$0.

Run		April Run Fog Condition	S	Time	Speed	Escort	Total Cost
No.	Fog	Factor	All Others	(hr)	(kn)	(hr)	(US\$)
1	OFF	OFF	OFF	191.7	16.33	0.0	193,853
2	OFF	OFF	MC	561.8	5.60	521.4	716,687
3	-25% PDF	MC	MC	564.4	5.56	520.0	718,686
4							
5							
6	MC	MC	MC	564.6	5.57	517.9	717,796
7	+25% PDF	MC	MC	566.1	5.55	518.9	719,634
8							
9							
10	MC	MC	OFF	196.2	15.95	0.0	199,226

Effect of turning off FOG wrt* normal run (Run 2/Run 6) Reduced FOG wrt normal run (3/6)

Enhanced FOG wrt normal run (7/6)

Effect of only FOG wrt normal run (Run 10/Run 6)

1.00	1.01	1.01	1.00
1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00
			·
0.35	2.86	0.00	0.28

Run		August Run Fog Conditions		Time	Speed	Escort	Total Cost
No.	Fog	Factor	All Others	(hr)	(kn)	(hr)	(US\$)
1	OFF	OFF	OFF	191.3	16.33	0.0	194,157
2	OFF	OFF	MC	308.0	10.24	75.8	333,967
3	-25% PDF	MC	MC	316.5	9.95	74.9	342,095
4							
5							
6	MC	MC	MC	324.3	9.71	74.5	349,794
7	+25% PDF	MC	MC	323.6	9.72	74.2	348,988
8							
9							
10	MC	MC	OFF	196.2	15.95	0.0	199,226

Effect of turning off FOG wrt normal run (Run 2/Run 6) Reduced FOG wrt normal run (3/6)

Enhanced FOG wrt normal run (7/6)

Effect of only FOG wrt normal run (Run 10/Run 6)

0.95	1.05	1.02	0.95
0.98	1.02	1.01	0.98
1.00	1.00	1.00	1.00
0.60	1.64	0.00	0.57

^{*} wrt = "with respect to"

APPENDIX A.4. Sensitivity results of topside icing during 500-voyage transits of a *Noril'sk* MPC with ice-breaker escort MC-selected. Daily ship costs = \$23,000, daily escort fee = \$7,500, fixed passage fee = \$0.

Run		April Run loing Conditions		Time	Speed	Escort	Total Cost
No.	lcing	Factor	All Others	(hr)	(kts)	(hr+H25)	(US\$)
1	OFF	OFF	OFF	191.7	16.33	0.0	193,853
2	OFF	OFF	MC	565.1	5.56	518.7	718,656
3	-25% PDF	MC	MC	568.1	5.53	521.9	724,008
4							-
5		,					
6	MC	MC	MC	564.6	5.57	517.9	717,796
7	+25% PDF	MC	MC	567.8	5.55	521.9	722,129
8							
9							
10	MC	MC	OFF	191.7	16.33	0.0	193,798

Effect of turning off ICING wrt* normal run (Run 2/Run 6) Reduced ICING wrt normal run (3/6)

Enhanced ICING wrt normal run ((7/6)

Effect of only ICING wrt normal run (Run 10/Run 6)

1.00	1.00	1.00	1.00
1.01	0.99	1.01	1.01
1.01	1.00	1.01	1.01
0.34	2.93	0.00	0.27

Run	August Run loing Conditions			Time	Speed	Escort	Total Cost
No.	leing	Factor	All Others	(hr)	(kn)	(hr)	(US\$)
1	OFF	OFF	OFF	191.3	16.33	0.0	194,157
2	· OFF	OFF	MC	321.7	9.80	77.6	348,180
3	-25% PDF	MC	MC	317.9	9.91	74.9	343,369
4							
5							
6	MC	MC	MC	324.3	9.71	74.5	349,794
7	+25% PDF	MC	MC	320.2	9.84	76.8	345,770
8							
9							
10	MC	MC	OFF	191.5	16.33	0.0	194,212

Effect of turning off ICING wrt normal run (Run 2/Run 6) Reduced ICING wrt normal run (3/6)

Enhanced ICING wrt normal run (7/6)

Effect of only ICING wrt normal run (Run 10/Run 6)

0.99	1.01	1.04	1.00
0.98	1.02	1.01	0.98
0,99	1.01	1.03	0.99
·			
0.59	1.68	0.00	0.56

^{*} wrt = "with respect to"

APPENDIX A.5. Sensitivity results of snowfall during 500-voyage transits of a *Noril'sk* MPC with icebreaker escort MC-selected. Daily ship costs = \$23,000, daily escort fee = \$7,500, fixed passage fee = \$0.

Run	April Run Snow Conditions			Time	Speed	Escort	Total Cost
No.	Snow	Factor	All Others	(hr)	(kn)	(hr+H25)	(US\$)
1	OFF	OFF	OFF	191.7	16.33	0.0	193,853
2	OFF	OFF	MC	565.1	5.57	519.7	718,993
3	-25% PDF	MC	MC	562.9	5.56	514.8	715,794
- 4							
5							
6.	MC	MC	MC	564.6	5.57	517.9	717,796
7	+25% PDF	MC	MC	567.2	5.56	522.0	722,017
8							
9							
10	MC	MC	OFF	198.5	15.80	0.0	202,538

Effect of turning off SNOW wrt* normal run (Run 2/Run 6) Reduced SNOW wrt normal run (3/6)

Enhanced SNOW wrt normal run (7/6)

Effect of only SNOW wrt normal run (Run 10/Run 6)

1.00	1.00	1.00	1.00
1.00	1.00	0.99	1.00
1.00	1.00	1.01	1.01
0.35	2.84	0.00	0.28

Run	August Run Snow Conditions			Time	Speed	Escort	Total Cost
No.	Snow	Factor	All Others	(hr)	(kn)	(hr+H9)	(US\$)
1	OFF	OFF	OFF	191.3	16.33	0.0	194,157
2	OFF	OFF	MC	320.2	9.82	75.4	346,004
3	-25% PDF	MC	MC	321.9	9.78	76.3	347,500
4							
5							
6	MC	MC	MC	324.3	9.71	74.5	349,794
7	+25% PDF	MC	MC	321.1	9.83	75.9	346,812
8							
9							
10	MC	MC	OFF	191.9	16.32	0.0	195,316

Effect of turning off SNOW wrt normal run (Run 2/Run 6) Reduced SNOW wrt normal run (3/6)

Enhanced SNOW wrt normal run (7/6)

Effect of only SNOW wrt normal run (Run 10/Run 6)

0.99	1.01	1.01	0.99
0.99	1.01	1.02	0.99
0.99	1.01	1.02	0.99
			,
0.59	1.68	0.00	0.56

^{*} wrt = "with respect to"

APPENDIX A.6. Sensitivity results of wave conditions during 500-voyage transits of a *Noril'sk* MPC with ice-breaker escort MC-selected. Daily ship costs = \$23,000, daily escort fee = \$7,500, fixed passage fee = \$0.

Run		April Run Wave Conditions		Time	Speed	Escort	Total Cost
No.	Waves	Factor	All Others	(hr)	(kn)	(hr+H25)	.(US\$)
1	OFF		OFF	191.7	16.33	0.0	193,853
2	OFF		MC	565.3	5.56	519.1	719,037
3	-25% PDF		MC	563.8	5.56	515.8	771,338
4							
5							
6	MC		MC	564.6	5.57	517.9	717,796
7	+25% PDF		MC	566.2	5.54	521.1	721,152
8							
9							
10	MC		OFF	194.8	16.14	0.0	197,984

Effect of turning off WAVES wrt* normal run (Run 2/Run 6) Reduced WAVES wrt normal run (3/6)

Enhanced WAVES wrt normal run (7/6)

Effect of only WAVES wrt normal run (Run 10/Run 6)

1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.07
1.00	0.99	1.01	1.00
		· · · · · · · · · · · · · · · · · · ·	
0.35	2.90	0,00	0.28

Run	А	ugust Run Wave Conditions		Time	Speed	Escort	Total Cost
No.	Waves	Factor	All Others	(hr)	(kn)	(hr)	(US\$)
1	OFF		OFF	191.3	16.33	0.0	194,157
2	OFF		MC	314.4	10.04	76.7	341,165
3	-25% PDF		MC	321.8	9.80	78.8	348,160
4							
5							
6	MC		MC	324.3	9.71	74.5	349,794
7	+25% PDF		MC	324.2	9.73	76.3	349,892
8			ļ				
9							
10	MC		OFF	191.6	16.26	0.0	194,718

Effect of turning off WAVES wrt normal run (Run 2/Run 6) Reduced WAVES wrt normal run (3/6)

Enhanced WAVES wrt normal run (7/6)

Effect of only WAVES wrt normal run (Run 10/Run 6)

0.97	1.03	1.01	0.98
0.99	1.01	1.03	1.00
1.00	1.00	1.00	1.00
0.59	1.67	0.00	0.56
0.59	1.67	0.00	0.5

^{*} wrt = "with respect to"

APPENDIX A.7. Sensitivity results of permanent currents during 500-voyage transits of a *Noril'sk* MPC with ice-breaker escort MC-selected. Daily ship costs = \$23,000, daily escort fee = \$7,500, fixed passage fee = \$0.

Run	April R	Run Permanent Curr	ent Conditions	Time	Speed	Escort	Total Cost
No.	Direction	Speed	All Others	(hr)	(kn)	(hr+H25)	(US\$)
1	OFF	OFF	OFF	191.7	16.33	0.0	193,853
2	OFF	OFF	MC	566.3	5.55	518.3	572,449
3	-90 degrees	MC	MC _	569.3	5.53	518.3	574,771
4	MC	-50%	MC	565.8	5,55	516.2	571,656
5							
6	MC	MC	MC	564.6	5.57	517.9	717,796
7	+90 degrees	MC	MC	565.0	5.54	517.5	571,113
8	MC	100%	MC	565.4	5.53	516.2	571,411
9							
10	MC	MC	OFF	191.1	16.37	0.0	188,212

Effect of turning off PCURRENTS wrt* normal run (Run 2/Run 6) Reduced PCURRENTS DIRECTION wrt normal run (3/6) Reduced PCURRENTS SPEED wrt normal run (4/6)

Enhanced PCURRENTS DIRECTION wrt normal run (7/6) Enhanced PCURRENTS SPEED wrt normal run (8/6)

Effect of only PCURRENTS wrt normal run (Run 10/Run 6)

·	1.00	1.00	1.00	0.80
	1.01	0.99	1.00	0.80
ĺ	·1.00	1.00	, 1.00	0.80
	1.00	0.99	1.00	0.80
	1.00	0.99	1.00	0.80
Ī				
	0.34	2.94	0.00	0.26

Run	August	Run Permanent Curi	ent Conditions	Time	Speed	Escort	Total Cost
No.	Direction	Speed	All Others	(hr)	(kn)	(hr)	(US\$)
1	OFF	OFF	OFF	191.3	16.33	0.0	194,157
2	OFF	OFF	MC	320.1	9.84	75.1	298,740
3	-90 degrees	MC	MC	319.0	9,86	76.0	298,115
4	MC	-50%	MC	320.6	9.84	76.6	299,063
5							
6	MC	MC	MC	324.3	9.71	74.5	349,794
7	+90 degrees	MC	MC	318.9	9.86	79.1	298,700
8	MC	100%	MC	321.7	9.80	79.6	300,359
9							
10	MC	MC	OFF	191.2	16.35	0.0	189,397

Effect of turning off PCURRENTS wrt normal run (Run 2/Run 6) Reduced PCURRENTS DIRECTION wrt normal run (3/6) Reduced PCURRENTS SPEED wrt normal run (4/6)

Enhanced PCURRENTS DIRECTION wrt normal run (7/6) Enhanced PCURRENTS SPEED wrt normal run (8/6)

Effect of only PCURRENTS wrt normal run (Run 10/Run 6)

0,98	1.02	1.02	0.85
0.98	1.02	1.02	0.85
0.99	1.01	1.03	0.85
0.98	1.02	1.06	0.85
0.99	1.01	1.07	0.86
0.59	1.68	0.00	0.54

^{*} wrt = "with respect to"

APPENDIX B

LIST OF ROUTE SEGMENTS

APPENDIX B. LISTING OF ROUTE SEGMENTS, LEG ENDPOINTS, AND THEIR GEOGRAPHIC LOCATIONS

CRREL Segment Numbers	CRREL Leg End Points	INSROP2 Point Labels	Proshutinsky Point Numbers	Latitude (deg)	Longitude (deg)	Distance to Next Point (nm)	Heading to Next Point (deg)
				5/0500	T 5000	2/5/2	- /
1.00	H-01 to B1-01	H-01	292	54.0000	7.5000	315.19	342.92
1.01		H-02	293	59.0000	4.5000	170.74	355.24
1.02		H-03	294	61.8333	4.0000	441.49	25.05
1.03		H-04	295	68.3330	12.5000	213.66	43.85
1.04		H-05	296	70.7500	20.0000	119.07	70.15
. 1.05		B1-01	297	71.3333	25.8333		
2.00	B1-01 to B4-04	B1-01	297	71.3333	25.8333	42.07	95,81
2.01		B4-01	309	71.2500	28.0000	134.47	121.79
2.02		B4-02	310	69.9833	33,5667	24.04	180.00
2.03		B4-03	311	69.5833	33,5667	10.73	158.84
2.04		B4-04	312	69.4167	33.7500		
3.00	B1-01 to B5-02	B1-01	297	71.3333	25.8333	42.07	95.81
3.01 3.02		B4-01 B5-02	309 314	71.2500 70.8000	28.0000 38.3667	203.81	92.68
4.00	B1-01 to B1-02	B1-01	297	71.3333	25.8333	732.34	43.61
4.01	D1-01 to D1 02	B1-02	298	77.1833	68.0000	102.04	40.01
5.00	B4-04 to B5-02	B4-04	297	69.4167	33.7500	30.65	43.55
5.01		B5-01	313	69.7833	34.7667	95.13	48.37
5.02		B5-02	314	70.8000	38.3667		
6.00	B5-02 to B7-03	B5-02	314	70.8000	38.3667	399.86	39.76
6.01	D7 00 to D4 00	B7-03	321	75,3333	55.5000	70.00	40.00
7.00 7.01	B7-03 to B1-02	B7-03 B5-03	321 315	75,3333 76.1167	55.5000 59.0000	70.03 140.10	46.08 58.50
7.02		B1-02	298	77.1833	68.0000	140.10	56.50
8.00	B4-04 to B6-03	B4-04	312	69.4167	33.7500	30.65	43,55
8.01	0,0,00000	B5-01	313	69.7833	34.7667	45.34	125.81
8.02		B6-01	316	69.3333	36.5000	136.29	129.17
8.03		B6-02	317	67.8333	41.1667	20.73	165.00
8.04		. B6-03	318	67.5000	41.4000		
9.00	B6-03 to B7-02	B6-03	318	67.5000	41.4000	96.91	20.83
9.01 9.02		B7-01 B7-02	319 320	69.0000 70.5000	43.0000 45.5833	104.90	29.59
10.00	, B5-02 to B7-02	B5-02	320 314	70.8000	38,3667	144.65	93.74
10.01	, 50 02 10 51 02	B7-02	320	70.5000	45.5833	144.00	00.17
11.00	B7-02 to B7-03	B7-02	320	70.5000	45.5833	336.62	26.40
11.01		B7-03	321	75.3333	55,5000		
12.00	B7-02 to B2-01	B7 - 02	321	70.5000	45.5833	213.04	93.16
12.01	50.04 / 0.04	B2-01	299	70.0000	56.0000		
13.00	B2-01 to S-01	B2-01	299	70.0000	56.0000	77.80	105.53
13.01 13.02		B3-01 B3-03	303 304	69.6167 69.6483	59.5833 60.1983	13.01 2.70	81.31 96.33
13.03		B3-04	305	69.6433	60.3267	293.54	27.60
13.04	•	S-01	15	73.8333	68.5000	200.01	27.00
14.00	B2-01 to S-01	B2-01	299	70.0000	56.0000	42.99	65.76
14.01		B2-02	300	70,2833	57.9333	6.45	6.00
14.02		B2-03	301	70.3900	57.9667	10.33	33.34
14.03 14.04		B2-04 20	1	70.5333	58.2500 58.0447	20.02	43.15
14.05		40	2 3	70.7750 71.0167	58.9417 59.6417	20.02 20.03	43.14 43.20
14.06		60	4	71.2583	60.3517	20.03	43.09
14.07		80	5	71.5000	61.0683	20.04	43.19
14.08		100	6	71.7417	61.7967	20.00	43.09
14.09		120	7	71.9833	62.5317	20.03	43.15
14.10	•	140	8	72.2250	63,2783	20.03	43.15
14.11		160	9	72.4667	64.0350	20.01	43.09
14.12 14.13		180	10	72.7083	64.8000	20.03	43.12
14.13 14.14		200 220	11 12	72.9500 73.1917	65,5767 66,3633	20.02 20.02	43.08 43.12
14.15		240	13	73.1917	67.1617	20.02	43.12 43.11
14.16		260	14	73.6750	67.9717	13.02	42.78
14.17		S-01	15	73.8333	68,5000		

CRREL Segment Numbers	CRREL Leg End Points	INSROP2 Point Labels	Proshutinsky Point Numbers	Latitude (deg)	Longitude (deg)	Distance to Next Point (nm)	Heading to Next Point (deg)
15,00	S-01 to S-02	S-01	15	73,8333	68.5000	20.03	20.40
	3-01 (0 3-02	20	16	73.8333	69.6967		89.43
15.01		40	17	73.8333	70.8950	20.06	89.42
15.02		60	18	73,8333	70.0930	20.03	89.43
15.03		. 80	19	73.8333	73.2883	20.03	89.43
15.04						20.06	89.42
15.05		100	20	73.8333	74.4867	20.03	89.43
15.06		120	21	73,8333	75.6833	20.03	89.43
15.07		140	22	73.8333	76,8800	20.06	89.42
15.08		160	23	73.8333	78.0783	20.03	89.43
15.09		180	24	73.8333	79.2750	14.92	89.57
15.10		S-02	25	73.8333	80.1667		
16.00	S-01 to N-01	S-01	15	73.8333	68.5000	289.01	39.65
16.01		N-01	153	77.1833	82.5000		
17.00	B1-02 to N-01	B1-02	143	77.1833	68,0000	20.05	89.27
17.01		20	144	77.1833	69.5033	20.02	89.27
17.02		40	145	77.1833	71.0050	20.05	89.27
17.03		60	1 <u>46</u>	77.1833	72.5083	20.02	89.27
17.04		80	147	77.1833	74.0100	20.05	89.27
17.05		100	148	77.1833	75.5133	20.05	89.27
17.06		120	149	77.1833	77.0167	20.02	89.27
17.07		140	150	77.1833	78.5183	20.05	89.27
17.08		160	151	77.1833	80.0217	20.02	89.27
17.09		180	152	77.1833	81.5233	13.02	89,52
17.10		N-01	153	77.1833	82,5000		
18.00	S-02 to S-05	S-02	25	73,8333	80,1667	20.07	40.24
18.01		20	26	74.0867	80.9533	19.98	40.42
18.02		40	27	74.3383	81.7517	20.05	40.18
18.03		60	28	74.5917	82.5617	19.99	40.44
18.04		80	29	74.8433	83.3867	20.05	40.17
18.05		100	30	75.0967	84.2233	19,98	40.40
18.06		120	31	75.3483	85.0750	19.99	40.40
18.07		140	32	75.6000	85.9417	20.05	40,16
18.08		160	33	75,8533	86.8217	11.56	40.05
18.09		S-03	34	76.0000	87.3333	20.03	55.72
.18.10		20	35	76.1850	88.4867	20.03	55.71
18.11		40	36	76,3700	89.6550	20.02	55.69
18.12		60	37	76.5550	90,8383	20.03	55,69
, 18.13		80	38	76.7400	92.0383	19.98	55.93
18.14		100	39	76.9233	93.2550	20.03	55.67
18.15		120	40	77.1083	94.4883	20.04	55.68
		140	41	77.2933	95.7400	4.19	54.86
18.16 18.17		S-04	42	77.3333	96,0000	20.02	66.95
18.18		20	43	77.4600	97.4117	20.05	66.68
		40	→S 44	77.5883	98.8367	20.02	66.93
18.19		60	45	77.7150	100.2767	20.00	66.91
18.20		80	46	77.8417	101.7300	3.73	66.11
18.21		S-05	47	77.8667	102.0000	00	
18.22	N-01 to N-02	N-01	153	77.1833	82.5000	20.04	60.01
19.00	14-01 to 14-02	20	154	77.3467	83.8183	20.01	60,30
19.01		40	155	77.5083	85.1550	20.03	59.98
19.02				77.6717	86,5067	20.03	60.28
19.03		60	156 457	77.8333	87.8783	16.25	59.88
19.04		80	157		89,0000	10.20	59,00
19.05		N-02	158	77.9667	89.0000	20.03	91.23
20.00	N-02 to S-05	N-02	274	77,9667			91.51
20.01		20	275	77.9550	90.5967	20.03	
20.02		40	277	77.9417	92.1917	20.03	91.23 91.51
20.03	,	60	278	77.9300	93.7850	20.03	91.51 91.53
20.04	•	80	279	77.9167	95.3767	20.04	91.53
20.05		100	280	77.9033	96.9667	20.03	91.22 91.53
20.06		120	281	77.8917	98,5550	20.03	91.53
20.07		140	282	77.8783	100.1417	20.03	
20.08		160	283	77.8667	101.7267	3.45	89.87
20.09		S-05	284	77.8667	102.0000	00.00	360.00
21.00	N-02 to N-05	N-02	158	77.9667	89,0000	20.03	360.00 #PEEI
21.01		20	159	78,3000	89.0000	#REF!	#REF!

CRREL Segment Numbers	CRREL Leg End Points	INSROP2 Point Labels	Proshutinsky Point Numbers	Latitude (deg)	Longitude (deg)	Distance to Next Point (nm)	Heading to Next Point (dea)
							
21.02		40	160	78,6333	89.0000	2704.94	180.00
21.03		60	161	78.9667	89.0000	20.03	360.00
21.04		80	162	79.3000	89.0000	, 20.03	360.00
21.05		100 120	163 164	79.6333 79.9667	89.0000 89.0000	20.04 20.03	360,00 360,00
21.06 21.07		140	165	80.3000	89.0000	20.03	360.00
21.07		160	166	80,6333	89.0000	20.03	360.00
21.09	•	180	167	80.9667	89.0000	20.03	360.00
21.10		182	168	81.3000	89.0000	2.00	360.00
21.11		N-03	169	81.3333	89.0000	20.04	85.18
21.12		20	170	81.3550	91.2100	20.03	85.46
21.13		40	171	81.3750	93.4250	20.05	85.17
21.14		43	172	81.3967	95.6467	3.18	86.25
21.15 21.16		N-04 20	173 174	81.4000 81.1317	96.0000 97.2967	20.00 20.09	143.08 143.27
21.17		40	175	80.8617	98.5550	20.03	143.14
21.18		60	176	80.5933	99.7767	20.08	143.34
21.19		80	177	80.3233	100.9633	20.00	143.17
21.20		100	178	80.0550	102.1183	20.09	143.34
21.21		120	179	79.7850	103.2433	20.01	143.17
21.22		140	180	79.5167	104.3400	20.08	143.38
21.23		160 180	181 182	79.2467 78.9783	105.4083 106.4500	20.00 20.08	143.24 143.42
21.24 21.25		200	183	78.7083	107.4667	20.01	143.21
21.26		220	184	78.4400	108.4617	20.08	143.46
21.27		240	185	78.1700	109,4317	20.01	143.26
21.28		249	186	77.9017	110.3817	8.87	143.14
21.29		N-05	187	77.7833	110.8000		
22.00	S-05 to S-06	S-05	47	77.8667	102.0000	20.03	91.53
22.01		20	48	77.8533	103.5833	20.03	91.51
22.02 22.03		40 S-06	49 50	77.8400 77.8333	105.1650 106.0000	10.58	91.77
23.00	S-06 to N-05	S-06 S-06	287	77.8333	106.0000	20.03	92,08
23.01	0-00 to 11-00	20	288	77.8167	107.5783	20.04	92.10
23.02		40	289	77.8000	109.1550	20.93	91.94
23.03		N-05	291	77.7833	110.8000		
24.00	N-05 to N-07	N-05	187	77.7833	110.8000	20.02	137.70
24.01		20	188	77.5350	111.8383	20.10	137.90
24.02		40	189	77.2850	112.8567	20.01	137.73
24.03 24.04		60 N-06	190 191	77.0367 76.9167	113.8550 114.3333	9.70 20.03	137.84 112.01
24.05		20	192	76.7883	115.6850	20.03	112,30
24.06		40	193	76,6583	117.0217	20.03	112.00
24.07		60	194	76,5300	118.3483	15.01	112.30
24.08		N-07	195	76.4333	119.3333		
25.00	S-06 to S-07	S'-06	50	77.8333	106.0000	20.06	125.84
25.01 25.02		20	51 53	77.6350	107.2633	20.02	125.60 125.85
25.02 25.03		40 60`	52 · 53	77.4383 77.2400	108.5083 109.7333	20.06 20.01	125,63
25.04		80	54	77,0433	110.9400	20.06	125.87
25.05		100	55	76,8450	112.1283	20.01	125.64
25.06		120	56	76.6483	113.3000	20.07	125.87
25.07		140	57	76.4500	114.4550	20.05	125,92
25.08		160	58	76.2517	115.5917	20.02	125.65
25.09		180	59	76.0550	116.7150	20.07	125.90
25.10 25.11		200 220	60 61	75.8567 75.6600	117.8217 118.9117	19.99	125.73 125.93
25.11 25.12		240	62	75.6600 75.4617	119.9883	20.06 20.02	125.69
25.13		260	63	75.2650	121.0517	20.02	125.95
25.14		280	64	75,0667	122.1000	20.00	125.73
25.15		300	65	74.8700	123.1350	20.08	125.92
25.16 25.17		320	66	74.6717	124.1583	20.06	126.00
25,17 25,18		340 360	67 68	74.4733	125.1667	20.00	125.74
25.18		380	68 69	74.2767 74.0783	126.1633 127.1483	20.07 20.01	125,98 125,73
		- 	20		, , , , , , ,		

CRREL Segment	CRREL Leg	INSROP2 Point Labels	Proshutinsky Point	Latitude	Longitude	Distance to Next Point	Heading to Next Point
Numbers	End Points	Lapeis	Numbers	(deg)	(deg)	(nm)	(deg)
25.20		400	70	73.8817	128.1217	20.07	125.99
25.21		420	71	73,6833	129,0833	15.59	124.97
25.22		S-07	72	73.5333	129.8333		
26.00	N-07 to S-07	N-07	195	76.4333	119.3333	237.80	131.67
26.01	11 07 1 0 00	S-07	72	73,5333	129.8333	000.07	100 70
27.00	N-07 to S-09	N-07 S-09	195 82	76.4333 74.3667	119.3333 139.0833	320.67	102.78
27.01 28.00	N-07 to N-10	N-07	195	76.4333	119.3333	20.03	86.73
28.01	14-01 10 14 10	20	196	76.4483	120.7533	20.03	87.00
28.02		40	197	76.4617	122,1750	20.02	86.73
28.03		60	198	76.4767	123,5967	20.04	86.73
28.04		80	199	76.4917	125.0217	20.02	87.02
28.05		100	200	76.5050	126.4467	20.05	86.73
28.06		120 140	201 202	76.5200 76.5350	127.8750 129.3033	20.02 20.02	86.72 87.02
28.07 28.08		160	202	76.5483	130,7333	20.02	86.72
28.09		180	204	76.5633	132.1650	20.03	86.72
28.10		200	205	76.5783	133,5983	20.03	87,00
29.11		220	206	76.5917	135.0333	20.04	86.72
28.12		240	207	76.6067	136.4700	20.04	86.72
28.13		260	208	76.6217	137.9083	20.01	87.01
28.14		280	209	76.6350	139,3467 140,7883	20.04	86.72
28.15		300 N-08	210 211	76.6500 76.6667	142,0000	16.84 20.04	85.99 107.09
28.16 28.17		20	212	76.5650	143.3717	20.03	106.80
28.18		40	213	76,4650	144.7350	20.04	107.10
28.19		60	214	76.3633	146,0867	20.04	107.09
28.20		80	215	76.2617	147.4283	20,03	106.82
28.21		100	216	76.1617	148.7617	20.05	107.11
28.22		120	217	76.0600	150.0850	20.01	106.84
28.23		140 160	218 219	75.9600 75.8583	151,3983 152,7033	20.05 20.04	107.12 107.12
28.24 28.25		180	220	75.7567	153,9983	5.15	105.67
28.26		N-09	221	75.7333	154.3333	20.01	143.80
28.27		20	222	75.4633	155.1167	20.10	143.94
28.28		40	223	75.1917	155.8867	20.02	143.78
28.29		60	224	74.9217	156.6433	20.02	143.79
28.30		80	225	74.6517	157.3867 158.1167	20.02 20.10	143,83 143,98
28.31		100 120	226 227	74.3817 74.1100	158.8350	20.02	143.81
28.32 28.33		140	228	73.8400	159.5417	20.00	143.90
28.34		160	229	73.5700	160.2350	20,03	143.79
28.35		180	230	73.3000	160,9200	20.10	144.01
28.36		200	231	73.0283	161.5933	4.61	143.28
28.37		N-10	232	72.9667	161,7500	20.05	· 89.44
29.00	S-07 to S-09	S-07	72 73	73.5333 73.5333	129.8333 131.0100	20.05 20.02	89.44
29.01		20 40	73 74	73.5333	132,1850	20.05	89.44
29.02 29.03		60	75	73.5333	133,3617	20.02	89.44
29.04		80	76	73,5333	134.5367	20.05	89.44
29.05		100	77	73,5333	135.7133	4.89	89.86
29.06		S-08	78	73.5333	136,0000	20.05	45.20
29.07		20	79	73.7667 73.9983	136.8467 137.7050	19.97 20.0 4	45.40 45.16
29.08		40 80?	80 81	73.9963 74.2317	138.5750	11.59	45.16 45.29
29,09		S-09	82	74.3667	139.0833	11.00	10.20
29.10 30.00	S-09 to S-12	S-09	82	74.3667	139.0833	20.01	68.32
30,01	C 55 55 72	20	83	74.4867	140.2400	13.10	68.10
30.02		S-10	84	74.5667	141.0000	20.02	99.50
30.03		20	85 86	74.5083	142,2300	20.04	99.48 101.17
30.04		40	86 87	74.4500 74.3817	143.4567 144.6783	20.15 19.96	97.79
30.05		60 80	. 87 88	74.3317 74.3333	145.8967	12.14	99.14
30.06 30.07		S-11	89	74.3000	146.6333	20.06	120.78
30.08		20	. 90	74.1267	147.6817	20.00	120.57
30.09		40	91	73.9550	148.7183	20.04	120.83

CRREL Segment Numbers	CRREL Leg End Points	INSROP2 Point Labels	Proshutinsky Point Numbers	Latitude (deg)	Longitude (deg)	Distance to Next Point (nm)	Heading to Next Point (deg)
30.10 30.11 30.12 30.13 30.14 30.15 30.16 30.17 30.18 30.19 30.20 30.21 30.22 30.23 30.24 30.25 30.26 30.27 30.28 30.29 30.30 31.00 31.01 32.00 32.01 32.02 32.03 32.04 32.05 32.06 32.07 32.08	N-10 to S-12 S-12 to Y-01	60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 5-12 N-10 S-12 S-12 20 40 60 80 100 120 140 S-13	94 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 232 112 112 113 114 115 116 117 118 119 120	73.78.17 73.6083 73.4367 73.2633 73.0900 72.9167 72.7450 72.5717 72.3983 72.2267 72.0533 71.8800 71.7083 71.5350 71.1883 71.0167 70.8433 70.6700 70.4983 70.28367 70.1817 70.1483 70.1150 70.0817 70.0467 70.0167	151.7633 150.7583 151.7633 152.7583 152.7583 152.7583 154.7183 155.6833 156.6400 157.5867 158.5250 159.4550 160.3750 161.2867 162.1917 163.0867 163.9750 164.8550 165.7267 166.5917 167.4483 168.5333 161.7500 168.5333 168.5333 169.5150 170.4950 171.4733 172.4500 173.4250 174.3983 175.3700 176.3167	20.05 20.00 20.06 20.05 20.05 19.99 20.06 20.05 20.00 20.04 19.99 20.07 20.04 20.06 20.00 20.04 20.05 19.99 25.42 205.63 20.02 20.02 20.02 20.02 20.02 20.02 20.02 20.02 20.02 20.02 20.02 20.02 20.02 20.02 20.02 20.02 20.03 19.52 20.02	120.83 120.56 120.83 120.82 120.84 120.62 120.83 120.60 120.85 120.85 120.84 120.90 120.88 120.63 120.92 120.88 120.63 120.92 120.88 120.63 120.92 120.88 120.5 138.19 95.27 95.28 95.57 95.28 95.57 94.86 119.30
32.09 32.10 32.11 32.12 32.13 32.14 32.15 32.16 32.17 32.18 32.19 32.20 32.21 32.22 32.23 32.24 32.25 32.26 32.27 32.28 32.29 32.30 33.00 33.01 33.02 33.03 33.04 33.05 33.06 33.07 33.08 33.09 33.10 33.11	N-10 to Y-01	20 40 60 80 100 S-14 20 40 60 80 120 140 15-15 20 40 60 Y-01 N-10 20 40 60 80 100 120 140 160 80 120 140 15-15 20 40 80 120 80 120 80 80 80 80 80 80 80 80 80 80 80 80 80	121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 232 233 234 235 236 237 238 239 240 241 242 243	69.8517 69.6867 69.5217 69.3567 69.1917 69.1833 68.9567 68.7317 68.5050 68.2783 68.0517 67.8250 67.6000 67.3733 67.2000 66.7600 66.7600 66.5217 66.2817 66.1667 72.9667 72.7633 72.5600 72.3550 72.1517 71.9483 71.7450 71.5400 71.3367 71.1333 71.0000 70.9383	177.1600 177.9983 178.8283 179.6533 180.4700 180.5167 181.2017 181.8800 182.5517 183.2167 183.8733 184.5250 185.1700 185.8100 187.1350 187.9650 188.4333 189.0233 189.0233 189.0233 190.1883 190.1883 190.1883 190.4667 161.7500 162.6450 163.5300 164.5733 165.2717 166.1283 166.9750 167.8117 168.6400 170.0000 171.0033	20.05 20.04 20.01 1.12 20.05 19.99 20.06 20.03 20.05 19.98 20.07 15.42 20.04 19.99 11.29 20.05 19.99 20.07 9.66 20.02 20.02 20.02 22.56 17.69 20.03 20.02 20.07 20.01 20.02 13.23 20.01 20.04	119.25 119.31 119.27 119.34 116.83 132.48 132.27 132.48 132.55 132.50 132.31 132.48 132.26 103.20 103.25 103.11 135.74 135.51 135.68 135.57 127.22 127.20 122.60 133.35 127.21 127.22 127.48 127.25 127.21 100.21 100.21 100.17

CRREL Segment Numbers	CRREL Leg End Points	INSROP2 Point Labels	Proshutinsky Point Numbers	Latitude (deg)	Longitude (deg)	Distance to Next Point (nm)	Heading to Next Point . (deg)
33.12		40	244	70.8767	172.0050	20.04	100.20
33.13		60	245	70.8150	173.0033	20.00	100.22
33.14		80	246	70.7533	173.9967	20.02	100.19
33,15		100	247	70.6917	174.9883	20.04	100.50
		120	248	70.6283	175.9767	20.05	100.18
33.16		140	249	70.5667	176.9633	20.01	100.10
33.17		160	250	70.5057	177.9450	2.46	96.96
33.18		N-12	251	70,5000	178.0667	20.04	79.47
33.19		20	251 252	70.5583	179.0517	20.00	79.73
33.20		40	253	70.6150	180.0383	20.02	79.73
33.21		4 0 60	253 254	70.6717	181.0283	20.02	79.45
33.22		80	255	70.7300	182.0200	6.65	79.43
33.23		N-13	256 256	70.7500	182.3500	20.06	146.79
33.24		20	256 257	70.4700	182.8967	20.05	146.75
33,25		40	257 258	70.1900	183.4350	20.03	146.89
33,26		60	259	69.9100	183.9650	20.04	146.80
33.27		80	260 260	69.6300	184.4900	19.96	146.71
33.28			261	69.3517	185.0067	20.04	146.88
33.29		100	262	69.0717	185.5167	20.04	146.81
33,30		120		68.7917	186.0217	20.03	146.92
33.31		140	263		186.5183		
33,32		160	264	68.5117	187.0100	20.05	146.86
33,33		180	265	68.2317		20.06	146.81
33.34		200	266	67.9517	187.4967	20.05	146.86
33.35		220	267	67.6717	187.9767	20.04	146.92
33.36		240	268	67.3917	188.4500	20.04	146.89
33.37		260	269	67.1117	188.9183	20.05	146.87
33.38		280	270	66.8317	189.3817	20.05	146.86
33.39		300	271	66.5517	189.8400	19.95	146.80
33.40		320	272	66.2733	190.2917	7.68	146.42
33.41		Y-01	273	66.1667	190.4667		

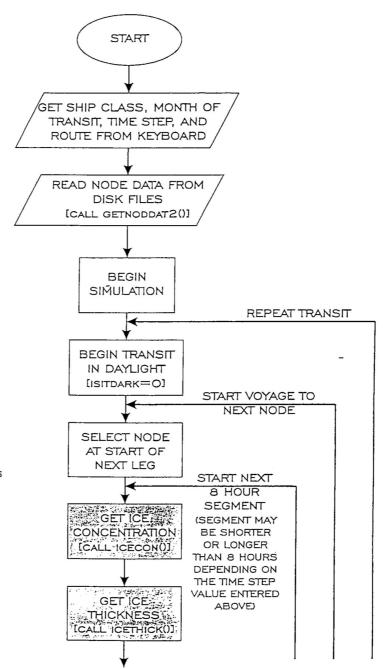
APPENDIX C

DETAILED FLOW CHART

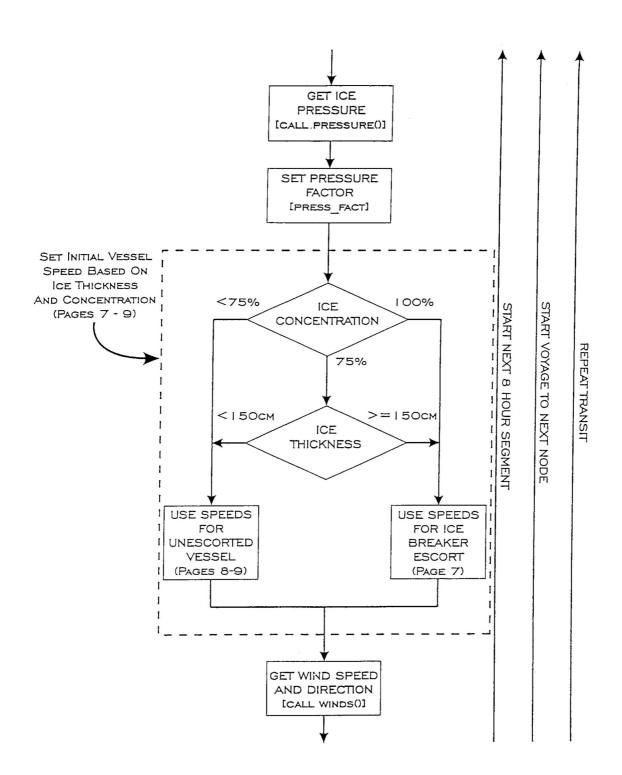
FOR NSRSIM2A

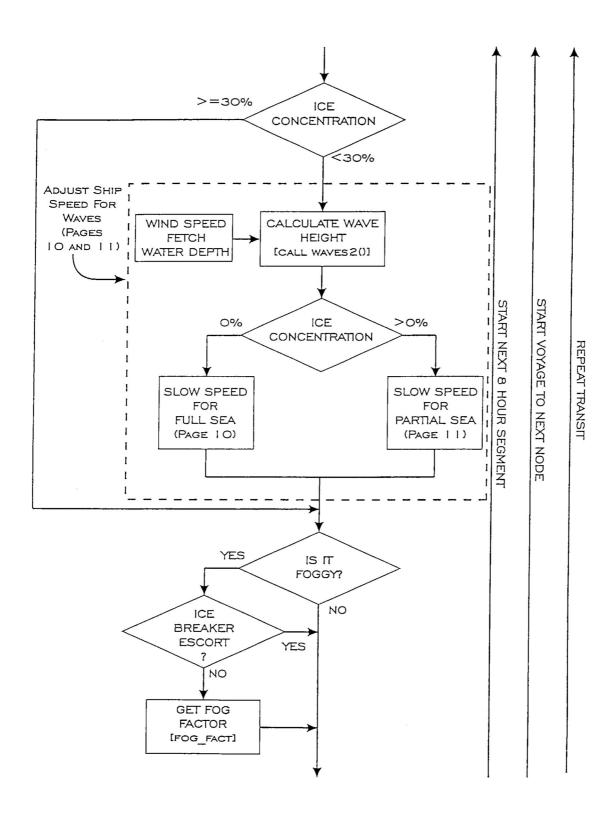
NSRSIM2A

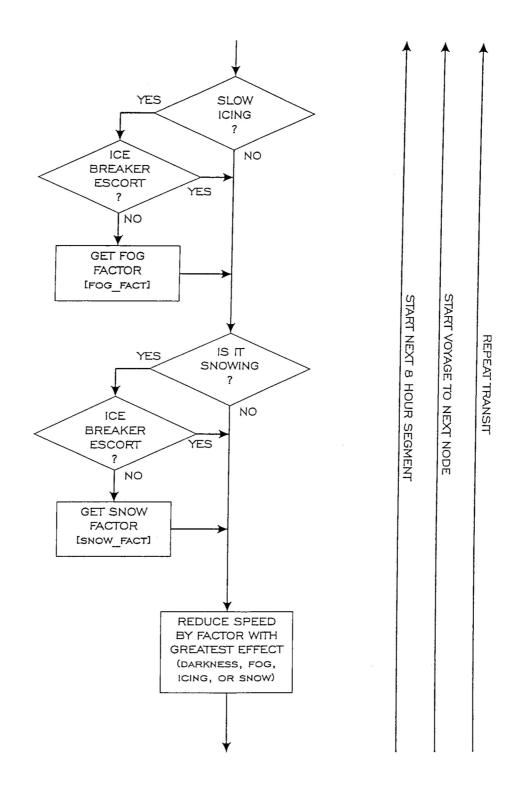
(CURRENT TO 2-15-99)

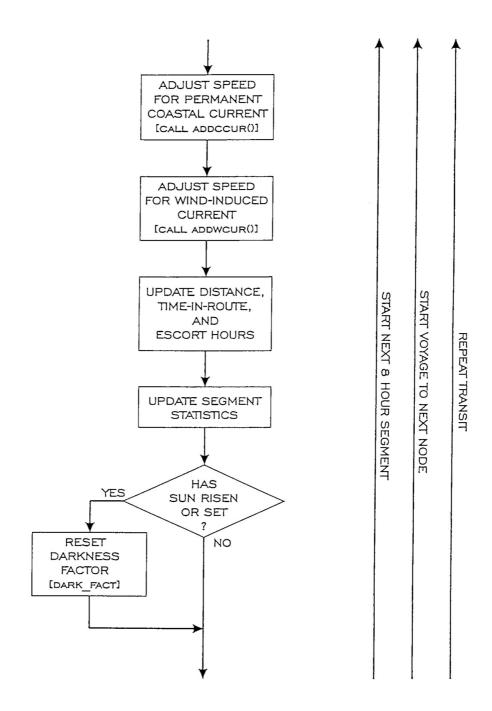


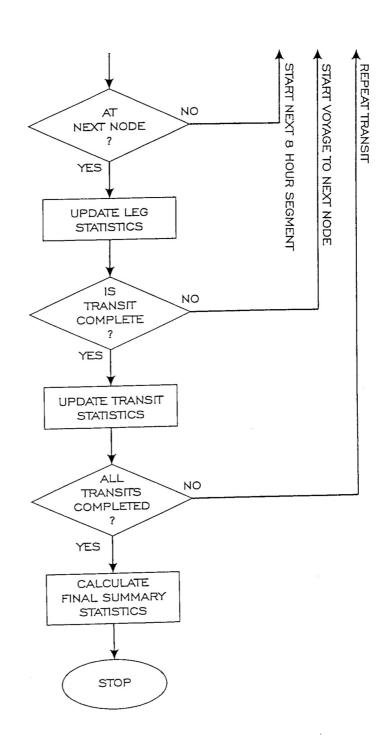
(SHADED BOXES DENOTE STEPS IN WHICH VARIABLES ARE SET USING MONTE CARLO METHODS)

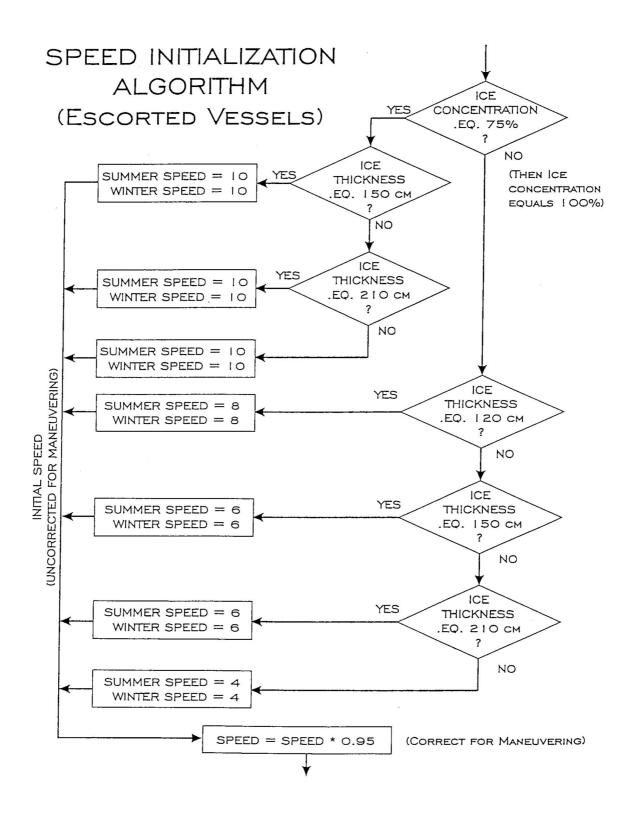






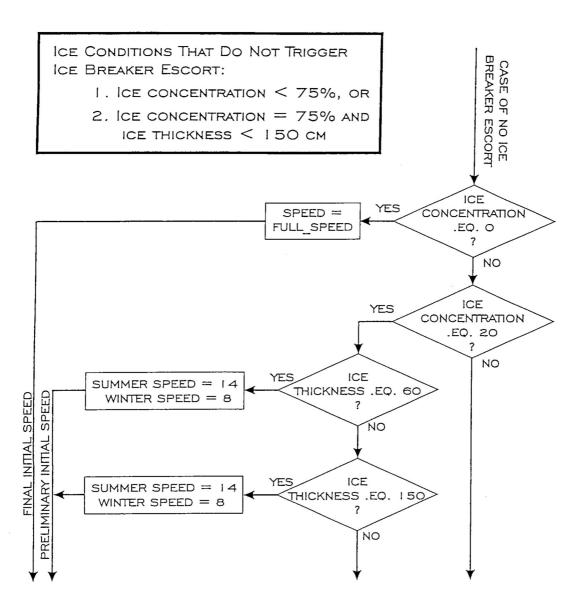


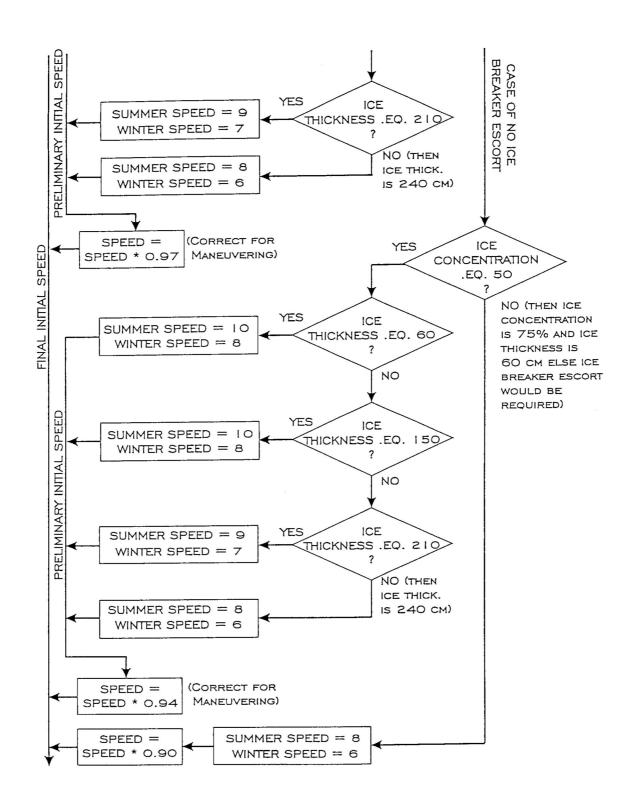


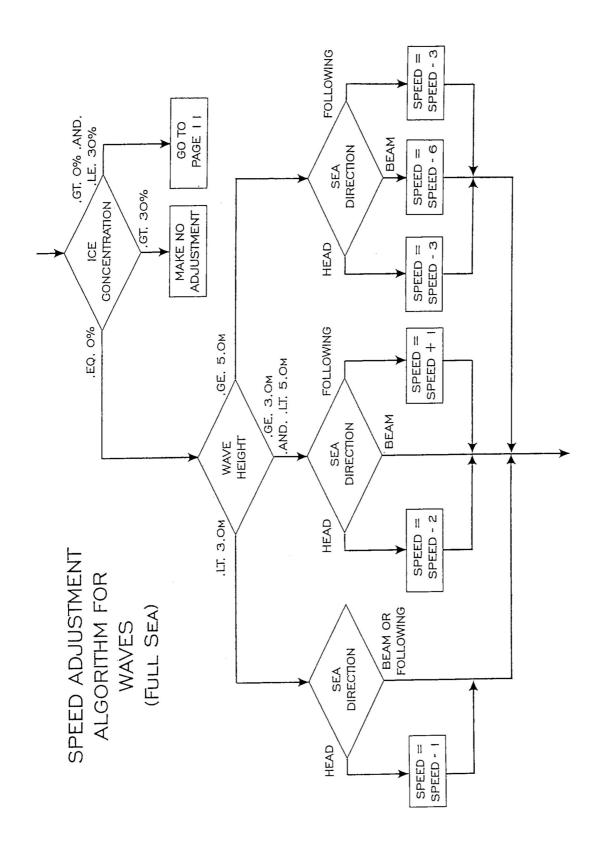


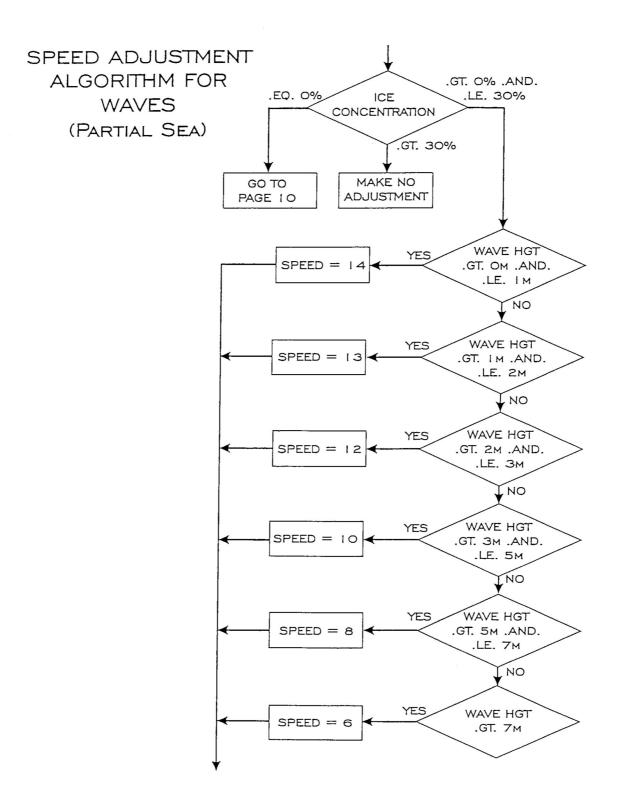
SPEED INITIALIZATION ALGORITHM

(UNESCORTED VESSELS)









APPENDIX D INPUT DATA FILE FORMATS

APPENDIX D. INPUT DATA FILE FORMATS

TABLE D.1. List of data files required to run NSRSIM2A.

FILE NAME	DESCRIPTION	MONTH
ICECONC.ALL	Ice concentration probability density functions. (Table D.2)	ALL
COST.DAT	Ship cost data. (Table D.3)	ALL
FOG.APR	Probability of fog.	APRIL
FOG.AUG	(Table D.4)	AUGUST
ICEPRES.APR	Ice pressure probability density functions.	APRIL
ICEPRES.AUG	(Table D.5)	AUGUST
ICETHICK.APR	Ice thickness probability density functions.	APRIL
ICETHICK.AUG	(Table D.6)	AUGUST
NDESWE.DAT	West-to-east route table. (Table D.7)	ALL
PERMCURR.ALL	Speed and direction of permanent ocean currents. (Table D.8)	ALL
ICING.AUG	Probability of icing. (Table D.9)	AUGUST
WINDS.APR	Wind speed and direction probability density functions.	APRIL
WINDS.AUG	(Table D.10)	AUGUST
SNOW.APR	Probability of snow. (Table D.11)	APRIL
WTR_DPTH.DAT	Water depth at route node points. (Table D.12)	ALL

ICE CONCENTRATION FILE (ICECONC.ALL)

Number of Header Records: 6 Length of Data Record: 84 bytes

TABLE D.2. Data record format specifications for ice concentration file.

DATUI	M	FIRST BYTE	LAST BYTE	FORMAT
Ice Concentration	n Category	1	10	A10
	January	11	16	F6.0
	February	17	22	F6.0
	March	23	28	F6.0
	April	29	34	F6.0
	May	35	40	F6.0
Probability of	June	41	46	F6.0
Occurrence by Month	July	47	52	F6.0
•	August	53	58	F6.0
	September	59	64	F6.0
	October	65	70	F6.0
	November	71	76 .	F6.0
	December	77	82	F6.0
Carriage Control Chara	cters (hex 0D0A)	83	84	A2

Point=		:	1 Occ	urrer	ce of	ice	conce	ntrat	ion,	용			
month:	1	2	3	4	5	6	. 7	8	9	10	11	12	
ice free	0.	3.	0.	2.	2.	32.	65.	73.		90.	43.	13.	
10-30	0.	0.	0.		2.				6.	0.	3.	0.	
40-60	0.	0.			2.		4.		0.			3.	
70-80	0.	0.	0.		4.					5.			
90-100	100.	97.	98. 	96.	91.	47.	19. 	6.	3.	5.	46.	74.	
Point=		:	2 Occ	urren	ice of	ice	conce	ntrat	ion,	용			
month:	1	2	3	4	5	6	7	8	9	10	11	12	
ice free	0.	3.	2.	0.	4.	15.	40.	64.	81.	87.	45.	11.	
10-30	0.	0.	0.	0.	0.	5.	10.	12.	5.	0.	З.	3	
40-60	0.	3.		0.	0.		9.		З.		0.	0.	
70-80	0.	3.	0.	2.	2.	2.	9.	3.	0.	4.	5.	5.	
90-100	100.	92.	96.	98.	94.	67.	33.	12.	11.	9.	47.	82. 	
Point=		:	3 Occ	urren	ice of	ice	conce	ntrat	ion,	용			
month:	1	2	3	4	• 5	6	7	8	9	10	11	12	
ice free	0.	3.	0.	0.	0.	7.	36.	65.	77.	81.	41.	5.	
10-30	0.	0.	0.	0.	0.	2.	5.	8.	10.	0.	2.	3.	
40-60	0.	0.	0.	0.	4.	9.	11.	17.	8.	0.	0.	0.	
70-80	0.	0.	0.	2.	0.	2.	10.	1.	3.	4.	2.	5.	
90-100	100.	97.	100.	98.	96.	79.	38.	8.	3.	15.	54.	87.	

Figure D.1. Partial listing of ICECONC.ALL file.

COST FILE (COST.DAT)

Number of Header Records: 2 Length of Data Record: 52 bytes

TABLE D.3. Data record format specifications for cost file.

DATUM	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 (US\$)	39	50	F12.2
Carriage Control Characters (hex 0D0A)	51	52	A2

SHIP COST DATA	in US\$ (Curre	nt to 4-6-95)	
Ship Class	Daily Cost	Escort Cost	Tariffs
1 NORISLK	16450.00	0.00	116000.00
2 LUNNI	13500.00	0.00	100000.00
3 STREKALOVSKI	11250.00	0.00	100000.00

Figure D.2. Example of COST.DAT file.

FOG FILES (FOG.***)

Number of Header Records: 2 Length of Data Record: 11 bytes

TABLE D.4. Data record format specifications for fog files.

DATUM	FIRST BYTE	LAST BYTE	FORMAT
Node Number	1	5	I 5
Probability of Fog	6	9	F4.0
Carriage Control Characters (hex 0D0A)	10	11	A2

```
Fog (Aug)
   num %
    1 10.
            B2-04
    2 12.
    3 14.
    4 15.
    5 16.
      18.
      19.
      20.
    9 20.
   10 20.
   11 20.
   12 20.
   13 20.
   14 21.
   15 21.
            S-01
   16 21.
   17 21.
   18 22.
   19 22.
   20 22.
   21 19.
   22 16.
   23 14.
   24 12.
   25 10.
            S-02
```

Figure D.3. Partial listing of FOG.AUG file.

ICE PRESSURE FILES (ICEPRES.***)

Number of Header Lines: 2

Length of Data Record: 51 bytes

TABLE D.5. Data record format specifications for ice pressure files.

DATUM		FIRST BYTE	LAST BYTE	FORMAT
Node Numl	per	, 1	7	I7
Node Identific	ation	8	17	A10
	None	18	25	F8.1
Probability of	Light	26	33	F8.1
Ice Pressure	Medium	34	41	F8.1
·	High	42	49	F8.1
Carriage Control Charact	ers (hex 0D0A)	50	51	A2

באר דאויזי	SECM 1	O PRESSURE	т.тсит	MEDIUM	HIGH
1	B2-04	74.7	15.5	9.7	0.1
2	D2 '04	99.2	0.8	0.0	0.0
3		99.3	0.7	0.0	0.0
4		99.5	0.5	0.0	
5		99.5	0.5	0.0	0.0
6		99.3	0.7	0.0	0.0
7		98.5	1.5	0.0	0.0
8		97.8	2.2	0.0	0.0
9		97.8	2.2	0.0	0.0
10		97.6	2.4	0.0	0.0
11		97.6	2.4	0.0	0.0
12		97.8	2.2	0.0	0.0
13		98.5	1.5	0.0	0.0
14		98.5	1.5	0.0	0.0
15	S-01	99.0	1.0	0.0	0.0
16		99.5	0.5	0.0	0.0
17		59.6			0.3
18		99.7	0.3	0.0	0.0
19		99.5	0.5	0.0	0.0
20		99.5	0.5	0.0	0.0
21		98.9	1.1	0.0	0.0
22		98.9	1.1	0.0	0.0
23		99.5	0.5	0.0	0.0
24		99.5	0.5	0.0	0.0
25	S-02	80.7	12.5	6.6	0.2
27		99.8	0.2	0.0	0.0
28		99.8	0.2	0.0	0.0
28 29		99.8 99.8	0.2	0.0	0.0

Figure D.4. Partial listing of ICEPRES.AUG file.

ICE THICKNESS FILES (ICETHICK.***)

Number of Header Lines: 4 Length of Data Record: 71 bytes

TABLE D.6. Data record format specifications for ice thickness files.

	DATUM	FIRST BYTE	LAST BYTE	FORMAT
	Node	1	6	A6
Maximu	m Ice Thickness	7	12	F6.0
Minimu	m Ice Thickness	13	18	F6.0
Mean	Ice Thickness	19	24	F6.0
	No Ice (Ice 0 cm Thick)	25	33	F9.2
Probability of Ice	Ice <120 cm Thick	34	42	F9.2
Thickness	Ice 120 cm to 180 cm Thick	43	51	F9.2
THIORHOSS	Ice 181 cm to 240 cm Thick	52	60	F9.2
	Ice >240 cm Thick	61	69	F9.2
Carriage Contro	l Characters (hex 0D0A)	70	71	A2

Point	max	min	mean	None	<120	120-180	180-240	>240
1		0.		0.02	0.06			
2		0.	145.		0.04			0.00
3	204.	0.	163.	0.02	0.02	0.93	0.02	0.00
4	180.	60.	164.	0.00	0.05	0.95	0.00	0.00
5	180.	135.	168.	0.00	0.00	1.00	0.00	0.00
6	180.	135.	169.	0.00	0.00	1.00	0.00	0.00
7	180.	135.	169.	0.00	0.00	1.00	0.00	0.00
8	180.	135.	170.	0.00	0.00	1.00	0.00	0.00
9	180.	144.	171.	0.00	0.00	1.00	0.00	0.00
10	180.	144.	170.	0.00	0.00	1.00	0.00	0.00
11	180.	144.	170.	0.00	0.00	1.00	0.00	0.00
12	180.	144.	170.	0.00	0.00	1.00	0.00	0.00
13	180.	144.	170.	0.00	0.00	1.00	0.00	0.00
14	180.	144.	171.	0.00	0.00	1.00	0.00	0.00
15	180.	135.	170.	0.00	0.00	1.00	0.00	0.00
16	180.	30.	160.	0.00	0.09	0.91	0.00	0.00
17	180.	30.	150.	0.00	0.17	0.83	0.00	0.00
18	180.	0.	140.	0.02	0.20	0.78	0.00	0.00
19	180.	0.	131.	0.02	0.27	0.71	0.00	0.00
20	180.	27.	132.	0.00	0.31	0.69	0.00	0.00

Figure D.5. Partial listing of ICETHICK.APR file.

NETWORK NODE FILE (NDESWE.DAT)

Number of Header Records: 3 Length of Data Record: 66 bytes

TABLE D.7. Data record format specifications for network node files.

	DATUM	FIRST BYTE	LAST BYTE	FORMAT
	CRREL Point Number	1	5	F5.2
	CRREL Point Name	6	12	A7
Current Point	Number of Branches	13	15	13
	Node Number	16	20	I5
	Latitude	21	29	F9.4
	Longitude	30	38	F9.4
•	CRREL Point Number	39	44	F6.2 -
Next Point	Node Number	45	49	I5
I TOXL I OIIIL	Distance (nm)	50	57	F8.3
	Heading (degrees)	58	64	F7.2
Carriage Cont	rol Characters (hex 0D0A)	65	66	A2

<		-Thi	s Poi	nt						
CRREL	CRREL			h		CRREL	Prosl	n Dist	Head	
Num	Name	chs	Num	Lat	Lon	Num	Num	(nm)	(deg)	
1.00	H-01	.1	292	54.0000	7.5000	1.01	293	315.189	342.92	
1.01	H-02	1	293	59.0000	4.5000	1.02	294	170.740	355.24	
1.02	H-03	1	294	61.8333	4.0000	1.03	295	441.487	25.05	
1.03	H-04	1	295	68.3330	12.5000	1.04	296	213.656	43.85	
1.04	H-05	1	296	70.7500	20.0000	1.05	297	119.069	70.15	•
1.05	B1-01	0	297	71.3333	25.8333	0.00	0	0.000	0.00	
2.00	B1-01	1	297	71.3333	25.8333	2.01	309	42.070	95.81	
2.01	B4-01	1	309	71.2500	28.0000	2.02	310	134.471	121.79	
2.02	B4-02	1	310	69.9833	33.5667	2.03	311	24.043	180.00	
2.03	B4-03	1	311	69.5833	33.5667	2.04	312	10.732	158.84	
2.04	B4-04	0	312	69.4167	33.7500	0.00	0	0.000	0.00	
3.00	B1-01	1	297	71.3333	25.8333	3.01	309	42.070	95.81	
3.01	B4-01	1	309	71.2500	28.0000	3.02	314	203.808	92.68	
3.02	B5-02	0	314	70.8000	38.3667	0.00	0	0.000	0.00	
4.00	B1-01	1.	297	71.3333	25.8333	4.01	298	732.341	43.61	
4.01	B1-02	0	298	77.1833	68.0000	0.00	0	0.000	0.00	
5.00	B4-04	1	312	69.4167	33.7500	5.01	31.3	30.648	43.55	
5.01	B5-01	1	313	69.7833	34.7667	5.02	314	95.125	48.37	
5.02	B5-02	0	314	70.8000	38.3667	0.00	0	0.000	0.00	

Figure D.6. Partial listing of NDESWE.DAT file.

PERMANENT CURRENT FILE (PERMCURR.ALL)

Number of Header Records: 2 Length of Data Records: 18 bytes

TABLE D.8. Data record format specifications for permanent current file.

DATUM	FIRST BYTE	LAST BYTE	FORMAT
Node Number	1	5	I5
Current Direction	6	10	F5.0
Current Speed	11	16	F6.1
Carriage Control Characters (hex 0D0A)	17	18	A2

Perman	nent C	urrent	s	
num	Dir	spd (kn)	
1	45.	0.2	B2-04	
2	45.	0.2		
3	45.	0.2		
4	45.	0.2		
5	45.	0.2		
6	45.	0.2		
7	45.	0.2		
8	45.	0.2		
9	45.	0.2		
10	225.	0.1		
11	225.	0.1		
12	225.	0.1		
13	225.	0.1		
14	225.	0.1		
15	225.	0.1	S-01	
16	0.	0.1		
17	0.	0.1		
18	0.	0.1		
19	0.	0.1		
20	0.	0.1		

Figure D.7. Partial listing of PERMCURR.ALL file.

ICING FILE (ICING.AUG)

Number of Header Records: 2 Length of Data Records: 12 bytes

TABLE D.9. Data record format specifications for icing file.

DATUM	FIRST BYTE	LAST BYTE	FORMAT
Node Number	1	5	I5
Probability of Icing	6	10	F5.0
Carriage Control Characters (hex 0D0A)	11	12	A2

	Icing	(Aug)		
	num	용		
1	1	1.	B2-04	
Ì	2	1.		
	3	1.		*
	4	1.		
	5	1.		
	2 3 4 5	1.		
	7	2.		·
- 1	8	2.		•
	9	2.		
	10	2.		
	11	2.		
	12	3.		*
	13	3.		
	14	4.		
	15	4.	S-01	
	16	5.		
1	17	5.		
	18	6.		
	19	7.		
	20	8.		
	21	8.		
	22	7.		
1	23	6.		
	24	5.		
	25	5.	S-02	
	26	8.		
	27	10.		
İ	28	12.		
	29	15.		

Figure D.8. Partial listing of ICING.AUG file.

WIND FILES (WINDS.***)

Number of Header Records: 2 Length of Data Record: 93 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 D.10 specifies the format for each of these data records.

TABLE D.10. Data record format specifications for wind files.

DATUM	FIRST BYTE	LAST BYTE	FORMAT'	
Direction		1	7	A7
Number of Observ	vations	8	13	F6.1
Maximum Wi	nd	14	19	F6.1
Mean Wind		20	25	F6.1
	0 - 5 kn	26	31	F6.1
	6 - 10 km	32	37	F6.1
	11 – 15 kn	38	43	F6.1
	16 – 20 kn	44	49	F6.1
77. 10 1	21 – 25 kn	50	55	F6.1
Wind Speed	26 – 30 kn	56	61	F6.1
(percent of observations)	31 – 35 kn	62	67	F6.1
	36 – 40 kn	68	73	F6.1
	41 – 45 kn	74	79	F6.1
	46 – 50 kn	80	85	F6.1
	> 50 km	86	91	F6.1
Carriage Control Characte	92	93	A2	

PROBABIL	S) YTL) OF WI	ND SPE	ED (m/s)	AND	DIRECT	ION (de	eg), Al	PRIL					
DIR	N	MAX	MEAN	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	>50
1 B2-0	4													
000-045	11.8	22.5	7.5	3.1	6.3	1.8	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0
045-090	7.8	24.0	7.0	3.0	3.4	0.9	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0
090-135	9.7	25.9	8.6	2.2	4.8	1.5	0.9	0.3	0.1	0.0	0.0	0.0	0.0	0.0
135-180	12.9	28.2	8.3	3.5	5.3	2.7	1.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0
180-225	15.8	24.3	9.2	3.1	6.5	4.0	1.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0
225-270	14.9	25.8	8.9	3.3	6.2	3.4	1.8	0.2	0.1	0.0	0.0	0.0	0.0	0.0
270-315	13.9	29.0	8.8	2.9	6.7	2.4	1.2	0.6	0.1	0.0	0.0	0.0	0.0	0.0
315-360	13.1	23.8	8.1	3.7	5.7	2.3	1.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
2														
000-045	13.1	23.7	7.7	3.2	6.7	2.3	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0
045-090	7.4	24.3	6.9	3.1	2.6	1.1	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0
090-135	9.6	24.7	8.3	2.1	4.9	1.5	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
135-180	13.9	24.6	9.0	3.6	5.2	3.1	1.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0
180-225	14.6	28.5	8.8	3.2	6.5	2.9	1.7	0.1	0.1	0.0	0.0	0.0	0.0	0.0
225-270	14.6	24.2	8.3	4.0	6.1	2.8	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0
270-315	13.5	27.1	8.2	3.2	6.6	2.4	0.9	0.3	0.1	0.0	0.0	0.0	0.0	0.0
315-360	13.4	27.2	8.1	3.8	6.0	2.1	1.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0

Figure D.9. Partial listing of WINDS.APR file.

SNOW FILE (SNOW.APR)

Number of Header Records: 2 Length of Data Records: 9 bytes

TABLE D.11. Data record format specifications for snow file.

DATUM	FIRST BYTE	LAST BYTE	FORMAT
Node Number	1	3	I3
Probability of Snow	4	7	F4.0
Carriage Control Characters (hex 0D0A)	8	9	A2

Snow storms	
Apr. %	
1 5.	
2 5.	
3 6.	
4 6.	
5 7.	
6 7.	
7 8.	
8 8.	
9 9.	
10 10.	
11 10.	
12 10.	
13 11.	
14 11.	
15 12.	
16 12.	
17 13.	
18 14.	
19 14.	
20 15.	
21 14.	
22 13.	
23 12.	
24 11.	
25 10.	
26 11.	:

Figure D.10. Partial listing of SNOW.APR file.

WATER DEPTH FILE (WTR_DPTH.ALL)

Number of Header Records: 2 Length of Data Records: 14 bytes

TABLE D.12. Data record format specifications for water depth file.

DATUM	FIRST BYTE	LAST BYTE	FORMAT
Node Number	1	5	I5
Water Depth (m)	. 6	12	F7.0
Carriage Control Characters (hex 0D0A)	13	14	A2

DATA	WATER	_
NODE	DPTH (m)	
1	128.0	
2	200.0	
3	175.0	
4	105.0	
5	100.0	
6	130.0	
. 7	100.0	
8	100.0	
9	65.0	
10	60.0	
11	70.0	
12	56.0	
13	39.0	
14	34.0	
15	23.0	
16	13.0	
17	18.0	
18	30.0	
19	20.0	
20	26.0	
21	22.0	
22	24.0	
23	22.0	
24	25.0	
25	35.0	
26	38.0	
27	35.0	
28	40.0	
29	46.0	
30	36.0	
		_

Figure D.11. Partial listing of WTR_DPTH.ALL file.

APPENDIX E

OUTPUT FILE FORMATS

Appendix E.1. Output file for Option 0.

SUMMARY STATISTICS FOR 100 VOYAGES

number of voyages simulated = 100

month = ARRIL

direction = Hamburg to Bering Sea [W to E]

ship class = NORLISK

daily cost of cargo ship (USS) = 16450.00

daily cost of escort vessel (USS) = 16450.00

total cost of fees and tariffs (USS) = 11600.00

time step between dice rolls = 8.000

The transit route consists of the following legs:
1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33

	MIN	MAX	MEAN	VARIANCE	STANDARD
ELARSED TIME (hr) MEAN SPEED (kn) DISTANCE TRAVELLED (nm) ESCORT TIME (hr)	1795.11 61 11169.63 1569.46	2018.89 18.02 11169.65 1863.77	1894.18 5.90 11169.63 1725.56	1934.75 .02 .00 .3558.96	43.99 .14 .00 .59.66
HOURS WITH FOG PERCENT ALL HOURS WITH FOG FOG FACTOR	104.91 5.69	247.39 12.61 1.00	172.08	763.68 1.94	27.63 1.39
HOURS WITH ICING PERCENT ALL HOURS WITH ICING ICING FACIOR	00.	1.00	00.1	00.00	00.
HOURS WITH SNOW STORMS RAGING PERCENT ALL HOURS WITH SNOW SNOW STORM RAGE FACTOR	134.98	255.90 13.02 1.00	193.69 10.22	633.14 1.65	25.16 1.28 .01
PERCENT ALL HOURS WITH DARKNESS DARKNESS DACTOR	296.00 16.49	336.00 16.67 1.00	314.11 16.58 .98	56.97 00.	7.55
HOURS WITH WAVES PERCENT ALL HOURS WITH WAVES MEAN WAVE HEIGHT	117.76	279.98 14.75 16.20	162.03 8.57 1.02	694.39 2.10	26.35 1.45
PERMANENT CURRENT VECTOR WIND-INDUCED CURRENT VECTOR	50	1.30	.06	00.	.00
ICE FREE HOURS PERCENT HOURS ICE FREE ICE FREE DISTANCE (nm) PERCENT DISTANCE ICE FREE (nm)	117.76 6.02 1823.97 16.33	178.34 9.61 2683.03 24.02	148.43 7.85 2236.54 20.02	180.73 .65 30160.13 2.42	13.44 .81 173.67 1.55
TOTAL COST (US\$) COST PER HOUR (US\$) COST PER MILE (US\$)	11346397.00 742.87 120.54	1499782.00 750.04 134.27	1414304.00 746.69 126.62	2.00	30148.58 1.41 2.70

FOG STATISTICS for EACH IEG

	1		RAGE ATION	.00	0.24	1.36	4.80	8.59	9.58	6.26	8.12	4.31	6.07 1	9.63	1.80 1	6.65	6.98	2.90	3.68	2.97	1 91.9	6.38	9.19	7.31	7.35	7.49 [3.99	1 96.5	0.20	9.37	99.9	1 08.0	6.10	4.83	8.61	7.23	10 11 10 11
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	1	-	A AVE	<u> </u>		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	-	<u></u>	<u></u>	-	-		_	_		-	-	_		<u></u>	_	
The column The		G (nm)	STANDARI)0.	1 57.68	1 57.36	1 18.92	42.2	62.40	18.95	55.86	51.5	1 51.96	52.9	13.95	1 31.78	1 9.35	1 7.43	16.37	1 6.03	1 8.0	1 8.04	7.42	10.93	19.6	7.6	5.34	1 9.45	11.32	1 13.89	1 9.26	1 14.24	1 8.18	18.86	11.18	10.4	HERKER SE
Table Tabl		D WITH FO	VARIANCE	00.	3327.34	3289,62	357.88	1781.82	3894.31	360,55	3120.64	2661.87	2699.70	2807.80	195,73	1010.19	87.40	55,23	267.87	36.34	64,55	64.66	55.04	119,35	92.28	94.71	28.55	90.05	128.22	192.85	85.70	202.71	66.92	355,77	125.07	109.34	HERRESTER
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	H H H	AVELLE	ORM.	000.	,552	.525	.055	.616	479	189	.689	.569	.534	.487	.168	.147	.050	.083	.110	.103	.037	.148	- 089	.038	178	.236	.116	.044	.149	680.	,025	.087	.028	.135	.027	.025	HENNE
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	***************************************	PANCE TE	MEAN RAW N	.00	16.56	29.05	40.39	77.48	.91.52	39.76	.60,55	14.74	77.21	.63,85	35.86	56.89	16,60	16.21	31.73	19.85	14.76	14.30	14,54	20.13	9,01	14.42	16.83	19.05	35.47	28.65	17.71	15,33	16.39	27.77	14.89	19.23	
The color of the		DISJ	AXIMUM]	<u> </u>	_	_	-	_	_	_			_	_	_	_	_	_	_	_	_	-	_	_	_	_	_	_	_	_	_	-	_	_	_		
International Processes Marco Market Mar			MIMUMIN	tt	_	_	_	_	-	_	_	_	_	_	_	_	-		_	_		-		-													-
The color of the			GE I	- -	_	_	_	_	_	_	_	_	-	_	-	-	-	-	-	-	_	-	_	÷	_	-	-	<u></u>	<u>-</u>		-	_			_	_	**
The color of the			AVER		m -	1 4	1 2.	<u>س</u>	11.	4.	7.	9	4	- 80	-i -	.4	-	-i	1 2	_	-	i i	-i	_	- 2	τ -	_	1	1	1 2.	-	-	ر ا	т -	- 2	1	H H H
The color of the			STANDARD	.00	4.72	6.13	3.43	4.05	14.53	5.67	9.19	8.03	90*9	10.96	2.30	5.32	1.58	1.52	2.69	1.08	1.63	1.39	1.43	2.18	3.71	2.19	1.01	1.72	1.90	2,63	1.85	2.73	1.98	1.98	3.23	2,17	Hunnann
IENGTH TOTAL PASSES PERCENT MARANIMI RAW PASSES PERCENT MARANIMI PASSES PERCENT PASS		H FOG (hr.)	VARIANCE	00.	22.31	37.58	11.74	16.38	211.15	.32.20	84.41	64.42	36,68	120.19	5.31	28.28	2.51	2.32	7.24	1.16	2.66	1.94	2.04	4.77	13.77	4.80	1.02	2.95	3.61	6.92	3.43	7.43	3,91	3.94	10.42	4.70	
I.BNGTH TOTAL PASSES PERCENT		IME WIT	N NORM.	0000	.0448	.0455	.0100	.0555	0160.	.0524	.0830	6670.	.0520	.0940	.0314	.0242]	1 6800.	.0148	1 7810.	.0182	.0074	.0254	.0165	.0068	.0549	.0474	0209	.0075	1720.	.0200	.0047	.0156	.0055	.0272	.0080	.0053	
IENGTH TOTAL PASSES PERCENT	77.1	APSED T	MEA	00.	9.46	11.18	7.29	6.99	36.40	11.01	19,35	16.12	7.53	31.65	6.70	9.36	2.97	2.89	5.40	3.52	2.94	2.45	2.70	3.66	2.78	2.89	3.03	3.29	6.46	6.42	3,30	2.75	3.27	5.59	4.48	4.11	
Carrell Carr		TE -	MAXIMUM	00.	16.83	35,19	16.00	19.97	68.30	27.83	43.71	34.80	35.56	55,31	8.00	23.34	7.43	6.98	11.55	6.36	6.88	3,55	5.31	9.30	7.06	4.90	3.75	8.26	8.00 1	12.00 1	7.50	10.91	9.17	8.00 1	12.28	8.98	
LENGTH TOTAL PASSES PAS	********		INIMOM	00.	.71	1.31	.78	11.	4.51	.04	2.76	2.93	.27	4.00	.74	.43	.15	.39	.36	1.26	.74	90.	.65	.27	.44	.55	1.12	.07	4.00	3.58	.45	10.	.18	4.00	.02	.04	
LENGTH TOTAL PASSES PAS	-		RCENT!	.00.	1 00.8	1.00 1	1.00.1	1 00.9	1 00 8	12.00 1	1 00.00	18.00 1	1.00.1	00.00	8.00 1	12.00 1	1 00.8	1 00.0	9.00	1 00.6.	7.00	6.00	3.00	17.00 1	3.00	3.00	6.00	13.00 1	6.00	2.00 1	12.00 1	1.00	1 00.0	7.00	12.00	17.00	-
H-01 (~~) B1-01 B1-01 (~~) B4-04 B1-01 (~~) B4-04 B1-01 (~~) B5-02 B1-01 (~~) B5-02 B1-03 (~~) B1-03 B1-03 (_	SSESIPI		1 86	91 1	21 3	96	86	92	100 10	98	71	100 170	18	92	48 1	20 3	1.9	19	27 2	 9	13	37	<u>ო</u>	-	9	33 –	16	12	35	21	30	7	45 1	47 1	
H-01 (~~) B1-01 B1-01 (~~) B4-04 B1-01 (~~) B4-04 B1-01 (~~) B5-02 B1-01 (~~) B5-02 B1-03 (~~) B1-03 B1-03 (_	OTAL P	<u> </u>	100	1001	100	100	100	1001	1001	1001	100	100	1001	100	1001	1001	1001	100	100	100	100	1001	100	100	100	100	1001	100	100	1001	100	100	100	100	
H-01 (~~) B1-01 B1-01 (~~) B4-04 B1-01 (~~) B4-04 B1-01 (~~) B5-02 B4-04 (~~) B5-02 B4-03 (~~) B1-03 B4-04 (-	TI HISTER	50.14 1	11.32	15.88	32.34	1 77.52	98.66	10.13	33.01	11.81	14.65	36.62	13.04	37.05	33.06	35.27	39.01	93.36	99.88	96.34	53.71	35.06 1	50.65	51.01	44.94	36.45	37.80	20.67	07.81	76.73	91.60	05.64	57.73	71,34	×
H-01 (~~) B1-01 B1-01 (~~) B4-04 B1-01 (~~) B4-04 B1-01 (~~) B5-02 B4-04 (~~) B5-02 B4-03 (~~) B1-03 B4-04 (į		112	1 2.	- 5	1 7	H -	<u>—</u>	- 23	- 2	- 5	i –	<u>—</u>	- 23	_	_	<u>-</u>	- 5	- -	<u>~</u>	-	1	<u>-</u>	_	_	<u>-</u>		- 2	m —	- 7	-	<u></u>	7		7	-
H-01 () B1-01 () B1-01 () B1-02 () B1-03 (g D	-01	-04	-02	-02	-02	-03	-02	-03	-02	-02	-03	-07		via	02	01	01	05	02	05	0.5	90	05	70	07	07	60	10	60	12	17	ŭ	01	
H-01 H-01 B1-01 B1-01 B1-04 B2-02 B2-03 B2-01 B2			ID	(> B1																		_		~		~	~				_				٠.	>>	
				H-01	B1-01	B1-01	B1-01			B7-03	B4-04														S-05	S-06	N-05	S-06		N-07	N-07	5-07	S-09	N-10		N-10	
					7 2	 m	- 4	5 -	9	٦ -	 80	6.	10 1	11	12	_ =	14	15	16 1	17.1	18	19	70	21 1	22	73	24	25	1 56 1	27]	28 1	1 29	- e	31 -	32	33	111111

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	AVERAGE		00.	1 00.	1 00.	1 00.	1 00.	1 00.	1 00.	1 00.	- 00.	- 00.	- 00.	- 00.	.00	1 00.	1 00.	- 00.	00.	- 00.	- 00.	- 00.	- 00.	- 00	-00	.00	.00	.00	00.	- 00,	- 00.	- 00.	- 00.	- 00.	00.	2 6 11 11 11 11 11 11 11 11 11 11 11 11 1
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TRAVELLE	IN NORW	WILLIAM TO THE PROPERTY OF THE	000	000	000.	000	000	000	000	000.	000	000.	000	000	000	000	000	000	000	000	000	000.	000.	000.	000.	000.	000.	000	000	000.	000.	000	000	000.	000.	
DISTANCE TR	MEAN NA		00	00	00:	00	00	00	.00	00:	00:	00:	00	00	00:	00	00	00	00	00	00	.00	00	00:	00:	00:	00:	00:	00	00	00	00:	00	00	00	
DIST	MAYTMIN]	- HERENE	- 00.	1 00.	- 00	1 00.	1 00.	1 00.	1 00.	- 00.	1 00.	1 00.	1 00.	1 00.	- 00.	1 00.	00.	00.	.00	.00	00.	00.	00.	00.	- 80.	00.	00.	- 00	- 00.	- 00.	- 00.	- 00.	- 00	- 00.	- 00.	-
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************	AVERAGE	THE PERSON NAMED IN	1 00.	00.	.00	.00	00.	.00	.00	.00	.00	.00	.00	.00	- 00.	00.	00.	00.	00.	00.	00.	1 00.	1 00.	00.	00.	- 00	- 00.	- 00.	- 00.	.00	1 00.	00.	1 00.	00.	00.	HANKARA
жжиппектен (hr)	STANDARD	BERKERREE	.00	00.	00.	00.	00.	00.	00.	1 00.	.00	1 00.	.00	.00	.00	1 00.	.00	.00	.00	.00	1 00.	00.	00.	- 00.	00.	00.	00.	- 00.	. 00.	- 00.	00.	- 00.	00.	00.	.00	KARRESHAR
TH ICING (h			00.	00.	. 00.	. 00.	1 00.	00.	00.	00.	00.	00.	00.	00.	- 00.	00.	- 00-	00.	00.	- 00.	. 00.	1 00.	1 00.	. 00.	00.	00.	- 00.	- 8.	- 00.	- 00.	- 00.	1 00.	1 00.	. 00.	1 00.	
ELAPSED TIME WI	MEAN NOBM	ш	•	•	٠	0000.00.	•	0000 000			-	-	-	-	-	-	-	-	0000.00.	-	-															
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	- MINIMINIM	z chanana	.00	.00	.00	00.	- 00:	- 00.	00.	00.	1 00.	.00	1 00.	.00	1 00.	1 00	.00	1 00.	- 00	00.	1 00.	1 00.	00.	00.	00.	- 00.	1 00.	.00	1 00.	1 00.	.00	1 00.	00.	1 00.	- 00	-
	PERCENT!	Januario Januario	00.	00.	- 80	80.	00.	00.	.00	00.	.00	00.	00.	00.	- 00	00.	00.	00.	00.	.00	.00	.00	00.	00.	00.	00.	00.	00.	00,	00.	00.	.00	.00	00.	.00	********
	PASSES [#/ 10110 1 ===================================	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-	0	0	0	0	0	0	0	0	-	BERRITA
	TOTAL PASS		100	100	100	1001 .	100	1001	100	1001	1001	100	100	1001	100	100	100	100	100	100	100	100	1001	100	100	100	100	100	100	700	100	100	100	100	100	KHHHHH
	LENGIH	#	11260.14	1 211.32	245.88	732.34	125.77	1 399.86 1	1 210.13	1 233.01	1 201.81	1 144.65	336.62	213.04	1 387.05	1 333.06	1 195.27	1 289.01	1 193,36	1 399.88 1	1 96.34 1	1 163.71	1 535.06	50.65	61.01	144.94	1 436.45	1 237.80 1	1 320.67 1	1 707.81	1 176.73	591.60	205.64	557.73	171.34	BRHHHHH
			^	B1-01 <> B4-04	B1-01 <> B5-02	B1-01 <> B1-02	\	^!	B7-03 <> B1-02	B4-04 <> B6-03	B6-03 <> B7-02	^	B7-02 <> B7-03	B7-02 <> B2-01	<> S-01 via	B2-01 <> S-01 via B2	S-01 <> S-02	î	^ V	S-02 <> S-05	N-01 <> N-02	N-02 <> S-05	N-02 <> N-05	S-05 <> S-06	^ ! V	Ŷ	ĵ	^	Ŷ	?	S-07 <> S-09	Ŷ	N-10 <> S-12	S-12 <> Y-01	N-10 <> Y-01	
	1 221		1 1	2	3	4	- 50	9 -	1 1		- 6	10 1	11 -	12	13	14	15	16	17	18	19	20	21 1	22	23	24	25	26 1	27	28	29	30	31 –	32	33	-

SNOWSTORM STATISTICS for EACH LEG

-	RAGE	.00	1.43	31.29	7.89	3.88 [9.90	2.95	8.55	5.00	4.34	1.41	9.74	4.77	6.20	5.51	3.28	2.89	1.02	7.90	2.94	8.37	5.92	6.55	1.93	0.86	6.54	7.83	8.21	8.52	3.68	8.06	2.30	6.63	82200
) 1)	A AVE	<u> </u>				_	_	_	_		_		_	_	_	-	_	-	_		_	_	_	_	_	_	_	_	_	_	_	_	_	_	
TORMS (nr.	STANDARD	00	29,57	39.86	58.92	31.49	24.42	28.56	1 24.90	1 20.74	1 28.76	1 28.01	22.80	33.82	20.58	18.83	30.47	15.62	1 27.04	11.18	16.75	35.17	7.23	11.55	14.36	1 29.15	1 22.57	23.84	34.91	12.57	1 29.25	1 23.16	29.30	33.62	
TH SNOW ST	VARIANCE	.00	874.50	1588.83	3471.15	991.46	596.42	815,69	620.06	430.20	827.39	784.65	519.87	1143.87	423.71	354.47	928.65	243.96	730.89	124.98	280.67	1237,16	52.31	133,32	206.23	849,93	509.52	568.41	1218.44	158.04	855.55	536.39	858.47	1130.45	
LLED WI	IN I	000	169	.234	.149	.405	.100	.197	.155	169	.292	.123	.174	.133	960*	.151	177	.148	.135	.225	.180	.161	.270	.357	.183	139	186	113	.113	.121	.098	.185	.095	.108	[======
TRAVE	MEAN RAW NC	00,	35,65	57.64	108.93	50.89	39.81	41.33	36.12	34.14	42.19	41,32	37.07	51.43	32,10	29.50	51,03	28.58	54.17	21.65	29.48	86.34	13,66	21,78	26.46	60,71	44.13	38,07	80,20	21,37	57,79	37.95	52.89	83.19	******
ISTANCE	XIMUM	.00	12.26	179.89	17.20 11	15,13	12.44	14.89	18.48	1 05.86	1 76.08	35.41	16.37	11.32	4.49	90.02	54.07	72.59 1	10.19	55.83	14.68	15,33	10.01	51.01	1.58	13.89	16.52	39.46	33,38	30,16	11.48	19.51	74.85 1	35.04	
	IMUMI MA	11	_	.94 117	_	_	_	_	_	_	_	_	_	_	_	_		_	_	_	_	_	_	_		_	_	_	_	_	_	_	_		HHHH H
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	AVERAC DEVIATI		-	3,14	88	2.0	3.5	4.4	2.,	-		۳. ۳.		.4	2.8	2.7	3,5	2	е е	;;	1 2.1		1:	;	1 2.0	3.	5.	 		-	4.5	3.6	7.1	_ 	HHHHHH
(hr)	STANDARD DEVIATION	.00	2,12	3.74	10.92	2.56	4.04	5.51	3,16	2,11	4.18	4.93	3.91	5,62	3,63	3.40	5.19	2.82	5.10	1,92	3,41	6.41	2.03	1.72	2.51	5.35	3.89	4.88	65.9	2.24	5.66	4.94	9.04	7.22	
NOW STORMS	VARIANCE	.00	4.48	14.02	119.25	6.55	16.30	30,37	9.96	4.46	17.46	24.32	15.32	31,58	13.17	11.58	26.93	7.95	25.97	3.69	11.65	41.08	4.11	2.97	6.29	28.60	15.10	23.78	43.37	5.03	31.98	24.44	81.74	52.19	
WITH SI	V NORM.	0000	0141	0233	0274	.0347	0190	.0435	0181	.0287	0332	0232	0317	0226	0172	.0265 1	0303 1	0265 1	0255	0384	0354	0287	0612	0536	0314	0250	0330	0262	0211 [0217	0187 [.0423 [0280	1 7220	-
D TIME	MEAN NEAN	. 00	2.99	5.72	20.04	4.36	7.59	9.13	4.22	5.80	4.80	7.81	6.76	8.73	5.72	5.18	8.76	5.13	10.20	3.70	5.80	15,35	3.10	3.27	4.55	10.91	7.86	8.40	14,94	3.83	11.07	8.71	15.59	17.52	
ELAPSE	XIMOMIX	- 00.	8.00	14.69	52.00	8.00	1 00.91	24.11	12.23	9.04	1 00.97	3.83	1 00.9	30.20 1	1 92.03	13.16 1	1 00.82	13.09	1 96.95	9.46	1 00.81	32.04	10.60	9.13	10.39	32.90]	20.00 1	26.23 1	32.61	14.26	28,23	21.12	16.37]	34.96]	×
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	LENGTH TOTAL PASS (nm) PASSES w/SI				- 0	- 0		- 0		·· 0			-0	- 0							_ _ _	0 - 12	- 0	_	_	_	_	_	-	_	-	_		1 0	H
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		 1260.14	211.32	1 245.8	1 732.34	125.7	399.8	1 210.13	1 233.03	201.83	144.65	336.62	1 213.04	387.05	1 333.06	1 195.27	1 289.0	1 193.36	1 399.8	1 96.34	1.63.7	1 535.06	1 50.65	61.01	144.94	1 436.45	1 237.80	1 320.67	1 707.81	1 176.73	1 591,60	205.64	1 557.73	771.3	
		11-01													via B2																				HANNELL .
		1 "		B5-02	B1-05		► B7~03	▶ B1-02				B7-03	B2-01		- S-01 via	s-05	N-01	_		N-02		7				× S-07			N-10	S-09			× Y-01	× Y-01	
	a a	0.	01 ←→	01 <>	01 ♦	04 <>	-02 <>	03 <>	-04 <>	€03 <>	02 <>	02 <->	02 <>	01 ♦	01 ←→	S-01 <>	S-01 <>	B1-02 <>	S-02 <>	N-01 <>	N-02 <>	N-02 <>		S-06 <>	N-05 <>	<> 90-s	N-07 <>	N-07 <>	N-07 <>	S-07 <>	<> 60-s	^> 01-N	S-12 <>	V-10 <>	
			B1-01	B1-01	B1-01	B4~04	B5-02	B7~03	B4-04	B6-03	1 B5-02	I B7-02	1 B7-02	1 B2-01	<u>ш</u> 	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	S	-k	, BEBER
	TEG		7		1		9	1	8	ъ -	10	_	1 12	13	14	15	16	1 17	18	13	- 20	21	22	- 23	1 24	- 25	1 26	27	1 28	- 29	1 30	33	32	33	HEHER

DARMESS STATISTICS for EACH LEG

	AVERAGE DEVIATION	11 87	13.04	12.15 1	13.55	11.62	7.80	11.11	13.55	10.95	8.53	6.20	9.66	9.69	2.25	2.43	6.41	8.43	6.23	5.42	1 84 1	8.43	7.66 1	8.19	8.88	7.88	7.66	7.11	13.20	8.61	
SSS (nm)	STANDARD DEVIATION	14 95	14.70	15.44	16.38	14,60	10.33	13.91	16.26	13.34	10.10	7.94	10.35	10.69	3.24	ענייר ר	7.49	9.69	7.81	6.34	0.70	10.44	8.65	10.00	10.47	8.72	9.34	8.93	16.86	10.29	
TITH DARKNE	VARIANCE	223 39	216.16	238.43	268.33	213.12	106.71	193.59	264.33	177.96	102.00	62.99	107.16	114.23	10.47	57.19	56.17	93.83	61.00	40.16	80.33	108.96	74.74	100.001	109.52	76.00	87.15	79.82	284.32	105.90	
AVELLED V	EAN NORM.	i		-																				_	_		Ċ	·	Ċ	2 .168	
NCE IR	<u> </u>	151	24.5	1 40.3	30.1	1 66.3	1 34.3	36,3	31.8	55.1	34.8	64.4	1 56.4	32.0	47.9	67.5	1 18.3	1 28.2	1 88.7	13.4	124.0	74.1	38.6	1 52.7	1116.7	1 30.9	8.86	33.0	100.5	1129.9	-
DISTA	 	1185.90	54.05	75.77	1 60.70	1 95.44	63.95	75.89	63.79	92.57	1 52.86	84.96	172.08	1 56.14	58.75	89.82	28.26	1 46.33	1101.77	1 24.18	20.62	96.90	1 46.81	67.48	143.68	1 46.78	1119.62	1 60.76	1138.28	1151.50	
# F	MINIMUM	1114 00	1.07	98 54	1.87	28.54	2.05	2.43	0.33	121.71	12.91	44.64	39.10	14.15	41.26	54 96	.22	14.48	62.34	1.16	15 53	1 49.65	21.67	20.96	94.60	19.28	1 69.37	11.70	1 49.16	1105.52	
	AVERAGE DEVIATION	00	1.29	1.05	1.29	2.63	1.07	1.14	1.16	2.13	1.69	1.20	1.81	1.68	.38	100	1.07	1.53	.57	1.14	7.18	1.55	1.36	1.92	1.60	1.55	1.50	1.97	2.24	1.68	
(hr)	STANDARD	00	1.42	1.55	1.41	3.54	1.64	1.61	1.82	2.74	1.89	1.42	1.87	1.80	.55	27.1	1.23	1.66	.88	1.26	1.3b	1,11	1.55	2.58	1.72	1.69	1.70	2.53	3.02	1.86	
DARKNESS	VARIANCE	THE CO.	2.02	2.39	1,98	12.50	2.68	2.60	2.08	7.50	3,59	2.01	3.51	3.24	.30	3.00	1.52	2.77	.77	1.59	T. 83	2,92	2,39	99.9	2.95	2.87	2.89	6.39	9.12	3.45	
IME WITE	AN NORM.	12		•																					_	Ė		•	-	-	
APSED I	2	12.00	2.33	3.53	2.82	12.31	1 7.65	4.50	3.03	10.77	1 6.32	1 11.07	1 10.08	5.58	8.24	12 70	3.13	1 5.52	15.72	3.02	7.00	13.48	1 6.93	111.46	1 21.74	5.54	1 18.73	7,50	27.93	1 26.57	
Ĭ	MAXIMUM	12.00	4.00	08.00	4.00	1 20.00	12.00	8.00	8.00	16.00	12.00	12.00	12.00	8.00	10.83	18.00	4.00	1 8.00	17.49	4.00	9.00	16.00	9.46	19.87	1 24.00	1 8.00	1 23.30	12.00	1 40.00	31.61	
	 	12.00	80.	16.00	11.	1 4.00	1 4.00	.36	00.	4.00	4.00	1 8.00	1 8.00	4.00	8.00	71 17	.04	4.00	12.53	.03	5.0	11.96	1 4.00	1 8.00	1 20.00	1 4.00	16.00	4.00	1 24.00	24.00	
	PERCENT W/DARK	100.00	58.00	86.00	55.00	100.00	100.00	98.00	67.00	100.00	100.00	100,00	100.00	100.00	100.00	100	84.00	100.00	100.00	62.00	00.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
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		11260 14	211.32	1 245.88	125.77	399.86	210.13	233.01	144.65	336.62	1 213.04	387.05	1 333.06	1 195.27	1289.01	349 88	96.34	163.71	1 535.06	50.65	10.10	436.45	1 237.80	1 320.67	1 707.81	1 176.73	1 591.60	1 205.64	1 557.73	1771.34	
		V>	†	() ()	1	^- -	?	ĵ (? ?	1	B7-02 <> B2-01	<> S-01 via	<> S-01 via	\ \ \	ĵ,) (1	\>	ĵ	ĵ:	į į	1	N-07 <> S-07	^-	1	^ >	^	^>	^ >	1	
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	ELAPSED TIME WITH DARKNESS	ELAPSED TIME WITH DARKNESS (hr) DISTANCE TRAVELLED WITH DARKNESS (hr) DISTANCE TRAVELLED WITH DARKNESS (hr) LENGTH ITOTAL PASSES PERCENT MEAN MEAN STANDARD AVERAGE MENNIMUM MAXIMUM RAW NORM, VARIANCE DEVIATION DEVIATION MINIMUM MAXIMUM RAW NORM, VARIANCE	ELAPSED TIME WITH DARKNESS (hr)	ELAPSED TIME WITH DARKNESS (hr) DISTANCE TRAVELLED WITH DARKNESS (hr) DISTANCE TRAVELLED WITH DARKNESS (hr) DISTANCE TRAVELLED WITH DARKNESS (hr) LENGTH TOTAL [PASSES] PERCENT] MEAN STANDARD AVERACE HEALD MEAN STANDARD AVERACE HEALD MEAN MEAN	ELASEED TIME WITH DARKNESS (ht) DISTRACE TRAVELLED WITH DARKNESS (ht) LENGTH TOTAL PASSES PERCENT MEAN STANDARD AVERAGE MEAN VARIANCE DEVIATION BEVIATION BEVIATION MEAN WARTANCE DEVIATION MEAN MARTANCE DEVIATION MEAN WARTANCE DEVIATION MEAN MARTANCE MA	ELASED THE WITH DARKNESS (ht) DISTANCE TRAVELLED WITH DARKNESS (ht) LENGTH TOTAL PASSES PERCENT LENGTH TOTAL PASSES PE	IENGCH TOTAL PASSES PERCENT	Inviging Properties Prope	IENGER TOTAL PASSES PERCENT	I.ENGCH TOTAL PASSES PERCENT	TENGCH TOTAL PASSES PERCENT	IRNGCH IOPATA PRESES PERCENT NEAR NORM NORM NARIANCE DEVIATION DEVIA	INCOME PARKER P	I.ENGCHH TOTAL PASSES PERCENT	Tenger T	Table Total Passes Percent Febrea Fe	The color of the	Table Color Colo	The column Parkers P	Image: March March	The color of the	ELAPSED TIMES PARKINE PARKINES PARKI	The color of the	Table Tabl	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Table Property P	120 120	Column C	Column C	This collection This colle	The column The

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) 	AVERAGE	00.	00.	4.25	16,62	4.82	10.79	5.68	10.96	5,92	4.18	6.51	5.70	3.22	1.88	1.73	.43	.52	2.69	.50	1.74	2.30	1.71	.30	.39	3.38	. 93	9.30	3.28	1.17	3,16	8.98	12.49	5,32	HENCHWARE .
11 11 11 11 11 11 11 11 11 11 11 11 11	STANDARD DEVIATION	00.	00.	4.55	19.02	.5.46	14.80	7.26]	12.03	8.57	5.75	9.70	7.69	4.65	2.30	2.17	.58	.68	3.47	1 69.	2.20	3.09	2.10	.50	1 75.	4.26	2.94	12.76	4.24	1.55	3.93	11.74	16.05	6.91	- maxeliana
H ICE (hr)	VARIANCE	00.	00.	20.67	361,58	29.81	218,98	52.70	144.77	73.43	33.08	94.09	59.21	21.67	5.28	4.73	.33	.47	12.02	.48	4.84	9.53	4.40	.25	.33	18.16	8.62	162.82	17,99	2.41	15.45	137.86	1 257.49	47.75	
вы тіме мі	MEAN RAW NORM.	i -		-:	:		77.29 .1933	-:	•	•	21.53 .1488	•	•	•	•	•	•	•	•	•	•	•	•	•	٠	•	•	٠	•	•	12.73 .1905	-	•	.05 .2062	
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		1260.14	211.32	245.88	732.34	125.77	399.86	1 210.13	1 233.01	1 201.81	144.65	1 336,62	213.04	387.05	1 333.06	1 195.27	1 289.03	1 193,36	399.88	1 96.3	1 163.73	1 535.06	1 50.65	1 61.03	1 144.94	1 436.45	1 237.80	1 320.67	1 707.81	1 176.73	1 591,60	1 205.64	1 557.73	1 771.34	- norsere
	\$E \$E \$E	H-01 <> B1-01	B1-01 <> B4-04	B1-01 <> B5-02	ĵ	;	ţ	B7-03 <> B1-02	B4-04 <> B6-03	B6-03 <> B7-02	B5~02 <> B7-02	B7-02 <> B7-03	B7-02 <> B2-01	B2-01 <> S-01 via B3	B2-01 <> S-01 via B2	S-01 <> S-02	S-01 <> N-01	?	ĵ	?	N-02 <> S-05	N-02 <> N-05	S-05 <> S-06	S-06 <> N-05	N-05 <> N-07	S-06 <> S-07	N-07 <> S-07	N-07 <> S-09	N-07 <> N-10	S-07 <> S-09	S-09 <> S-12	N-10 <> S-12	S-12 <> Y-01	N-10 <> Y-01	
			7	<u>س</u>	4	 	- - -	7		- - -	10	11	12	13	14	15	16 1	17 1	18	19	1 20	21	1 22 1	23	1 24	1 25 1	26 1	27	28	29	30	띪	32	33	

| AVERAGE | | DEVIATION | (EL) |STANDARD | |DEVIATION| BREAKER ESCORT 0.00 49. 4275. 2009. ICE TRAVELLED WITH DISTANCE 732. 95. 95. 2399. 1270. 1174. 213. 213. 337. 213. 339. 96. 195. 50. 50. 61. 732. 1 95. 1399. 140. 20. 96. 144. 1336. 1213. 1322. 175. 175. 1289. 96.. 1163. 1515. 150. 144. 116. 1320. 176. 176. 176. 176. 176. 176. DEVIATION 16.625 10.625 10.625 10.74 10. AVERAGE STANDARD (hr) .00 19.025 11.1444 BREAKER ESCORT 20.00 20.61 361.88 25.30 25.30 38.03 38.03 38.03 94.14 94.14 5.47 12.02 4.84 4.84 4.84 17.73 17.73 17.73 17.21 17. VARIANCE ICE 0000 0000 1852 1219 MEAN IW NORM. WITH RAW TIME ELAPSED W/ESCRT | MINIMUM | .00 26.06 98.56 12.09 12.09 12.13 10.14 17.79 11.79 25.18 11.79 26.35 26.35 56.35 69.07 69.07 88.11 5.68 | 23.63 | 71.45 | 41.10 | 41.10 | 58.56 | 120.78 | 30.09 | 104.08 | 27.02 00 PERCENT PASSES W/ESCT TOTAL 1260.14 211.32 221.32 732.34 1125.77 399.86 399.86 399.86 333.06 195.27 195.27 195.27 195.27 195.31 195.27 195.31 LENGIH (ma) B3 via B7-03 B2-01 H-01.

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						EL	ELAPSED TRAVEL	TIME (hr)		1	1	DISTANCE T	RAVELLED (r	(nm)	
		LENGTH	TOTAL			MEAN	_	STANDARD	AVERAGE [MEAN		STANDARD	AVERAGE
LEG	QT	(nm)	PASSES	MINIMOM	MAXIMUM	RAW NORM	A, VARIANCE	DEVIATION	DEVIATION	MINIMUM	MAXIMUM	RAW NORM.	VARIANCE	DEVIATION	DEVIATION
-	H-01 <> B1-01		100	75.29	80.59	77.81 .06			96.	1260.14	1260.14	1260.14 1.000	00.	8.	00.
7	B1~01 <> B4-04	1 211.32	1000	1 12.43	20.72	15,31,072	-	_	1.72	1 211.32	211.32	211.32 1.000	00.	- 00.	- 00.
г -	B1-01 <> B5-02	245.88	100	14.27	1 38.67	18.95 .07	71 28.14	1 5.30	3.22	245.88	245.88	Н	1 .00	- 00.	00.
1 4	B1-01 <> B1-02	732.34	100	98.56	166.04	-	_	_	16.62	732.34	1 732.34	Н	1 .00	00.	- 00.
10	B4-04 <> B5-02	1125.77	100	7.26	21.05	•	_	-	2.18	125.77	125.77	Н	00·	1 00.	- 00.
9	B5-02 <> B7-03	399.86	100	24.31	1108.85	73.81 .1846	_	_	14.41	399.86	1 399.86 1	399.86 1.000	00.	1 00.	.00
7	B7-03 <> B1-02	1 210.13	100	1 25.81	99.89	•	_	-	1 5.68	210.13	1 210,13 1	H	00· I	1 00.	00.
8	?	1 233.01	100	115,39	49.05	-	_		1 6.72	1 233.01	1 233.01 1	Н	00.	1 00.	00.
9	B6-03 <> B7-02	1 201.81	100	12.53	51.56	-	_	_	1 8.14	201.80	201,81	Н	00.	- 00.	.00
1 10	B5-02 <> B7-02	144.65	100	1 8.03	37.95	-	_	_	3.67	144.65	144,65	Н	00.	- 00.	.00
11	B7-02 <> B7-03	336.62	100	1 21.96	82.42	-	_	-	1 9.74	336.62	336,62	-	00.	1 00.	1 00.
1 12	Ŷ	1 213.04	100	21.42	69 09	•	_		1 5.70	213.04	1 213.04 1	H	00.	1 00.	1 00.
13	Ŷ	1 387.05	100	1 54.08	72.35	-	_	_	3.22	387.05	387.05	-	00° -I	- 00.	1 00.
14	B2-01 <> S-01 via B2	1 333.06	100	1 56,35	66.38	•		_	1.87	1 333.06	1 333.06	Н	1 .00	.00	1 00.
135	Ŷ	195.27	100	1 30.38	40.59		-	_	1.73	1 195.27	1 195,27	Н	00° I	1 00.	- 00
16	į	1 289.01	100	1 48,11	51.42	-	_	_	.43	1 289.01	1 289.01	Н		.00	.00
1.	^	193,36	100	32.82	36.69	-	_	_	1 .52	193.36	193.36	Н	00.	.00	.00
18	?	399.88	1 100	1 69.07	86.53	-	_	_	1 2.69	38.88	399.88		00.	- 00.	.00
13	?	F 96.34	100	14.96	18.49	-	<u> </u>	-	1 .50	96.34	1 96.34 1	Ч	00.	- 00.	1 00.
1 20	^	163.71	100	1 28.05	1 38.79	-	_	_	1.74	163.71	1 163.71	Н	00.	- 00.	.00
21	1 N-02 <> N-05	1 535.06	100	1 85.63	1104.28	-	_	_	1 2.30	1 535.06	1 535.06		00.	- 00.	- 00
- 22	ţ	1 50.65	100	1 8.14	1 17.98		<u></u>	_	1.71	1 50.65	1 50.65		00.	- 00:	- 00.
73	ĵ	1 61.01	100	8.21	1 10.89		_	_	.30	10.19	1 61.01	Н	00.	- 00.	- 00:
1 24	ĵ	144.94	100	23.63	1 27.07		_	_	.39	144.93	144.93	-	00-	- 00°	- 00,
1 25	Ŷ	436.45	100	71.45	97.26		_	<u></u>	3,38	436.45	436.45		00·	- 00.	- 00.
56	?	1 237.80	100	41.10	63.51		_	-	.93	237.80	237.80	Н	00.	- 00.	- 00.
27	1 N-07 <> S-09	1 320.67	100	58.56	1107.60		_	-	1 9.30	1 320.67	320.67	-	00.	- 00:	- 00.
- 58	^	1 707.81	1700	121.24	1143.67	131.14 .18	_	_	3.28	1 707.81	1 707.81	Н	00.	- 00.	.00
29	?	1 176.73	100	30.09	39.37		_		1.17	1 176.73	176.73	-	00·	- 00.	- 00
30	^V	1 591.60	100	1105.62	1123.57		_	_	3.16	1 591.60	1 591.60	-	00.	1 00.	00.
31	N-10 <> S-12	1 205,64	100	27.02	1 72.87		_		8.98	1 205.63	1 205.63	Н	00.	. 00.	- 00.
32		1 557,73	100	1138.54	1228.75	167.26 .29	_	_	12.49	1 557.73	557.73	Н	00.	1 00.	00.
33	1 N-10 <> Y-01	1 771.34	100	1146.00	1184.58	159.05 .20	62 47.75	_ :	5.32	1 771.34	771.34	Н	00.	1 00-	00.
			-	_ 4				ARTHUR DESCRIPTION OF THE PROPERTY OF THE PROP	-					***************************************	

Appendix E.2. Output File for Option 1.

COMPAND INDE VARIABLES:

month = 4 = APRIL
print option = 1 = Sunmary Stats Sent to Print File
print option = 1 = Sunmary Stats Sent to Print File
direction of voyages = 1 = Hamburg to Bering Sea [W to E]
number of voyages = 1 = Hamburg to Bering Sea [W to E]
ship class = 1 = NORILISK
cost per day = \$ 16450.00(US)
tariffs (per transit) = \$116000.00(US)
cost of escort per day = \$.00(US)
maxhum speed = 17.0 Knots
time step between dice rolls = 8.00 hr

The transit route consists of the following legs:
1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33

SUMMARY OF DATA LOGGED FOR TRANSIT I

	4000000	######################################	NAMES OF THE PROPERTY OF THE P	никиминини	annumentanna and an annumentan	
	MINIMOM	MAXIMUM	MEAN	VARIANCE	STANDARD	DEVIATION
Free control of the c	. 58	1.00	96.	10.	.09	90.
Icing Factor	1.00	1,00	1.00	00.	. 00*	00.
Snow Storm Factor	.85	1.00	1.00	00.	.02	00 .
Darkness Factor	.62	1.00	66.	00.		
Permanent Current Vector (kn)	50		90.	.03		
Wind-Induced Current Vector (kn)	-1.24	.74	03	.03	.16	.12
Ship Speed (kn)	24	17.44	5,74	9.57	3.09	1.64
. Wave Height (m)	.21	1.89	.59	.15		.28
Wind Speed (kn)	2.50	52.50	7.70	25.47	5.05	3.16
THE STATES OF ST	HHHHHHHHHH	HILLIER	#=####################################			

							ICE	ICE CONCENTRATION (%)	TION (%)	***************************************	n n n	IC	ICE THICKNESS (cm)	SS (cm)	
	FOG		FOG ICING WAVES SNOW STM DARKNESS ICE FREE	SNOW STM	SNOW SIM DARKNESS ICE FREE	ICE FREE	20	50	75	100	100 ICE FREE	<120	150	210	>240
H .	20.18		.00 133.71 229.10 324.00 133.71	229.10	324.00	133.71	00.	.00	10.13	1803.25	.00 133.71 229.10 334.00 133.71 .00 .00 10.13 1803.25 133.71 72.81 853.61 618.48	72.81	853.61	618.48	268.48
PERCENT OF TRANSIT TIME TOTAL DISTANCE ENCOUNTERED (nm) PERCENT OF TRANSIT DISTANCE	11.31 1421.10 12.72	000	.00 6.87 11.77 16.64 6.87 .00 2073.51 1143.79 1810.06 2073.51 .00 18.56 10.24 16.21 18.56	1143.79	16.64 1810.06 16.21	6.87 2073.51 18.56	00.00	00.	.52 96.91	.52 92.61 6.87 96.91 8999.22 2073.51 .87 80.57 18.56	6.87 2073.51 18.56	3.74 557.75 4.99	3.74 43.84 31.76 557.75 4296.35 3306.11 4.99 38.46 29.60	31.76 3306.11 29.60	13.79 1 935.92 1 8.38
TOTAL NUMBER OF SEGMENTS PERCENT OF SEGMENTS	t i	000.	34 59	34 59 59 6.17 10.71	137	34 6.17	00.	00.	.36	515 93.47	46 0 34 59 137 34 0 0 2 155 34 24 230 197 66 8.35 .00 6.17 10.71 24.86 6.17 .00 .00 .36 93.47 6.17 41.74 35.75 11.98	4.36	230	197 35.75	11.98

And so on for each voyage in the simulation. This output includes and is followed by that from Option 0.

Appendix E.3. Output file for Option 2.

COMMAND LINE WARLABLES:
neath - 4 - AFMIL
point old - 2 - Detailed Output Sent to Print File
plint old of 'Oyoges - 1 - Hamburg to Bering Sen [W to Z]
number of 'Oyoges - 1 - Hamburg to Bering Sen [W to Z]
number of 'Oyoges - 1 - Hamburg to Bering Sen [W to Z]
number of 'Oyoges - 1 - Howilist
eath of 'Oyoges - 1 - Howilist
cost per day - 8 - 15650.00(US)
cost of Secort par day - 8 - 00(US)
zanhum speed - 17.0 knots
tir: step between dice zolls - 8.00 hr

The transit route consists of the following legas: 1, 2, 3, 4, 5, 6, 7, 8, 5, 10, 11, 12, 13, 14, 15, 16, 17, 18, 15, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33 TABLE OF VALUES USED FOR EACH SEGNENT OF TRANSIT 1

	(hr) TOTAL	8.00 16.00 18.46	20.00 24.00 25.40	37.40 44.00 48.00 56.00	65.13 68.00 70.07	72.00
	TOTAL SEGMENT LEG	8.00 15.00 18.46	20.00 24.00 29.40	37.40 44.00 48.00 56.00 57.13	65.13 68.00 70.07	72.00
	ELAPS					
-	TALIS	137.93 8.00 272.97 8.00 315.19 2.46	341.30 1.54 394.24 4.00 485.93 5.40	621.5918.00 735.7516.60 769.3014.00 907.8018.00	1066.68 8.00 1115.63 2.87 1141.07 2.07	1165.4211.93
	(mm) T		.,,,		1700 0000	
	DISTANCE (nm)	272.93 272.97 915.18	394.24	621.59 735.75 769.30 907.80	066.68 115.63 141.07	165.42
	DIS		26.11 52.94 91.69	.56 .56 .56	00 0 1,00 17,41 43,8 139,26 1066,68 .00 0 1,00 17,08 43,8 48,55 1115,63 .00 1 .73 12,26 43,8 25,44 1141.07	.73 12.65 70.2 24.35 165.42 1.00 17.04 70.2 54.72 260.14
į	1 sec	91135		16.96 25.01135.66 17.30 25.0114.15 8.39 25.0 33.56 17.31 25.01138.50	8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	22
	- 1	4 3 4 2 8 3 4 2 9 3 4 2	16.91 355.2 13.23 355.2 16.98 355.2	61 25 01 25 91 25 11 25	555	5 1 7 0 T
d	3348	.00 0 1.00 17.19 342.9 137.93 .00 0 1.00 16.88 342.9 135.04 .00 0 1.00 17.19 342.9 42.22	.00 0 1.00 16.91 355.2 .00 1 .78 13.23 355.2 .00 0 1.00 16.98 355.2	00 0 1.00 16.96 25.0 135.66 100 11.00 11.11.15 11.11	117.4	112.6
	DARK N FACT	1.00	0 1.00 1 .78 0 1.00	0 1.00 0 1.00 1 .54 0 1.00	1.00	1.00
1	IRS 17/	000	0 7 0	00100	000	001 1 .73
	ESCOP Y/N I					
1	VEC	888	800	0100.	0000	88
	YECIFTCH DETH HELD YECIYAN HRSIYAN FACTISPECDIHEAD ISEGMENT	888	888	88888	888	88
	a sid					
TOWNS OF THE PARTY IN THE PARTY	IGHT H RGT	.24 100, 250, 1.05 .12 100, 250, .63 .19 100, 250, .63	631		63	.31 100. 200. 1.05
1	HAVE HEIGHT FTCH DPTH HGT	. 250. . 250.	. 265. . 265.	140.	130.	. 200.
177	ECLET	.241100. .121100.	091100. 061100. 021100.	.04 100. 140. .30 100. 140. .15 100. 140. .31 100. 140.	.411100. 130. .081100. 130.	.31/100.
5	WIND CUR	19 -	7.5 112.5 .1905 100. 265. 7.5 67.5 .1905 100. 265. 2.5 247.5 .0602 100. 265.	31	2 61	
Correct	WIND CUT	22.5 12.5 37.5	7.51112.5 .19	57.5 37.5 22.5	37.5	67.5
1	<u>-</u>	7.5[112.5 .19 - 7.5[337.5 .19	7.511	1.00[337.5 2.5[157.5 0604]100. 1.00[157.5 17.5]337.5 44 30]100. 1.00[22.5 7.5[202.5 1915]100. 1.00[202.5 12.5] 22.5 31 31]100.	1.00[202.5 17.5] 22.5 .44 .41[100. 1.00[157.5 7.5]337.5 .19 .08[100. 1.00[337.5 7.5]157.5 .1908[100.	2.51
YOU !	FACTI DIR SPD	1.00 202.5 1.00 292.5 1.00 157.5	92.5	27.5 57.5 22.5 02.5 1	02.5 1 57.5 37.5	47.5 1
1000	, kcr	90.1	1.00[247.5	60000	888	.0012
ABLE OF VALUES USED FOR EACH SECTION OF INNIGHT	3 3 3	NOME 1.00 202.5 12.5 22.5.31 24 100. NOME 1.00 202.5 7.5 112.5.19 -12 100. NOME 1.00 157.5 7.5 337.5 19 .19 100.	0. NONE 1.00[292.5 0. NONE 1.00[247.5 0. NONE 1.00[67.5	NONE 1.00[137.5 2.5]127.5, 0604[100.140. NONE 1.00[157.5 17.5]137.5, 4401[100.140. NONE 1.00[157.5 17.5]137.5, 1401[100.140. NONE 1.00[252.5 2.5] 3.1]100.140. NONE 1.00[252.5 2.5] 22.5, 31 .31[100.140. NONE 1.00[252.5 2.5] 22.5 .31 .31[100.140.	NONE 1.00[202.5 17.5] 22.5 .44 NONE 1.00[157.5 7.5]337.5 .19 NONE 1.00[337.5 7.5]157.5 .19	0. NONE 1.00[247.5 12.5] 67.5 .31 .
מחשים מל אינים	ICE TRIC PE	999	:::			
٠,	CONC			99999	:::	• •
	I TO FOG ICING SNOW SIM ICE LOW LEG.PT SEG X/N FACT X/N FACT CONG THIC PRES	0 1.00	0 1.00	1.00	0 1.00	1.00
		1.00 0 1.00 0 1.00 1.00			000	1.00 0 1.00 0 1.00
	I ICING	0 1.00	0 1.00	0 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0	1.00 0 1.00 1.00 1.00 1.00	0 1.0
-	FOG I	1.00	988	88888	888	88
1	24/3	000				00
1	- FT	1 2 2 1	1.02 1 1.02 2 1.02 3	1.0311	041	05 1
1	1 TO	7.5000 1.011 1 0 7.5000 1.011 2 0 7.5000 1.011 3 0	4.50001 1.02 1 0 4.50001 1.02 2 0 4.50001 1.02 3 0	4.0000 1.03 1 0 4.0000 1.03 2 0 4.0000 1.03 3 0 4.0000 1.03 4 0 4.0000 1.03 5 0	222	111
1	NO.	7.5000 1.01 1 0 7.5000 1.01 2 0 7.5000 1.01 3 0	4.50001		12.5000 1.04 1 0 1.00 0 1.00 12.5000 1.04 2 0 1.00 0 1.00 12.5000 1.04 3 0 1.00 0	20,00001 1.05 1 0 1.00 0 1.00 0 1.00 20.00001 1.05 2 0 1.00 0 1.00 0 1.00
	T T	1.00 54.0000 7.5000 1.011 1 0 1.00 54.0000 7.50001 1.011 2 10 1.00 54.0000 7.50001 1.011 3 1 0	1.01 55.0000 4.50001 1.021 1 1 0 1.01 59.0000 4.50001 1.021 2 1 0 1.01 59.0000 4.50001 1.021 2 1 0	1.02 61.8333 4.00001 1.031 1 0 1.02 61.8333 4.00001 1.031 2 0 1.02 61.8333 4.00001 1.031 3 0 1.02 61.8333 4.00001 1.031 4 0 1.02 61.8333 4.00001 1.031 4 0	1.03 68.3330 12.5000 1.04 1 0 1.03 68.3330 12.5000 1.04 2 0 1.03 68.3330 12.5000 1.04 3 0	500 2
	FROH F LAT	1.00 54.0000 1.00 54.0000 1.00 54.0000	1.01 55.0000 1.01 59.0000 1.01 59.0000	1.02 61.8333 1.02 61.8333 1.02 61.8333 1.02 61.8333	1.03 68.3330 1.03 68.3330 1.03 68.3330	1.04 70.7500
	LZG. PI	1.00	1.0	9.0.1	1.0	0.1
		•				

33.38 66.8317 189.3817 33.391 1 | 0 1.00 | 0 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 0 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.00 | 10 1.

And so on for each voyage in the simulation. This output includes and is followed by that from Options 1 and 0.

APPENDIX F

OUTPUT SUMMARIES: ALL LEGS

Table F.1. Fog statistics for all legs of NSRSIM2A.

					_																	_															_
	% Total Transit	Distance with	0.0	0.5	0.7	Ξ.	0.5	1.0	5.0	9.0	8.0	9.0	6.0	0.7	0.7	0.5	0.3	8.0	0.4	0.4	6,3	0.4	1.4	0.1	0.2	0,3	0.7	63	9.0	1.5	0.3	1.3	0.4	6.0	1.3	21.2	9.0
	Mean Distance with		0.0	27.1	31.6	19.8	42.9	27.5	26.9	28.1	43.7	45.4	28.8	34.3	19.8	16.3	18.1	29.6	25.4	11.9	33.2	24.8	28.7	30.2	36.8	26.7	18.8	15.0	20.8	23.2	17.6	23.6	23.3	18.6	19.5	838.1	25.4
	% Total	Transit Time	0.00	57.35	77.60	145.21	53.94	109.96	56.46	65.47	88.21	65.67	97.04	73.06	76.71	54.43	35.26	85.52	49.06	47.57	32.02	40.52	153.79	15,32	22.47	38.74	82,09	35.58	09'99	164.45	31.11	139.84	47.94	103.69	150.30	2362.98	71.61
##	% Total	Transit Time	0.0	0.3	0.4	1	6.3	0.5	0.4	6,0 ,	0.4	0.3	0.5	0.4	1.3	0.7	0.7	1.1	0.5	9.0	6.3	0.4	1,5	0,2	0.2	0,4	1.4	9.0	1.2	2.1	5.0	1.9	8.0	1.7	1.8	24.6	0.7
August Transit		% Time with	0.0	34.5	38.1	23.5	53.0	33.3	31.2	34.7	33.8	55.6	5.53	42.2	22.7	21.4	22.0	31.8	29.3	13.5	36,5	26,3	31.1	33.7	41.9	29.9	22.6	18.7	24.3	26.1	21.0	26.8	27.5	21.8	23.1	987.2	29.9
Aı	Mean Time	with Fog This	0.0	4.7	6.2	19.8	4.4	8.8	6.5	5.5	7.	5.2	8.7	6.2	21.9	12.0	12.3	18.3	9.3	10.3	5.6	6.8	26.6	2.8	3.6	7.4	24.1	10.6	20.1	36.6	8.8	32.4	14.0	28.6	31.0	425.0	12.9
	Mean Travel		78.3	13.6	16.3	84.2	8.3	26.3	20.9	15.8	13.3	9.4	277	14.6	5'96	55.9	55.8	57.4	31.8	76.1	15.3	25.9	85.4	8.3	8.6	24.6	106.8	56.4	82.7	140.0	41.9	120.9	50.7	131.2	134.3	1729.5	52.4
	Total	Voyages with	0	312	284	440	248	380	351	394	250	212	105	178	497	492	468	473	494	491	452	479	200	159	320	473	200	386	478	200	473	200	420	200	200	12915	391
		Lee No.	1	2	m	4	5	9	7	× 0	ν;	01:	= :	77	E	14	15	16	17	18	19	20	21	22	23	24	. 25	26	27	28	59	30	31	32	33	TOTAL	MEAN
		Leg Length	1260.14	211.32	245.88	732.34	125.77	399.86	210.13	233.01	201.81	144.65	330.02	213.04	387.05	333.06	195,27	289.01	193.36	399.88	96,34	163.71	535.06	50,65	61.01	144.94	436.45	237.8	320.67	707.81	176.73	591.6	205.64	557.73	771.34	11169.68	338.48
	% Total Transit	Distance with Fog	0.0	111	1.1	0.3	0.7	1.8	0.4	3 :	T:0	8.0	1 :	60	5.0	0.2	0.1	0.3	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0,3	0.2	0.2	0.1	0.2	0.2	0.1	0.2	14.5	0.4
	% Distance	with Fog this Leg	0.0	58.7	51.7	5.0	63.9	49.4	19.0	71.6	7.70	5,30	8.8	7.51	14.2	5.8	8.5	12.0	8.5	4.0	17.3	9.6	3.6	29.7	29.1	10.3	3.7	14.1	8.3	2.7	9.4	3.0	12.7	2.8	2.3	710.4	21.5
	Mean Distance with	Fog This Leg (nm)	0.00	124.13	127.16	36.28	80.41	197.54	36.98	166.76	00,01	84.39	104.30	33,42	54.77	19.41	16.61	34.79	16.41	16,03	16.68	15,65	19.01	14.78	17.78	14.95	15.98	33.42	26.77	19.04	16.54	17.78	26.04	15.88	17.74	1615.93	48.97
+-	% Total	Transit Time with Fog	0.0	5.0	9.0	0.4	9.4	1.9	9.0	1.0	8.0	4.0	0. C	£,0	0.5	0.2	0.2	6.3	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.3	0.3	0.2	0.2	0,2	6.3	0,3	0.2	13.1	0.4
April Transit		with Fog This %Time with Leg (hr) Fog This Leg	0.0	65.4	6.7.5	5.0	70.2	50.5	24.7	73.5	8770	04.0	49.9	77	13.5	5.8	8.6	12.2	8,3	3.9	17.1	9.5	3.6	29.4	27.5	10.2	3.6	14.1	8.0	2.7	9.1	3.1	13.4	2.9	2.3	747.0	22.6
	Mean Travel Mean Time	with Fog This Leg (hr)	0.0	10.2	11.1	6.7	7.3	36.6	11.5	1.40	14.9	7.8	31.0	8,0	9.1	3,5	3.0	0.0	2.8	3.0	2.8	3.1	3.4	3.3	2.5	2.6	2.9	0.9	5.5	3,5	2,9	3,5	6.1	4.9	3.7	246.9	7.5
	Mean Travel	Time This	77.8	15.7	19.2	134.0	10.4	72.5	46.3	26.8	1.62	12.8	02.1	38.4	67.0	59.6	34.3	49.4	34.0	74.8	16.5	32,3	95.7	11.2	9.2	25.0	80.7	42.5	68.1	130.7	31.9	113.3	45.4	166.3	158.6	1886.5	57.2
	Total	Voyages with	0	498	453	96	475	497	461	200	401	412	965	T 6	482	192	82	87	78	114	43	47	158	14	17	53	158	80	47	186	119	161	20	203	212	7016	213
		Leg No.	_	2	æ	4	'n	9	7	× c	n <u>s</u>	9 :	= 5	7 :	E :	14	15	91	17	18	19	20	21	22	23	24	25	56	27	28	. 29	20	31	32	33	TOTAL	MEAN

Table F.2. Icing statistics for all legs of NSRSIM2A.

	. ——																	_								_		_		_			_				
	% Total	Transit	Distance with Toing	0.0	0.0	0.0	1.5	0.0	6.0	9.0	0.0	0.0	0.0	0.8	0.7	7.0	, co	0.7	0.4	8.0	6.0	0.5	2.4	0.2	0.2	0.4	6,0	0,3	6.0	2.9	6,0	1.8	0.7	6.0	1.8	21.3	9.0
		% Distance	with leing This Leg	0.0	0.0	0.0	22.6	0.0	24.8	29.4	0.0	0.0	0.0	25.9	30.0	7.0	£ 6	28.9	23.1	23.0	32.7	33.6	49.3	42.5	40.4	29.0	22.6	15.3	30.9	46.1	19.8	33,2	36.2	17.3	26.0	710.4	21.5
	Mean	Distance with	loing This Leg (mm)	0	0	0	165.45	0	99.36	61.85	0 (0 •	0	87.16	887/	66.6.2 16.3.4	18.78	83.45	44.64	92.16	31.47	55.01	263.81	21.54	24.62	42.05	98.63	36.3	98.16	326,22	35.08	196.33	74.44	96.33	200.63	2374.68	71.96
nsit			Transit Time with Joing	0.0	0.0	0.0	1.1	0.0	0.4	6.4	0.0	0.0	0.0	0.3	e -	9.0	£.0	T.0	0.4	1.0	6.3	5.0	2.4	0.2	0.2	0.4	1.3	0.5	1.5	3.8	0.5	2.3	1.1	1.3	2.1	24.1	0.7
August Transit		1	% Tume with Joing This Leg	0.0	0.0	0.0	23.1	0.0	24.4	30.4	0.0	0.0	0.0	25.8	7.75	ग ८	6.6	28.7	23.1	21.7	32.8	33.7	49.1	42.7	39.8	29.1	21.8	15.7	30.7	46.9	19.7	32,9	36.4	17.0	26.7	707.5	21.4
	I		with Joing This Leg (hr)	0.0	0.0	0.0	19.4	0.0	6.4	6.4	0.0	0.0	0 1	7.5	÷ ;	4. 6	5.5	16.4	7.3	16,5	5.0	8.7	41.9	3,5	3.4	7.2	23.2	×	25.4	9.59	8,3	39.8	18.5	22.3	35.8	416.5	12.6
		Mean Travel	vith loing (hr)	78.3	13.6	16.3	84.2	8.3	26.3	20.5	15.8	13.3	4.2	277	0.4.0	55.9	55.8	57.4	31.8	76.1	15.3	25.9	85.4	8,3	8,6	24.6	106.8	26.4	82.7	140.0	41.9	120.9	50.7	131.2	1343	1729.5	52.4
			oral voyages with Icing	0	0	0	430	0	231	782	0 0	o (0 6	502	17	186	305	468	481	499	436	494	200	380	360	480	200	305	493	200	472	200	476	200	200	10246	310
			Leg No.	1	7	m	4	5	y t	- 0	× c	ν :	3:	Ξ 5	7 5	7 7	: 21	16	11	18	19	20	21	22	23	24	25	8 1	27	78	53	20	31	35	#	TOTAL	MEAN
		÷	(um)	1260.14	211.32	245.88	732,34	125.77	399.86	210.13	233.01	201.81	144.05	79.055	387.05	333.06	195.27	289.01	193.36	399,88	96.34	163.71	535.06	50.65	61.01	144.94	436.45	237.8	320.67	707.81	176.73	591.6	205.64	557.73	771.34	11169.68	338.48
	% Total	Transit	Distance with Icing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		% Distance	with long This Leg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0,0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Distance with		0.00	000	0.00	00.00	0.00	0.00	0.00	0.00	0.00	000	000	000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0,00	0.00	0.00	0.00
sit		% Total		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
April Transit		100 miles		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	. 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0:0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Mean Time	_	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0, 0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-			vith Icing (hr)	77.8	15.7	19.2	134.0	10.4	72.5	40.3	20.8	1.4.1	12.8	179	70.4	59.6	34,3	49.4	34.0	74.8	16.5	32.3	95.7	11.2	9.2	25.0	80.7	47.5 5 :	68.1	130.7	31.9	113.3	45.4	166.3	158.6	1886.5	57.2
		. 115	otal voyages with Icing	0	0	0	0	0	0 0	- (-	-			5 6		. 0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	٥	0	٥
		Ē	Leg No. w	-	7	m	4	ς,	७।	(× 0	ъ S	3:	Ξ 5	7 5	17	: 23	16	11	18	19	20	21	22	73	24	25	26	27	78	53	30	33	32	33	TOTAL	MEAN

Table F.3. Snow storm statistics for all legs of NSRSIM2A.

			-	_							_	_				_		_			_	_	_	_	_		_		_				_		_	-		_
	% Total	Transit Distance with	Snow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0,0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		% Distance with Snow	This Leg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mean	Distance with Snow This	Leg (nm)	0.00	00.00	0.00	0.00	0.00	0.00	0.00	0.00	00.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	000	0.00
nsit	:	% Total Transit Time	with Snow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
August Transit		% Time with Snow This	Leg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Mean Time with Snow		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Mean Travel Total Voyages Time This Leg	(hr)	78.3	13.6	16.3	84.2	8.3	26.3	20.9	8.51	13.3	9.4	22.2	14.6	96.5	55.9	55.8	57.4	31.8	76.1	15.3	25.9	85.4	8.3	9.8	24.0	100.8	56,4	82.7	140.0	41.9	120.9	50.7	131.2	1343	1729.5	52.4
		Total Voyages	with Snow	0	0	0	0	0	0	0 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0 (o (o '	0	0	0	0	0	0	0	0	0	0
			Leg No.	1	7	6	4	δ	9	7	× 0×	6	10	11	12	13	14	15	16	17	18	19	20	21	22	23	7.7	3	76	27	78	53	30	31	32	33	TOTAL	MEAN
		Leg Length	(mu)	1260.14	211.32	245.88	732.34	125.77	399.86	210.13	233.01	201.81	144.65	336.62	213.04	387.05	333.06	195.27	289.01	193.36	399.88	96.34	163.71	535.06	50.65	61.01	144.94	430.45	237.8	320.67	707.81	176.73	591.6	205.64	557.73	771.34	89'69111	338.48
	% Total	Transit Distance with	Snow	0.0	6.3	0.4	1.0	0.4	0.4	0.4	6.0	0.4	5.0	0.4	6.3	5,0	6.3	6.3	0.4	0.3	5.0	0.2	0.3	0.7	0.1	0.2	0.2	ر د	0.4	0.4	0.7	0.2	5.0	0.3	5.0	0.8	13.1	0.4
		% Distance with Snow	This Leg	0.0	17.2	19.1	15.6	31.9	10.7	20.7	14.8	23.5	37.5	11.8	15.8	15.1	9.6	14.9	17.0	15.4	14.0	21.6	17.5	15.3	31.8	33.1	18.9	12.8	18.1	12.3	10.4	13.3	9.3	17.8	10.9	11.7	559.4	17.0
	Mean	Distance with Snow This	Leg (nm)	00.0	36.45	46.99	114.19	40.12	42.73	43.40	34.44	47.33	54,29	39.58	33.60	58,30	32.02	29.06	49.27	29.74	55.94	20.82	28.72	81.76	16.11	20.20	27.33	66.55	43.10	39.57	73.74	23.55	54.90	36.61	60.75	90.53	1461.13	44.28
sit		% Total Transit Time	with Snow	0.0	0.2	0.2	1.1	0.2	0,4	0.5	0.2	0.3	0.3	0.4	0.3	5.0	6.3	6.0	0.4	0.3	9.0	0.2	0.3	9.0	0.2	0.2	0.2	C'0	0.4	0.4	0.7	0.2	9.0	0.4	6.0	1.0	13.7	0.4
April Transit		% Time with Snow This	Leg	0.0	21.0	22.5	15.7	37.5	11.2	20.8	15.0	23.3	43.2	12.0	15.7	15.0	5.7	14.8	17.0	15.4	14.0	21.6	17.6	15.3	31.2	32.8	18.8	17.7	18.1	12,3	10.4	13.4	9.3	18,2	10.7	11.7	577.7	17.5
		Mean Time with Snow	This Leg (ltt)	0.0	3,3	4.3	21.0	3.9	8.1	9.6	4.0	5.6	5.5	7.5	6.0	10.1	5.8	5.1	8.4	5.3	10.5	9'6	5.7	14.6	3.5	3.0	4.7	10.3	1.7	8.4	13.5	4,3	10.6	8,3	, 17.7	18.6	258.3	7.8
		Mean Travel Mean Time Potal Vovages Time This Leg with Show	(F)	77.8	15.7	19.2	134.0	10.4	72.5	46.3	26,8	24.1	12.8	62.1	38.4	67.0	59.6	34.3	49.4	34.0	74.8	16.5	32.3	95.7	11.2	9.2	25.0	20.7	42.5	68.1	130.7	31.9	113.3	45.4	166.3	158.6	1886.5	57.2
		Total Vovages	with Snow	0	144	116	486	82	227	369	151	121	. 64	211	150	427	417	403	330	407	493	302	433	496	238	224	371	490	281	316	498	345	492	290	496	200	10370	314
			Leg No.	-	7	ю	4	S	9	7	∞	6	01	=	12	13	14	15	16	17	18	61	20	21	22	23	24	3	56	27	28	29	8	31	32	33	TOTAL	MEAN

Table F.4. Darkness statistics for all legs of NSRSIM2A.

	% Total	Transit Distance with	LAIK 13	0.2	0.4	6.0	0.3	. 5.0	n 0	03	0.3	0.4	6,3	5.0	0,4	0,2	0.4	0.3	0.5	0.2	0.2	8.0	0.1	0,2	0.2	9.0	6.3	0.4	1.0	0.2	8.0	6,3	0.7	0,1	15.1	0.5
		% Distance with Dark	11.9	9.1	17.7	14.2	25.8	14.7	10.7	18.5	26.1	13.3	17.7	14.2	13.5	13.6	15.3	15.2	15.2	20.3	16.0	15.9	30.7	29.4	15.7	14.6	13.8	14.3	15.1	14.6	15.2	14.0	14.6	14.8	550.8	16.7
	Mean	Dark This Leg	150.58	19.14	43.40	104,33	32.45	58.61	24.23	37.42	37.75	44.67	37.64	54.92	45.08	26.55	44.29	29.38	60.97	19.57	26.20	85.21	15.53	17.92	22.80	63.68	32.79	45.95	107.21	25.81	18'68	28.73	81.69	114.50	1683.78	51.02
nsit	, m	% Total Transit Time	0.7	0.1	0.2	8.0	0.2	0.3	0.2	0.2	0.2	0.2	0.2	6.0	0.5	5.0	9.0	0.3	0.7	0.2	0.2	8.0	0.2	0,2	0,2	1.0	5.0	8.0	1.3	0.4	. 1.2	0.5	1.3	13	17.2	0.5
August Transit		% Time with	15.3	12.0	21.5	16.9	31.3	17.9	22.8	23.0	31.9	16.4	22.7	17.0	16.5	16.6	16.8	16.7	16.7	21.2	16.7	16.6	33.1	32.4	16.6	16.6	16.8	16.6	16.6	16.7	16.7	16.4	16.7	16.7	638.4	19.3
	Mean Travel	Dark This Leg	12.0	1.6	3,5	14.2	2.6	4.7	9.E	3.1	3.0	3.6	33	16.4	9.2	9.2	9.6	5.3	12.7	3.2	43	14.2	2.8	2.8	4.1	17.7	9.5	13.8	, 23.3	7.0	20,2	8.3	21.9	22.4	297.4	9.0
		wear Layer Line With Total Voyages Time This Leg Dark This Leg % Time with with Dark On? Dark This Le	78.3	13.6	16.3	84.2	83 33	26.3	15.8	13.3	9.4	22.2	14.6	96.5	55,9	55.8	57.4	31.8	76.1	15.3	25.9	85.4	8,3	8.6	24.6	106.8	56.4	82.7	140.0	41.9	120.9	50.7	131.2	134.3	1729.5	52.4
1		Total Voyages	200	202	479	200	252	385	431	301	315	498	316	200	200	200	200	200	200	398	200	200	255	261	498	200	200	200	200	200	200	200	200	200	14591	442
		I.eg No	1	2	m	4	יטי	0 1	~ 00	6	10	Π	12	13	14	15	16	17	28	61	70	71	22	23	74	25	76	27	78	83	8	31	33	8	TOTAL	MEAN
		Leg Length	1260,14	211.32	245.88	732.34	125.77	399.86	233.01	201.81	144.65	336.62	213.04	387.05	333.06	195.27	289.01	193.36	399.88	96.34	163.71	535.06	50.65	61.01	144.94	436.45	237.8	320.67	707.81	176.73	591.6	205.64	557.73	771.34	11169.68	338.48
	% Total	Distance with	1.4	0.2	0.3	1.1	(J.	9.0	0.3	0.3	6.3	0.5	0.3	9.0	0.5	0.3	0.4	0.3	9.0	0.2	0.2	0.8	0.1	0.2	0.2	0.0	0.4	0.5	1.1	0.3	6.0	0.3	6.0	1.2	16.4	0.5
	9. Diefmos	with Dark	12.1	12.1	15.0	17.2	25.6	16.1	16.5	16.5	23.3	16.2	16.3	16.6	16.9	16.6	16.7	16.8	16.7	19.9	16.9	16.8	27.2	30.8	16.8	16.5	16.9	16.6	16.7	16.6	16.7	16.6	17.6	16.7	583.1	17.7
	Mean	Dark This Leg	152.49	25.58	36.78	126.25	32.24	24.44	38,34	33,20	33.74	54.52	34.82	64.30	56.30	32,40	48.21	32.55	06.99	19.17	27.73	29.63	13.76	18.81	24.28	72.22	40.25	53.24	118.35	29.26	99.02	34.05	97.92	128.97	1834.47	55.59
ısit	7. Tafet	% 10ta Transit Time with Dark	0.6	0.1	0.2	1.2	0.2	9.0	0.2	0.2	0.2	9.0	6,3	9.0	0.5	0,3.	4.0	0.3	0.7	0.2	0.3	0.8	0.2	0.1	0.2	0.7	0.4	9.0	1.2	0.3	1.0	0.4	2.1	1.4	16.9	0.5
April Transit		% Time with	15.4	14.8	16.7	17.2	28.4	16.6	17.4	18.0	26.4	16.7	16.4	16.6	16,9	16.5	16.7	16.8	16.6	19.8	16.8	16.7	26.4	30.6	16.7	16.4	16.9	16.7	16.6	16.4	16.7	16.6	16.7	16.7	597.5	18.1
	Access Throng Throng	Mean Line with Dark This Leg (hr)		2.3	3,2	23.0	3.0	12.0	4.7	4.3	3.4	10.4	6.3	11.2	10.1	5.6	8.2	5.7	12.4	3.3	5.4	16.0	3.0	2.8	4.2	13.3	7.2	11.4	21.8	5.2	19.0	2.6	27.7	26.5	319.6	2.6
	, my	Ineal Layer Total Voyages Time This Leg	77.8	15.7	19.2	134.0	10,4	25	26.8	24.1	12.8	62.1	38.4	67.0	59.6	34.3	49.4	34.0	74.8	16.5	32.3	95.7	11.2	9.2	25.0	80.7	42.5	68.1	130.7	31.9	113.3	45.4	166.3	158.6	1886.5	57.2
		otal Voyages	200	346	434	200	304	200	700	64	325	200	200	200	200	200	200	200	200	418	200	200	306	290	200	200	200	200	200	200	200	200	200	200	15368	466
	_	Tot	1	2	e	4	5	9 t	~ «	. 0	10	п	12	13	14	15	91	17	18	61	20	21	22	23	24	25	56	27	28	53	30	31	32	33	TOTAL	MEAN

Table F.5. Sea-ice cover statistics for all legs of NSRSIM2A.

		_													_											_				_		_	_	_
	% Total Transit Distance with Sea Ice	0'0	0.0	0.0	9.9	0.0	0.0	00	0.0	0.0	0.0	1.9	2.7	2.6	1.7	2.6	1.7	3.6	6.0	ៗ :	4.8	0.5	5,0	1 6	1.2	2.9	6.3	1.6	53	1.8	5.0	6.9	6.69	7.1
	% Distance with Sea Ice This Leg	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	76.5	87.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	92.1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	2322.8	70.4
	Mean Distance with Sea Ioe This Leg (un)	0.00	0.00	0.00	732.34	0.00	0000	0.00	0.00	0.00	0.00	213.04	296.26	292.06	195.27	289.01	193.36	399.88	96.34	163.71	535.06	50.65	56.19	436.45	237.80	320.67	707.81	176.73	591,60	205.63	557.72	771.34	7803.55	7,797.7
ısit	% Total Transit Time with Sea Ice	0.0	0.0	0.0	8,9	0.0	0.0	00	0.0	0.0	0.0	2.1	5.2	3.1	3.2	3.3	1.8	4.4	6'0	1.5	49	0.5	5.0	t. 6	33	4.8	8.1	2,4	7.0	2.9	7.6	7.8	93.5	7.8
August Transit	% Time with Sea Ice This Leg	0.0	0.0	0.0	183.8	0.0	142.9	0.0	0.0	0.0	0.0	242.4	92.8	95.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	96.4	100.0	100,0	100,0	100.0	100.0	100.0	100.0	100.0	100.0	2653,6	80.4
	Mean Tíme with Sea Ice This Leg (ht)	0.0	0.0	0.0	154.8	0.0	0.0	0.0	0.0	0.0	0.0	35,5	89.5	53.3	55.8	57.4	31.8	76.1	15.3	25.9	85.4	8,3	83	106.8	56.4	82.7	140,0	41.9	120.9	20.7	131.2	134.3	1616.6	49.0
	Mean Travel Total Voyages Time This Leg with Sea Ice (itr)	78.3	13.6	16.3	84.2	8.3	20.3	15.8	13.3	9.4	22.2	14.6	5'96'	55.9	55.8	57.4	31.8	76.1	15,3	25.9	85.4	8.3	8.6	106.8	56,4	82.7	140.0	41.9	120.9	50.7	131.2	134.3	1729.5	52.4
	Total Voyages with Sea Ice	0	0	0	171	0 (o <u>E</u>	0	0	0	0	30	200	200	200	200	200	200	200	200	200	200	500	900	200	200	200	200	200	200	200	200	10874	330
	i Leg No.	_	2	m	4	'n	0 1	- 00	6	10	11	12	EI	14	15	16	17	18	19	70	21	77	8 3	7 7	36	27	28	53	30	31	32	33	TOTAL	MEAN
	Leg Length	1260.14	211.32	245.88	732,34	125.77	210.13	233.01	201.81	144.65	336.62	213.04	387.05	333.06	195.27	289.01	193.36	399.88	96.34	163.71	535.06	50.65	61.01	44.94	237.8	320.67	707.81	176.73	591.6	205.64	557.73	771.34	11169.68	338.48
	% Total Transit Distance with	0.0	0.0	1.8	9.9	5,0	9.6	60	1,0	1.3	3.0	1.9	3.5	3.0	1.7	2.6	1.7	3.6	6.0	1.5	4.8	0.5	0.5	J 6	77	2.9	6.3	1.6	5,3	1.8	5.0	6.9	83.8	7.5
	% Distance with Sea Ice This Leg	0.0	0.0	82.9	100.0	41.5	100.0	42.3	57.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	2924.3	88.0
	Mean Distance with Sea Ice This Leg (nm)	00'0	0.00	203.81	732,34	52,14	210.13	98.52	116.44	144.65	336,62	213.04	387.05	332,98	195,27	289.01	193,36	399.88	96.34	163.71	535.06	50.65	61,01	744.95 436.45	237.80	320,67	707.81	176.73	591.60	205.63	557.72	771.34	9362,55	783.71
ısit	% Total Transit Time with Sea Ice	0.0	0.0	1.7	7.1	0.4	0.4 2.6	6.0	1.2	1.2	3,5	2.0	3,6	3.2	1.8	2.6	1.8	4.0	6.0	1.7	5.1	9.0	5.0	J 4	23	3.6	6.9	1.7	0.0	2.4	8.8	8.4	96.0	7.7
April Transit	% Time with Sea Ice This Leg	0.0	0.0	170.0	100.0	81.2	1000	64.0	96.2	177.7	105.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100,0	1000	100.0	100,0	100.0	100.0	100.0	100.0	100.0	100.0	3199.7	97.0
	Mean Time with Sea Ice This Leg (tr)	0.0	0.0	32.7	134.0	8.4	7.97	17.2	23,2	22.8	65.6	38.4	67.0	59.6	34.3	49.4	34.0	74.8	16.5	32,3	95.7	11.2	9.2	1.08 7.08	42.5	68.1	130.7	31.9	113.3	45.4	166.3	158.6	1811.1	54.9
	Mean Travel Total Voyages Time This Leg with Sea Ice (tr.)	77.8	15.7	19.2	134.0	10,4	77.7 46.3	26.8	24.1	12.8	62.1	38.4	67.0	59.6	34.3	49.4	34.0	74.8	16.5	32.3	95.7	11.2	9.2	80.7	42.5	68.1	130.7	31.9	113.3	45.4	166.3	158.6	1886.5	57.2
		0	0	46	200	130	461	464	322	107	458	200	200	200	200	200	200	, 500	200	200	200	200	500	900	200	200	200	200	200	200	200		_	424
	Leg No.	1	7	m	4	ς, ι	0 1	- ∞	6	21.	=	12	Ħ	14	15	16	17	18	61	20	21	77	5 73	3, 5	78	27	28	53	23	33	32	33	TOTAL	MEAN

Table F.6. Icebreaker escort statistics for all legs of NSRSIM2A.

_					_				_						_						_								-			_	_	_
	% Total Transit Distance with Escort	0.0	0.0	0.0	9.9	0.0	0.0	7 0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	2.6	9.0	1.7	5'0	1.0	3.0	0.3	E.0	3 =	2.1	2.9	2.8	0.4	2,3	1.8	1.2	2.5	36.0	1"1
	% Distance with Escort This Leg	0.0	0.0	0.0	100.0	0.0	0.0	200	0.0	0.0	0.0	0.0	0.0	11.3	10.4	100.0	37.1	46.5	56.2	70.2	62.1	57.2	4,4 4,0	27.9	100.0	100.0	44.2	23.6	44.1	100.0	24.5	35.6	1213.9	0,00
	Mean Distance with Escort This Leg (nm)	0.00	0.00	00.0	732,34	0.00	00.0	900	0.00	00.00	00'0	00'0	00'0	37.63	20.23	289.01	71.66	185.78	54.15	114.91	332.37	28.96	52.62	121.84	237.80	320.67	312.97	41.79	260,85	205.63	136.41	274.85	4018.83	141.10
ısit	% Total Transit Time with Escort	0'0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6,0	0.2	2.5	0.7	1.8	5.0	1.0	3.0	0.3	7.0	1,3	3.1	4.0	3.1	0.5	2.5	2.4	1.5	2.6	45.4	F**
August Transit	% Time with Escort This Leg	0.0	0.0	0.0	225.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.6	5.2	76.4	39.2	40.3	56,9	67.2	60.4	58.7	0.64 0.02	21,7	96.4	84,3	37.8	19,5	36.5	81.6	20.1	33.3	1345.6	2,00
	Mean Time with Escort This Leg (ltt)	0.0	0.0	0.0	189.5	0.0	0.0 3.6.6	0.0	0.0	0.0	0.0	0.0	0.0	5.9	2.9	43.8	12.5	30.6	8.7	17.4	51.6	6.9	4.4 2.0 2.0	23.2	54.3	2.69	52.9	8.2	44.1	41.4	26.3	44.7	785.8	2
i	Mean Travel Firne This Leg (Itr)	78.3	13.6	16.3	84.2	8.3	20.5	15.8	13.3	9.4	22.2	14.6	96.5	55.9	55.8	57.4	31.8	76.1	15.3	25.9	85.4	E.8	0.0 24.6	106.8	56.4	82.7	140.0	41.9	120.9	50.7	131.2	134.3	1729.5	1 14 1
	Mean Travel Fotal Voyages Time This Leg with Escort (hr.)	0	0	0	95	0 (۰ ر	; 0	0	0	0	0	0	418	124	246	495	200	496	200	200	437	705	498	38	170	200	465	200	131	200	200	244	
	Leg No.	-	7	m	4	v, v	9 1	- 00	6	10	=	12	13	14	15	16	17	18	61	50	21	77	2 2	23	56	2.1	28	53	33	31	32	33	TOTAL	114000 00.1
	ŧ.	1260.14	211,32	245,88	732,34	125.77	00,666	233.01	201.81	144.65	336.62	213.04	387.05	333,06	195.27	289.01	193.36	399.88	96.34	163.71	535.06	30.65	144 94	436.45	237.8	320.67	707.81	176.73	591.6	205.64	557.73	771.34	11169,68	21 22 22
	% Total Transit Distance with Escort	0.0	0.0	1.8	9.9	6,0	0.0	6.0	1.0	1.3	3.0	6.1	3.5	3.0	1.7	2.6	1.7	3.6	6.0	<u>.</u>	8,4	5,0	3 =	3.9	2.1	2.9	6.3	1.6	5.3	1.8	4.9	6.9	84.0	i
	% Distance with Escort This Leg	0.0	0.0	82,9	100.0	75.6	0.001	41.4	56.9	100.0	100.0	100.0	100.0	6'66	26.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.66	8.66	100.0	100.0	6.66	100.0	7.66	100.0	98.6	100.0	2952.5	44.25
	Mean Distance with Escort This Leg (nm)	0.00	0.00	203.81	732.34	95.13	208.50	96.47	114.78	144.65	336.62	213.04	387.05	332,66	194.61	289.01	193.36	399.88	96.34	163.71	534.90	50.65	144 93	435.41	237.80	320.67	706.98	176.73	589.62	205.63	550.10	771.34	9387.08 284.46	2 2 2 2
##.	al Time	0.0	0.0	1.7	7.1	0.8	1.4.	6.0	1.2	1.2	3.6	2.0	3.6	3,2	1.8	2.6	1.8	4.0	6.0	1.7	5.1	0.6] <u>-</u>	4.3	2.3	3.6	6.9	1.7	0.9	2.4	8.7	8.4	96.2	, in
April Transit	, % Time with Escort This Leg	0.0	0.0	170.0	100.0	145.9	106.0	62.7	95.4	178.6	107.9	100.6	100.0	6.66	99.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1000	9.66	100.0	100.0	8.66	100.0	5.66	98.1	5.86	100.0	3261.0	200
	H	0.0	0.0	32.7	134.0	15.2	£//	16.8	23.0	22.9	67.0	38.6	67.0	59.6	34.1	49.4	34.0	74.8	16,5	32.3	95.6	11.2	75.0	80.4	42.5	68.1	130.4	31.9	112.8	44.6	163.9	158.6	1815.0	2,7,7
	Mean Travel Total Voyages Time This Leg with Escort (hr)	77.8	15.7	19.2	134.0	10.4	C77/	892	24.1	12.8	62.1	38,4	0.79	59.6	34.3	49.4	34.0	74.8	16.5	32.3	95.7	11.2	2.6	80.7	42.5	68,1	130.7	31.9	113.3	45.4	166.3	158.6	1886.5	4.1.5
		0	0	46	200	9	422 500	433	314	84	411	482	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	479	200	200	13711	
	No.	_	7	м	4	S	0 (- cc	0	20	11	12	13	14	15	16	17	18	19	20	71	22	5 5	25	56	27	28	53	30	31	32	33	OTAL	TVT.

APPENDIX G

OUTPUT SUMMARIES:

NORTH AND SOUTH ROUTES

Table G.1. Fog statistics for a 500-voyage simulation between Murmansk and the Bering Strait.

	HIGH-	HIGH-LATITUDE APRIL TRANSIT (Legs 5, 6, 7, 17, 19,	APRIL TRAI	NSIT (Legs	5, 6, 7, 17, 1	-	21, 24, 28, and 33)						HIGH-LATI	TUDE AUG	HIGH-LATITUDE AUGUST TRANSIT	SIT		
						Mean										Mean		
	Total	Mean Travel	Mean Time	% Time with	% Total	Distance		% lotal	-		Total	Man Train			Total	Distance	2	% Total
	Vovades	Time This		Foo This	Transit Time	This I ad	,	Distance	- Leg	-	Vovades	Time This			Trancit Time	Thir Log	70 Distance	Lighten
Leg No.	with Fog	Leg (hr)	This Leg (hr)	Leg	with Fog	(nm)	This Leg	with Fog	(mn)	Leg No	with Fog	Leg (hr)	This Leg (hr)	Leg	with Fog	(nm)	This Lea	with Foo
2	475	10.4	7.3	70.2	1.2	80.41	l	2,5	125.77	co.	248	8.3			0.9	53,94	42.9	1.7
9	497	72.5	36.6	50.5	6.2	197.54		6.2	389.86	9	380	26.3			1.8	109,96	27.5	3.5
7	461	46.3	11.5	24.7	6.	39.98		1.3	210.13	_	351	20.9			6.1	56.46	26,9	1.8
17	78	34.0	2.8	8.3	0.5	16.41		0.5	193.36	17	494	31.8			1.9	49.06	25.4	1,5
19	43	16.5	2.8	17.1	0,5	16.68		0.5	96.34	6	452	15.3			7	32.02	33.2	1.0
77	158	95.7	3.4	3.6	9.0	19.01		9.0	535.06	21	200	85.4			5.5	153,79	28.7	4.8
24	53	25.0	2.6	10.2	0.4	14.95		0.5	144.94	24	473	24.6			1.5	38.74	26.7	1.2
78	186	130.7	3.5	2.7	9.0	19.04		9.0	707.81	78	200	140.0			7.5	164,45	23.2	5,2
33	212	158.6	3.7	2.3	9.0	17.74	-	9.0	771.34	33	. 500	134.3			6.4	150.30	19.5	4.7
TOTAL	2163	589.7	74.1	189.6	12.6	421.76		13.2	3184.61	TOTAL	3898	487.0			27.9	808.72	254.1	25.4
MEAN	240	65.5	8.2	21.1	1.4	46.86	- 1	1.5	353.85	MEAN	433	54.1			3.1	89.86	28.2	2.8
	I OW-I AT	OW-LATITUDE APRIL TRANSIT (Legs 5, 10, 12, 14, 15,	IL TRANSIT	. (Legs 5, 10	12.14.15	18. 22. 25	29.30. and	132)					FITA I-MO	TUDE ALIG	OW-I ATITUDE AUGUST TRANSIT	<u> </u>		
						Mean		,							,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	Moon		
						Distance		% Total								Distance		LetoT %
	Total	Mean Travel	Mean Time	% Time with	% Total	with Fog	% Distance	Transit	Lea		Total		Mean Time	% Time with	% Total	with Foo	% Distance	Transit
	Voyages		with Fog	Fog This	Transit Time	This Leg	with Fog	Distance	Length	-1	Vovages		with Foo	Fod This	Transit Time	This led	with Foo	Distance
Leg No.	with Fog		This Leg (hr)	Leg	with Fog	(mu)	(nm) This Leg with Fo	with Fog	(mu)	Leg No	with Fog	Leg (hr)	This Leg (hr)	Leg	with Fog	(mn)	This Leg	with Fog
ည	475	10.4	7.3	70.2	1.2	80.41	63.9	2.5	125.77	2	248		4.4	53.0	0.7	53.94	42.9	1.7
10	412	12.8	8.2	64.0	ل ن	84.39	58.3	2.6	144.65	유	212		5.2	55.6	0.8	65.67	45.4	2.0
12	61	38.4	5.8	15.2	6.0	33.42	15.7	1.0	213.04	12	128		6.2	42.2	1.0	73.06	34.3	2.3
14	192	59.6	3.5	5.8	0.5	19.41	5.8	9.0	333.06	4	492		12.0	21.4	1.9	54.43	16.3	1.7
15	82	34.3	3.0	8.6	0.5	16.61	8,5	0.5	195.27	15	468		12.3	22.0	2.0	35,26	18.1	Ţ
18	114	74.8	3.0	3,9	0.5	16.03	4.0	0.5	399.88	48	491		10.3	13.5	1.6	47.57	11.9	1,5
22	14	11.2	3,3	29.4	0,5	14.78	29.2	0.5	. 50,65	22	159		2.8	33.7	0.4	15.32	30.2	0,5
52	158	80.7	2.9	3.6		15.98	3.7	0.5	436.45	25	200		24.1	22.6	3.8	82.09	18.8	2.5
29	119	31.9	2.9	9.1	0,5	16.54	9.4	0.5	176.73	59	473		8.8	21.0	1.4	31.11	17.6	1.0
8	161	. 113.3	3.5	3.1	0.5	17.78	3.0	9.0	591.6	30	200		32.4	26.8	5.1	139.84	23.6	4.3
32	203	166.3	4.9	2.9		15.88	2.8	0.5	557.73	32	200		28.6	21.8	4.6	103.69	18.6	3.2
TOTAL	1994	633,6	48.2	215.9	7.6	331.23	204.4	10.3	3224.83	TOTAL	4171		147.1	333.6	23.4	701.98	277.8	21.8
MEAN	181	57.6	4.4	19.6		30.11	18,6	6.0	293.17	MEAN	379		13.4	30.3	2.1	63.82	25.3	2.0

Table G.2. Icing statistics for a 500-voyage simulation between Murmansk and the Bering Strait.

				_									_							•												1
	% Total	Transit	Distance	00	. E	- 6:	1.4	1.0	8.3	1.3	10.2	6.3	33.6	3,7			% Total	Transit	Distance	0.0	0.0	2.4	0.5	0,6	2.9	0.7	3.1	Ξ:	6.1	3.0	20.3 1.8	
		% Distance	with loing	0.0	24.8	29.4	23.1	32.7	49.3	29.0	46.1	26.0	260,5	28.9				% Distance	with Icing This I an	0.0	0.0	36,6	4.9	9.6	23.0	42.5	22.6	19.8	33.2	17.3	209.6 19.1	
늘	Mean	with Icing	This Leg	0.00	99,36	61.85	44.64	31.47	263,81	42.05	326.22	200,63	1070.03	118.89	∐ !	Mean	Distance	with loing	This Leg (nm)	0.00	00.00	77.88	16.34	18.78	92.16	21.54	98.63	35,08	196.33	96.33	653.07 59.37	
JST TRANS		% Total	ransit Time	0.0	<u>6</u>	6,	1.5	1.0	8.6	1.5	13.5	7.4	36.1	4.0	JST TRANS			% Total	fransit Time with Icina	0.0	0.0	0.7	0.5	6.0	2.6	9.0	3.7	. .	6.3	3.6	20.2 1.8	
UDE AUGI		% Time with	cing This	0.0	24.4	30.4	23.1	32.8	49.1	29.1	46.9	26.7	262.4	29.2	OW-LATITUDE AUGUST TRANSIT			% Time with	loing This '	0.0	0.0	32.2	6.0	6.6	21.7	42.7	21.8	19.7	32.9	17.0	203,8 18.5	
HIGH-LATITUDE AUGUST TRANSIT	٠		-	J											LOW-LATI				with loing This I ea (hr)	,	0,0	4.7	3.4	5.5	16,5	3.5	23.2	8.3	39.8	22.3	127.3 11.6	
		_	Time This															_											120,9	131.2	629.2 57.2	
		Total	Voyages	0	231	285	481	436	200	480	909	500	3413	379				Total	Voyages with Icino	0	0	17	186	305	499	380	200	472	200	200	3359 305	
			Ņ	0	ယ	7	17	9	7	24	28	33	TOTAL	MEAN					N C	5	10	12	14	5	8	22	52	29	30	32	TOTAL MEAN	
		Leg	Length	125.77	399.86	210.13	183,36	96,34	535,06	144.94	707.81	771.34	3184.61	353.85				Leg	Length (nm)	125,77	144.65	213.04	333.06	195,27	399,88	20.65	436.45	176.73	591.6	557.73	3224.83 293.17	
	% Total	Transit	Distance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	(32)		% Total	Transit	Distance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
21, 24, 28, and 33)		% Distance	with loing	0.0	0.0	2:00	0.0	0,0	0.0	0'0	0.0	0.0	0.0	0.0	29, 30, and 32)			% Distance	with loing This I ea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Mean Distance	with loing	This Leg	0.00	0.00	0.00	0.00	00'0	0.00	00'0	0.00	00.00	00'0	0.00	18, 22, 25,	Mean	Distance	with Icing	This Leg	0.00	0.00	00'0	00.00	0.00	0.00	0.00	0,00	0.00	00'0	0.00	0.00	
6, 6, 7, 17, 1		% Total	Transit Time	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12, 14, 15,			% Total	Transit Time	0.0	0,0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
SIT (Legs 5		% Time with	loing This	00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	(Legs 5, 10,			% Time with		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
PRIL TRAN		Mean Time	with loing	0.0	0.0	0:0	0.0	0.0	0.0	0'0	0.0	0.0	0.0	0.0	TRANSIT			Mean Travel Mean Time % Time with	with lefng	0.0	0,0	0.0	0.0	0.0	0.0	0.0	0.0	0,0	0.0	0.0	0.0	
HIGH-LATITUDE APRIL TRANSIT (Legs 5, 6, 7, 17, 19,		Mean Travel	Time This		72.5	46,3	34.0	16.5	95.7	25.0	130.7	158.6	589.7	65.5	LOW-LATITUDE APRIL TRANSIT (Legs 5, 10, 12, 14, 15, 18			Mean Travel	Time This	10.4	12.8	38,4	59.6	34.3	74.8	11.2	80.7	31,9	113,3	166.3	633.6 57.6	
HIGH		Total	Voyages	Ginal Intw	o c		0	0	0	0	0	0	0	0	W-LATIT			Total	Voyages	With John S	0	0	0	0	0	0	0	0	0	0	0 0	
				į) (C	· ~	17	19	24	24	78	33	TOTAL	MEAN					24		, 무	15	14	15	18	22	52	23	30	32	TOTAL	

Table G.3. Snow storm statistics for a 500-voyage simulation between Murmansk and the Bering Strait.

		: ==	9	» Mo														<u></u>	<u>=</u>	9 :	3													
	% Total	Transit	Distance	with Snow	0,0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			% Total	Transit	Distance	Mill Off	0,0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0,0	0.0	0.0	0.0	0.0
		% Distance	with Snow	This Leg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				% Distance	with Snow	ills red	0,0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SIT	Mean	with Snow	This Leg	(nn)	00.00	0.00	0.00	0.00	0.00	0.00	0.00	00'0	00.0	0.00	0.00	SIT	Mean	Distance	with Snow	This Leg	(min)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	00.0	0.00	0.00	0.00	00'0	0.00
UST TRAN		% Total	Transit Time	with Snow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	UST TRAN			% Total	Transit Time	WILL Ollow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HIGH-LATITUDE AUGUST TRANSIT		% Time with	Snow This	Leg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	LOW-LATITUDE AUGUST TRANSIT			% Time with	Snow This	ña'i	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HIGH-LAT		Mean Time	with Snow	This Leg (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	LOW-LATI			Mean Time	with Snow	I IIIS LBU (III.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Mean Travel	Time This	Leg (hr)	8.3	26.3	20.9	31.8	15.3	85.4	24.6	140.0	134.3	487.0	54.1				Mean Travel	Time This	Leg (III.)	ο, c	9,4	14.6	55.9	55.8	76.1	8,3	106.8	41.9	120.9	131.2	629.2	57.2
		Total	Voyages	with Snow	0	0	0	0	0	0	0	0	0	0	0				Total	Voyages	Will Stiow	-	o (0	o	ο.	0	0	0	0	0	0	0	0
				eg No	S	9	7	17	13	71	24	28	33	TOTAL	MEAN					1	2	o S	2 5	17	14	12	18	22	25	28	30	32	TOTAL	MEAN
		Leg	Length	(nm)	125.77	389.86	210.13	193.36	96.34	535.06	144.94	707.81	771.34	3184.61	353.85	***			Leg	Length	425 77	17.071	144.65	213.04	333.06	195.27	399.88	50.65	436.45	176.73	591.6	557.73	3224.83	293.17
	% Total	Transit	Distance	with Snow	1,3	6.1	1.4	6.0	0.7	2.6	0.9	2.3	2.8	14.1	1.6	132)		% Total	Transit	Distance	Will Glow	7.7	۲.۲	2.	0.	6.0	1.7	0.5	1.7	0.7	1.7	1.9	14.2	6,1
21, 24, 28, and 33)		% Distance	with Snow	This Leg	31.9	10.7	20.7	15.4	21.6	15.3	18,9	10.4	11.7	156.5	17.4	29, 30, and			% Distance	with Snow	IIIIs Leg	51.0	3/.0	15.8	9.6	14.9	14.0	31.8	12.8	13.3	9.3	10.9	201.8	18.3
	Mean Distance	with Snow	This Leg	(nn)	40.12	42.73	43.40	29.74	20.82	81.76	27,33	73.74	90,53	450.17	50.02	18, 22, 25,	Mean	Distance	with Snow	This Leg	(1111)	40.12	54.29	33,50	32.02	29.06	55,94	16.11	55.99	23,55	54.90	60.75	456,33	41.48
5, 6, 7, 17,		% Total	Transit Time	with Snow	0.7	1.4	1.6	6.0	9.0	2.5	0.8	2.3	3.2	13.9	1.5	, 12, 14, 15,			% Total	Transit Time	Will Glow	0.0	80	0.1	0.9	0,8	1.7	0,5	1.6	0.7	1.7	2.8	13.1	1.2
NSIT (Legs		% Time with	Snow This	Leg	37.5	11.2	20.8	15.4	21.6	15.3	18.8	10.4	11.7	162,7	18.1	(Legs 5, 10			% Time with	his	Ley 27 £	0./5	43.2	7:01	7.6	14.8	14.0	31.2	12.7	13.4	6,3	10.7	212.1	19.3
HIGH-LATITUDE APRIL TRANSIT (Legs 5, 6, 7, 17, 19,		Mean Time	with Snow	This Leg (hr)	3.9	8.1	9.6	5.3	3.6	14.6	4.7	13.5	18.6	81.9	9.1	LOW-LATITUDE APRIL TRANSIT (Legs 5, 10, 12, 14, 15, 18, 22, 25, 29, 30, and 32)			Mean Travel Mean Time % Time with	with Snow	(III) FEB (III)	ກຸເ	0.0	6.0	5.8	5.1	10.5	3.5	10.3	4.3	10.6	17.7	83.1	7.6
ATITUDE /		Mean Travel	Time This	Leg (hr)	10.4	72.5	46.3	34.0	16.5	95.7	25.0	130,7	158.6	589.7	. 65,5	UDE APRI			Mean Travel	Time This	107 (III)	10.4	12.8	38.4	59.6	34.3	74.8	11.2	80.7	31,9	113.3	166,3	633.6	57.6
HIGH-I		Total		with Snow	82	227	369	407	302	496	371	498	200	3252	361	OW-LATIT			Total	Voyages	- 1	7 6	4 5	nel	417	403	493	238	490	345	492	496	3670	334
				Leg No.	Ω	ဖ	7	1	9	77	24	28	33	TOTAL	MEAN					24	red No.	ი :	2 9	77	4	5	18	22	22	29	30	32	TOTAL	MEAN

Table G.4. Darkness statistics for a 500-voyage simulation between Murmansk and the Bering Strait.

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		7. Total	Transit	Distance	with Dark	1.0	1.8	7.	6.0	9.0	2.7	0.7	3.4	3.6	15.8	1.8			% Total	Transit	Distance	with Dark	1.0	1.2	1.2	1.4	0.8	1.9	0.5	2.0	0.8	2.8	2.5	16.0	<u> </u>
			% Distance	with Dark	This Leg	25.8	14.7	16.7	15.2	20.3	15.9	15.7	15.1	14.8	154.3	17.1				% Distance	with Dark	This Leg	25.8	26.1	17.7	13.5	13.6	15.2	30,7	14.6	14.6	15.2	14.6	201.6	2,72
E	=	Mean	with Dark	This Leg	(nm)	32,45	58.61	34.99	29,38	19.57	85.21	22,80	107.21	114.50	504.72	56.08	ļ.	Mean	Distance	with Dark	This Leg	(nm)	32.45	37.75	37.64	45.08	26.55	60.97	15.53	63.68	25.81	89.81	81.69	516.96 47.00	
TISNABL TSICILA BOLITITA I HOLD			% Total	Transit Time	with Dark	0.5	1.0	6.0	1:1	0.7	2.9	0.8	4.8	4.6	17.3	1.9	LOW-LATITUDE AUGUȘT TRANSI			% Total	Fransit Time	with Dark	0.4	0,5	0,5	1.5	1,5	2.0	0.4	2.8	Ξ	3.2	3.5	17.4 1.6	
014	ODE AGG		% Time with		Leg	31.3	17.9	20.0	16.7	21.2	16.6	16,6	16.6	16.7	173.7	19.3	UDE AUGL			% Time with	Dark This 1	Leg	31,3	31.9	22.7	16,5	16.6	16.7	33.1	16.6	16.7	16.7	16.7	235.5	
FITA LUCI	וויאן-נוסו		Mean Time %		This Leg (hr)	2.6	4.7	4.2	5.3	3.2	14.2	4.1	23.3	22.4	84.1	9.3	OW-LATIT			Mean Time %	with Dark	This Leg (hr)	2.6	3.0	3.3	9.2	9,2	12.7	2.8	17.7	7.0	20.2	21.9	109.7 10.0	
	=			Time This		8.3	26.3	20.9	31.8	15.3	85.4	24.6	140.0	134.3	487.0	54.1				Mean Travel		Leg (hr) T	8.3	9.4	14.6	55.9	55.8	76.1	8.3	106.8	41.9	120.9	131.2	629.2 57.2	
				Voyages		252	200	385	500	398	200	498	200	500	4033	448					10	with Dark	252	315	316	200	200	200	255	200	200	200	500	4638 422	
					Leg No	2	9	7	17	19	71	24	28	33	TOTAL	MEAN						Leg No	5	우	72	14	12	18	22	52	29	တ္တ	32	TOTAL	
			Leo	Length	(nm)	125.77	386.86	210.13	193,36	96,34	535.06	144.94	707.81	771.34	3184.61	353.85				Leg	Length	(uu)	125.77	144.65	213.04	333,06	195.27	399.88	50,65	436,45	176.73	591.6	557.73	3224.83	
		% Total	Transit	Distance	with Dark	1.0	2.0	7:	1.0	9.0	2.8	0.8	3.7	4.0	17.1	1.9	32)		% Total	Transit	Distance	with Dark	1.0	1.0	::	1.7	1.0	2.1	0.4	2.2	6.0	3.1	3.0	17.6	-
(CC F. 100)	21, 24, 20, and 33)		% Distance	with Dark	This Leg	25.6	16.1	16.5	16.8	19,9	16.8	16.8	16.7	16.7	162.0	18.0	29, 30, and 32)			% Distance	with Dark	This Leg	25.6	23.3	16.3	16.9	16.6	16.7	27.2	16.5	16.6	16.7	17.6	210.1 19.1	
		Mean		This Leg		32,24	64.44	34.71	32,55	19.17	89.67	24.28	118.35	128.97	544.38	60.49	18, 22, 25,	Mean	Distance	with Dark	This Leg	(uu)	32,24	33.74	34.82	56.30	32.40	66,90	13.76	72.22	29,26	99.02	97.92	568,58 51.69	
1	, 0, 7, 17, 1		% Total	Transit Time	with Dark	0.5	2.0	1.3	1.0	9.0	2.7	7.0	3.7	4.5	17.0	1.9	12, 14, 15,			% Total	Transit Time	with Dark	0.5	0.5	1.0	1.6	0.9	2.0	0,5	2.1	0.8	3.0	4.4	17.2	2
110	SEST) (Fede		% Time with		Leg	28.4	16.6	16.5	16.8	19,8	16.7	16.7	16.6	16.7	164.9	18.3	(Leds 5, 10,			% Time with		Leg	28.4	26.4	16.4	16.9	16.5	16.6	26.4	16.4	16.4	16.7	16.7	213.8	10.1
1	PRIL IRAN		Mean Time		This Leg (hr)	3.0	12.0	7.7	5.7	3.3	16.0	4.2	21.8	26.5	100.0	11.1	TRANSIT			Mean Travel Mean Time % Time with	with Dark	This Leg (hr)	3.0	3.4	6,3	10.1	5.6	12.4	3.0	13.3	5.2	19.0	27.7	108.9	2.0
L C	HIGH-LAIII UDE APRIL IRANSII (Legs 3, 6, 7, 17, 13,		Moan Travel			10.4	72.5	46.3	34.0	16.5	95.7	25.0	130.7	158.6	589.7	65.5	OW-LATITUDE APRIL TRANSIT (Legs 5, 10, 12, 14, 15, 18, 22, 25,			Mean Travel	Time This			12.8	38,4	59.6	34,3	74.8	11.2	80.7	31.9	113.3	166,3	633.6	21.0
	HGH		F	Vovages	with Dark	304	200	200	200	418	200	200	200	200	4222	469	W-LATIT			Total	Voyages	with Dark	304	325	200	200	200	900	306	200	200	200	200	4935	440
					Lea No.	2	9	7	17	19	77	24	28	33	TOTAL	MEAN		i 		_		Leg No.	2	10	12	14	15	18	22	25	33	8	32	TOTAL	MEAN
_			_						_			_																							

Table G.5. Sea-ice cover statistics for a 500-voyage simulation between Murmansk and the Bering Strait.

					_	_	_					_	<u> </u>					_		_		_									_	_	_
	% Total	Transit	Distance	With Sea Ice	0.0	4.4	6.1	3.0	16.8	-4.6	22.2	24.2	81.3	9.0			% Total	Transit	Distance	with Sea Ice	0.0	0.0	6.6	9.1	6.1	12.4	1.6	. 13,5	5,5	18,3	17.3	90.3	8.2
VSIT.		% Distance	with Sea Ice	DO DO	0.0	66.5	100.0	100,0	100.0	100.0	100.0	100.0	666.5	74.1				% Distance	with Sea Ice	This Leg	0.0	0.0	100.0	87.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	887.7	80.7
	Mean Distance	with Sea Ice	This Leg	000	0.00	139.70	193.36	96.34	535.06	144.93	707.81	771.34	2588.54	287.62	TIS	Mean	Distance	with Sea Ice	This Leg	(nm)	0.00	0.00	213,04	292,06	195.27	399.88	50,65	436.45	176.73	591.60	557.72	2913.40	264.85
UST TRAN			Fransit Time	0.0	0.0	6.1	6.5	3.1	17.5	5.1	28.8	27.6	94.7	10.5	JST TRAN			% Total	Fransit Time	with Sea Ice	0'0	0.0	5,6	8.5	8.9	12.1	1.3	17.0	6.7	19.2	20.9	100,1	9.1
TUDE AUG		% Time with	Sea Ice This	0.0	0.0	142.9	100.0	100.0	100.0	100.0	100,0	100.0	742.9	82.5	LOW-LATITUDE AUGUST TRANSIT			% Time with	Sea Ice This	Leg	0.0	0.0	242.4	95.4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1037.8	94.3
HIGH-LATITUDE AUGUST TRANSIT		_		0.0	0.0	29.9	31.8	15.3	85,4	24.6	140.0	134.3	461.4	51.3	LOW-LATI1					This Leg (hr)	0.0	0.0	35.5	53.3	55.8	76.1	8.3	106.8	41.9	120.9	131,2	629.7	57.2
		₩	Time This								140.0	134.3	487.0	54.1				Mean Travel		Leg (hr)	8.3	9.4	14.6	55.9	55.8	76.1	8,3	106.8	41.9	120.9	131.2	629.2	57.2
		Total	Voyages	0	0	173	200	200	500	200	200	500	3173	353					10	with Sea Ice	0	0	30	200	200	200	200	200	200	200	200	4030	366
			N DO	5	9	7	17	6	71	24	28	33	TOTAL	MEAN	G					Leg No	2	유	4	14	15	48	22	52	53	30	32	TOTAL	MEAN
		Leg	Length (nm)	125.77	399.86	210.13	193.36	96,34	535,06	144.94	707.81	771.34	3184.61	353.85				Leg	Length	(nm)	125.77	144.65	213.04	333.06	195.27	399.88	50.65	436.45	176.73	591.6	557.73	3224.83	293.17
	% Total	Transit	Distance	1.6	12.6	6.6	6.1	3.0	16.8	4.6	22.2	24.2	97.7	10.9	32)		% Total	Transit	Distance	with Sea Ice	1.6	4.5	9.9	10.3	6.1	12.4	1.6	13.5	5.5	18.3	17.3	7.79	8.9
21, 24, 28, and 33)		% Distance	with Sea Ice	41.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	841.4	93,5	29, 30, and			% Distance	with Sea Ice	This Leg	41.5	100.0	100.0	100.0	100,0	100.0	100,0	100.0	100,0	100.0	100.0	1041.4	94.7
HIGH-LATITUDE APRIL TRANSIT (Legs 5, 6, 7, 17, 19, 21, 24, 2	Mean Distance	with Sea Ice	This Leg	52.14	399.86	210.13	193,36	96.34	535.06	144.93	707.81	771.34	3110.97	345,66	18, 22, 25,	Mean	Distance	with Sea Ice	This Leg	(nm)	52.14	144.65	213.04	332.98	195.27	399.88	50,65	436,45	176.73	591.60	557.72	3151.11	286.46
				1.4	12.9	7.9	5.8	2.8	16.2	4.2	22.2	26.9	100.3	11.1	, 12, 14, 15,			% Total	Transit Time	with Sea Ice	.							12.7				101.3	
			Sea Ice This Transit Time	81.2	105.1	100.0	100.0	100,0	100.0	100.0	100.0	100.0	886,2	98.5	(Legs 5, 10			% Time with	Sea Ice This Transit Time	Leg	81.2	177.7	100.0	100.0	100,0	100.0	100.0	100.0	100.0	100.0	100.0	1158.8	105.3
APRIL TRAI		Mean Time	with Sea Ice	8.4	76.2	46.3	34.0	16.5	95.7	25.0	130.7	158.6	591.4	65.7	LOW-LATITUDE APRIL TRANSIT (Legs 5, 10, 12, 14, 15, 18, 22, 25, 29, 30, and 32)				with Sea Ice	This Leg (hr)	8.4	22.8	38.4	59.6	34,3	74.8	11.2	80.7	31.9	113.3	166.3	641.6	58.3
ATITUDE /		Mean Travel	Time This		72.5	46.3	34.0	16.5	95.7	25.0	130.7	158.6	589.7	65,5	'UDE APRIL			Mean Travel		Leg (hr)	10.4	12.8	38.4	59.6	34.3	74.8	11.2	80.7	31.9	113.3	166.3	633,6	97.9
HIGH-I		Total	Voyages with Sea Ice		461	200	200	200	200	200	200	200	4091	455	LOW-LATIT			Total	Voyages	With	130	107	200	200	200	200	200	200	200	200	500	4737	431
			N Ca	2	9	7	17	19	21	24	28	33	TOTAL	MEAN	_					Leg No.	Ω	우	12	14	15	48	22	22	29	30	32	TOTAL	MEAN

APPENDIX H REVIEW COMMENTS OF THE REPORT BY JOACHIM SCHWARZ, HSVA

Discussion of INSROP-Paper "Sensitivity Analysis of a Northern Sea Route Transit Model" by N.D. Mulherin and D.T. Eppler

Discusser: Dr. J. Schwarz, HSVA

The developed Sensitivity Analysis for Transit Models of Ship through Arctic Ice is a very valuable tool to estimate transit time and costs and to improve or help in developing new transit models. The concentration on the Northern Sea Route may be caused by the fact that the work was carried out under the INSROP 2 - Programme. Attempts should be made to generalise the sensitivity analysis to ice transit models in general.

The reviewer does not agree to the statement in the introduction that insurance costs, tariffs and transit fees are less indicative of future trends; in the opposite, these parameters most likely will decide on the economical competiveness of the NSR compared with the Suez-canal route.

The chapter "Model Description" covers "Assumption" and other items on parameters used in the simulation model. This is partly discussed with respect to their effect on the sensitivity analysis of the NSR transit model:

Icebreaker Escort:

The availability of escorting icebreakers should be a variable in the model because it effects the transit calculation significantly. In practise, waiting time costs should be compensated by the icebreaker fees.

Segmentation:

Eight hour time segmentation in ice seems too large. It is suggested to run a sensitivity calculation for 2 hours, 4 hours and 8 hours segments for ice situations which change every 2 hours significantly. (This was experienced during our ARCDEV-expedition in the KARA SEA.)

Mesh Description:

Mesh description destingishes between several alternative route combinations. It seems that some most realistic combinations are missing such as the route from $2 \text{ a} \rightarrow 4 \text{ and } 2 \rightarrow 2 \text{ a}$.

Input Variables:

1. Meteorological

Lack of visibility causes the reduction in ship speed, if ice concentration is higher than 70% and not 30%. At low visibility the icebreaker navigates anyhow by radar.

2. Oceanographic

In addition to ocean currents and wind induced currents Tidal currents need to be considered,

because especially the Tidal currents effect the ice conditions.

3. Ice Conditions

The ice compression not only depends on the atmospheric pressure data (wind) but also significantly on Tidal currents. This definitely needs to be considered in the sensitivity model.

One item, which is the most governing factor in the transit of Arctic Seas is totally missing in the sensitivity analysis:

The effect of ice reconnaissance by satellite or other means which sometimes is also called Ice Routing. To our experience the progress of ships / icebreakers in the Arctic depends more on Routing than on any other parameters.

It is certainly difficult to define the routing in terms of trafficability. This can only mean that transit models have still a way to go before we can predict the speed and costs of Arctic Transportation more accurately; not to mention political obstacles which are unpredictable in the present situation in Russia.

Hamburgische Schliffbau-Versuchsanstalt GmbH Hamburg Ship Model Basin



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Betr./Ref.: Review of INSROP-Discussion Paper

*NSRSIM 2A: A Time and Cost Prediction Model for Northern Sea Route

Shipping"

Authors: N.D. Mulherin, D.T. Eppler and D.S. Sodhi

The approaches taken to improve the simulation model NSRSIM 01 seam reasonable; they take partly into account the recommendations of the reviewers. Due to time and money constrains as well as due to unavailable information on certain effects the modifications had to remain limited. "Certain effects" are, for example, the unknown relationship between ship speed and lateral pressure in the ice.

The crucial point of the new model is certainly - as the authors state themselves, the almost same speed of travel in April (worst ice condition) and August (easiest ice condition). As this result does not coincide with experience in Arctic navigation, the simulation model, including input data, should be checked for reasons of this discrepancy.

The basic data of ship speed as a function of ice thickness, ice concentration and icebreaker assistance (Table 2) seem partly to be unrealistic. Especially for the ice concentration <30%, which represents more or less the ice conditions in August, the speed reduction from 15 knots openwater speed to 8 knots is incorrect to my experience. I would propose to increase the 8 knots to 12 knots and adjust the other speeds accordingly. This would increase the speed in August considerably and more in line with experience.

Since I assume that the data of Table 2 were also used in NSRSIM 01, there must be an additional reason for the unlogic prediction of NSRSIM 2A.

The authors show that the recommended reduction of the time step from 8 hrs to 6, 4 and 2 hrs did not change the sensitivity of the model. This result does not convince me; it can also be, that the model is insensitive to changes of certain ice conditions.

Geschäftsführer: Dr.-Ing. Gerhard Jensen



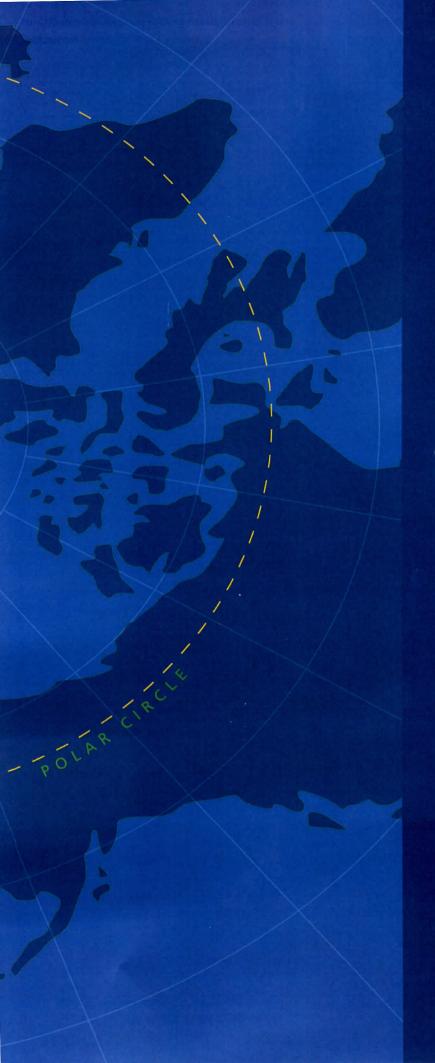
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Altogether, I believe the authors are on the right track to develop a model for Arctic navigation predictions. Further work is, however, necessary to elucidate discrepancies with full scale experiences.

Joachim Schwarz, HSVA January 1999



The three main cooperating institutions of INSROP



Ship & Ocean Foundation (SOF), Tokyo, Japan.

SOF was established in 1975 as a non-profit organization to advance modernization and rationalization of Japan's shipbuilding and related industries, and to give assistance to non-profit organizations associated with these industries. SOF is provided with operation funds by the Nippon Foundation, the world's largest foundation operated with revenue from motorboat racing. An integral part of SOF, the Tsukuba Institute, carries out experimental research into ocean environment protection and ocean development.



Central Marine Research & Design Institute (CNIIMF), St. Petersburg, Russia.

CNIIMF was founded in 1929. The institute's research focus is applied and technological with four main goals: the improvment of merchant fleet efficiency; shipping safety; technical development of the merchant fleet; and design support for future fleet development. CNIIMF was a Russian state institution up to 1993, when it was converted into a stockholding company.



The Fridtjof Nansen Institute (FNI), Lysaker, Norway.

FNI was founded in 1958 and is based at Polhøgda, the home of Fridtjof Nansen, famous Norwegian polar explorer, scientist, humanist and statesman. The institute spesializes in applied social science research, with special focus on international resource and environmental management. In addition to INSROP, the research is organized in six integrated programmes. Typical of FNI research is a multidisciplinary approach, entailing extensive cooperation with other research institutions both at home and abroad. The INSROP Secretariat is located at FNI.