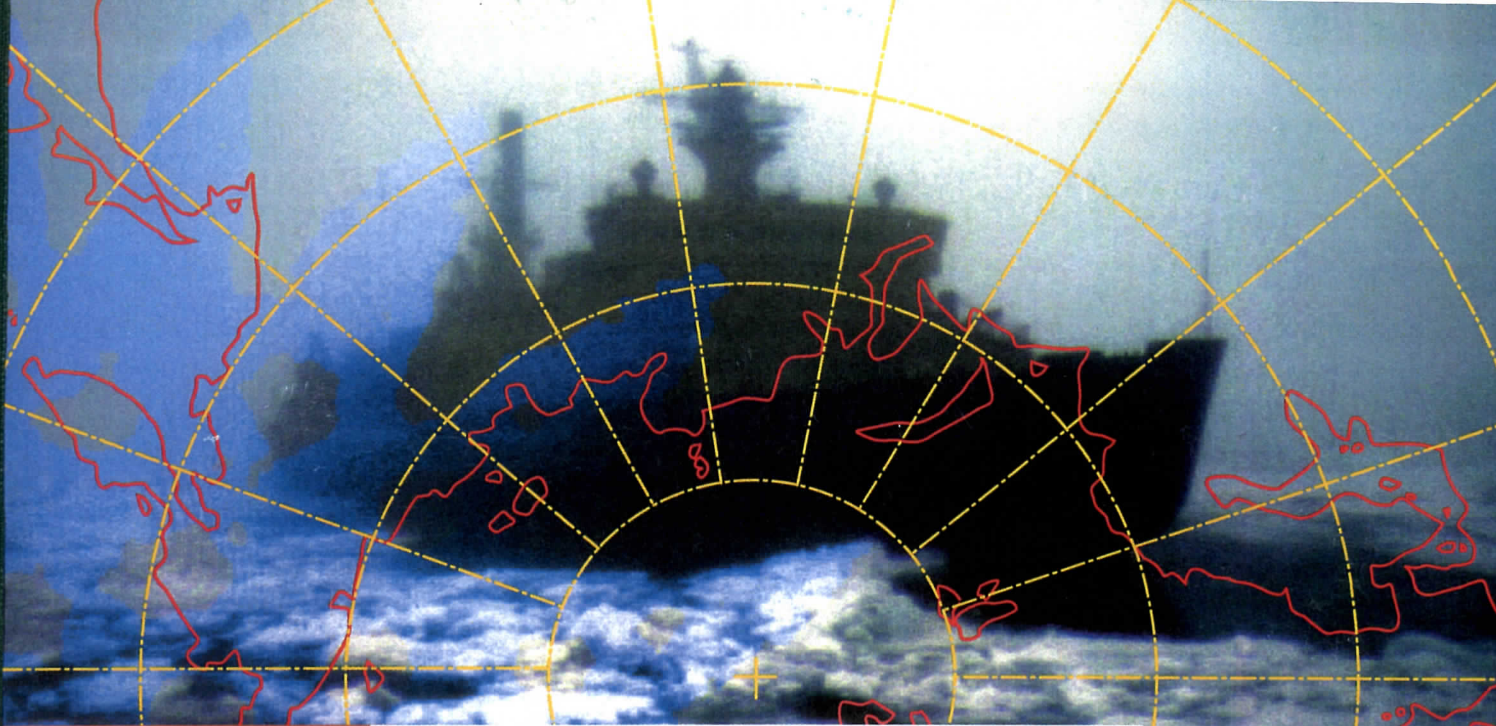

INSROP WORKING PAPER NO. 164 – 1999

The NSR Simulation Study Work Package 8:
Simulation of NSR Shipping based on Year-round and Seasonal Operation Scenarios

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International Northern Sea Route Programme (INSROP)

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

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INSROP WORKING PAPER NO. 164-1999

Box B: The Simulation Study of NSR Commercial Shipping

Work Package 8: Simulation based on Year-round and Seasonal Operation Scenarios

Supervisor: Kazuhiko Kamesaki, Ship & Ocean Foundation

Title: **Simulation of NSR Shipping based on Year-round and Seasonal Operation Scenarios**

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Date: 31 March 1999

Reviewed by: Dr. Alfred Tunik, American Bureau of Shipping, New York, USA

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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.

The complete series of publications may be obtained from the Fridtjof Nansen Institute.

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Contents

1.0 Introduction

The Northern Sea Route shall keep its advantages in costs against other alternative transportation means including railways or routes through the Suez Canal. It is quite natural that those who are attempting to utilize the NSR commercially will be firstly concerned about the cost benefit and associated risks. Box B project in Phase II are assigned tasks to perform a ship transit simulation in order to answer these straightforward concerns incorporating advanced ship design and historical ice data. In order to conduct the simulation; keeping with some confidences, multi disciplinary knowledge is necessary. Thus, Box B project is divided into nine work packages and WP8 takes the responsibility of integrating other project results. WP1 selected the routes both for regional and transit, and gathered knowledge for associated infrastructures. Two transit routes liking Yokohama and Hamburg were selected as compatible for 9m and 12.5m draft ships. The eastern route between Tiksi and Yokohama, and the western route between Dikson and Hamburg was selected as regional routes. These routes were plotted on sea charts in every 20 nautical miles to find out the obstacles near the routes. WP2 presented enormous historical environmental data over forty years consisting of 18 items along the selected routes in every 20 nautical miles on a monthly average basis. WP3 presented the cargo flow data in current and future. WP4 performed the preliminary design and ice tank tests for the two icebreaking cargo ships used for the simulation. They featured container/bulk carriers and eight-month independent navigation capability in ice. In addition to WP4 results, a 50,000DWT icebreaking bulk carrier was also used to examine the effect of balance between icebreaking and open water capability. WP5 gathered SA-15 performance data in ice and structural damage to calibrate the simulation data. WP6 developed the ship velocity calculation code that is essential to determine the simulated ship velocities in ice conditions provided by WP2. WP7 reviewed the selected route from the legal viewpoints and performed the environmental impact assessment. WP8 imported some of other seven project results and incorporated them into the simulation works. Eight projects are closely inter-related, therefore an intensive coordination effort was made to proceed the project smoothly. Box B project meetings were held in Tokyo and St. Petersburg on Feb. '97 and Oct.'98 respectively organized by WP0.

In the past, cost simulations through the NSR were attempted. Wergeland (1992) showed feasibility results. Schwarz (1995) also presented the feasibility results for container ships considering future technical advances. Mulherin et al. (1996) employed the Monte Carlo technique to describe ice conditions along the route. In these simulations, the ship transit velocity was simply determined based on the empirical data or a simple look up table defining the relation between ice conditions and velocity. The Monte Carlo technique may be the proper method to describe very complex probabilities numerically, however precise and detailed probabilistic descriptions will be necessary and may not be the method to compensate for lacking data. Ono (1995) indicated a seesaw phenomenon in ice condition along the NSR, namely when the ice condition in the East Siberian is heavy, the ice condition in the western NSR is light. Thus, each ice condition generated Monte Carlo technique may not be realistic. However it seems that the result found the Monte Carlo technique will converge to an average value as to entire route over sufficient long term period.

In this simulation, an effort is made to connect the ship velocity simulation code by WP6 and the ice conditions presented by WP2. The concept for the ice index originally introduced by the Canadian Arctic Ship Pollution Prevention Regulations as ice numerals is modified to express the ice conditions quantitatively as a solution, then the probabilistic relations between the ice condition and ship velocity are developed using the code provided by WP6. This method considerably enables shortening of the simulation time with keeping rational relation between the ice condition and transit time. WP8 simulation simply captured ice conditions as an only slowing factor. As a comparative study, Mulherin et al. (1998) performed the simulation study updating their original model to examine the other slowing factors including pressures, wind, waves, fogs, icing, snow and currents. They concluded that their effects are minor.

Chapter 2 summarizes the results utilized in this simulation. Chapter 3 describes the computer code developed for this simulation and inherent assumptions adopted in addition to Chapter 2. Chapter 4 summarizes the results. The simulation was performed in twofold. One is the simulation named Monthly Voyage Simulation (MVS) representing the required cost on each month. MVS is not representing the cost simulation conventionally adopted by the shipping industry, however the most preferable method to look at the general trends for the variations for transit times by season and sea area, and icebreaker escort times etc. The other is the simulation named Annual Serial Voyage Simulation (ASVS). ASVS aims to estimate a number of voyages per year or specified period and evaluated freight cost per voyage as $/ton. ASVS is widely used by the shipping industries to judge feasibility in terms of cost and profit.

2.0 Assumptions for the simulation study

This chapter summarizes studies from each WP and assumptions adopted by WP8 in order to implement the simulation.

2.1 Route selections

WP1 performed detailed studies for route selection (Baskin et al., 1998). The following four routes are chosen;

- Northerly route
- Southerly route
- Regional East route
- Regional West route.

Northerly route links between Yokohama and Hamburg and suites for transit ships with a draft up to 12.5m and locates high latitude. Southerly route is also designed for transit ships with a draft less than 9.0m and lies along the conventional coastal route. Regional East and Regional West routes link between Tiksi and Yokohama, and Dikson and Hamburg respectively. Regional East and West routes aim to investigate transportation costs when economic development is realized in the future. Table 2.1.1 summarizes the distances of four routes.

The routes are plotted for every 20 nautical miles on sea charts taking into account ice conditions and water depth. When plotting routes, associated prime hazard and operational infrastructure along the routes are also identified. Figure 2.1.1 shows Northerly and Southerly transit routes. The Northerly route starts from Mys Zhelaniya Cape and passing Mys Archtichskiy Cape in the Kara Sea and north of the New Siberian Island. The Southerly route starts from the Karskie Vorota Strait and passing north of Belyy island, Dikson island, and through Vil'kitzkogo Strait and Sannikova Strait. Latitude and longitude and water depths of primary way-points are listed in Table 2.1.2 and 2.1.3. One must realize that some locations in the Laptev sea and the East Siberian are extremely shallow. Southerly and northerly routes in the NSR measure 2680 and 2446 nautical miles in distance respectively. Regional East route branches from Southerly route at point E1-01 locating 40' east of S-07 and goes down southerly by 122 N.M. to an entrance point of the port of Tiksi. Regional West route starts from S-02 locating an entrance point of Dikson and goes through the same routes as Southerly routes to Hamburg.

Table 2.1.1 Distances of four routes

Route name	Route poits	Distance within the NSR (NM)	Distance outside the NSR (NM)	Total distance(NM)
Northerly route	Hamburg to Yokohama	2,446 (34)	4,750 (66)	7,196 (100)
Southerly route	Hamburg to Yokohama	2,680 (37)	4,650 (63)	7,330 (100)
Regional East route	Hamburg to Dikson	1,326 (33)	2,694 (67)	4,020 (100)
Regional West route	Yokohama to Tiksi	468 (20)	1,929 (80)	2,397 (100)

Table 2.1.2 Prime waypoints of Southerly Transit Route

Point ID.	Latitude ° '	Longitude ° '	Distance (nautical miles)	Water depth (m)	Sea Area	Remarks
H-01	54 00.0	07 30.0	-	25	Atlantic Ocean	Approch to the port of Hamburg
B1-01	71 20.0	25 50.0	1265	200	Barents Sea	North Cape
B2-04	70 32.0	58 15.0	664	128	Barents Sea	Mys Zheraniya Cape
S-01	73 50.0	68 30.0	273	23	Kara Sea	
S-02	73 50.0	80 10.0	195	35	Kara Sea	
S-03	76 00.0	87 20.0	171	42	Kara Sea	Ostrov Shmidta Isl.
S-04	77 20.0	96 00.0	144	70	Laptev Sea	Mys Archicheskiy Cape
S-05	77 52.0	102 00.0	84	122	Laptev Sea	
S-06	77 50.0	106 00.0	51	180	Laptev Sea	
S-07	73 32.0	129 50.0	436	14	Laptev Sea	
S-08	73 32.0	136 00.0	105	23	East Siberian Sea	Novosibirskie Ostrova Isl.
S-09	74 22.0	139. 05.0	72	22	East Siberian Sea	
S-10	74 34.0	146 38.0	33	22	East Siberian Sea	
S-11	74 18.0	146 38.0	92	15	East Siberian Sea	
S-12	70 17.0	168 32.0	466	35	East Siberian Sea	Ostrov Vrangelya Isl.
S-13	70 01.0	176 19.0	160	39	East Siberian Sea	Ostrov Vrangelya Isl.
S-14	69 11.0	179 29.0	101	41		
S-15	67 12.0	173 42.0	176	26		
S-16	67 00.0	171 34.0	51	37		
Y-01	66 10.0	169 32.0	70	45	Bering Straight	
Y-02	66 00.0	169 32.0	10	50	Pacific Ocean	
Y-03	64 00.0	172 00.0	135	50	Pacific Ocean	
Y-04	34 35.0	142 00.0	2463	6500	Pacific Ocean	
Y-05	34 35.0	140 00.0	113	2000	Pacific Ocean	Approach to the port of Yokoham
			7330			

Table 2.1.3 Prime waypoints of Northerly Transit Route

Point ID.	Latitude ° '	Longitude ° '	Distance (NM)	Water depth (m)	Sea Area	Remarks
H-01	54 00.0	07 30.0	-		Atlantic Ocean	Approch to the port of Hamburg
B1-01	71 20.0	25 50.0	1265	200	Barents Sea	North Cape
B1-02	70 32.0	58 15.0	764	270	Barents Sea	Mys Zheraniya Cape
N-01	77 11.0	82 30.0	193	30	Kara Sea	
N-02	77 58.0	89 00.0	96	70	Kara Sea	
N-03	81 20.0	89 00.0	202	90	Kara Sea	Ostrov Shmidta Isl.
N-04	81 24.0	96 00.0	63	100	Laptev Sea	Mys Archicheskiy Cape
N-05	77 47.0	110 48.0	269	230	Laptev Sea	
N-06	76 55.0	114 20.0	70	52	Laptev Sea	
N-07	76 26.0	119 20.0	75	57	Laptev Sea	
N-08	76 40.0	142 00.0	317	20	East Siberian Sea	Novosibirskie Ostrova Isl.
N-09	75 44.0	154 20.0	185	30	East Siberian Sea	
N-10	72 58.0	161 45.0	205	28	East Siberian Sea	
N-11	71 00.0	170 00.0	193	33	East Siberian Sea	
N-12	70 30.0	178 04.0	163	49	East Siberian Sea	Ostrov Vrangelya Isl.
N-13	70 45.0	177 39.0	87	40	East Siberian Sea	Ostrov Vrangelya Isl.
Y-01	66 10.0	169 32.0	328	45	Bering Straight	
Y-02	66 00.0	169 32.0	10	50	Pacific Ocean	
Y-03	64 00.0	172 00.0	135	50	Pacific Ocean	
Y-04	34 35.0	142 00.0	2463	6500	Pacific Ocean	
Y-05	34 35.0	140 00.0	113	2000	Pacific Ocean	Approach to the port of Yokohama
			7196			

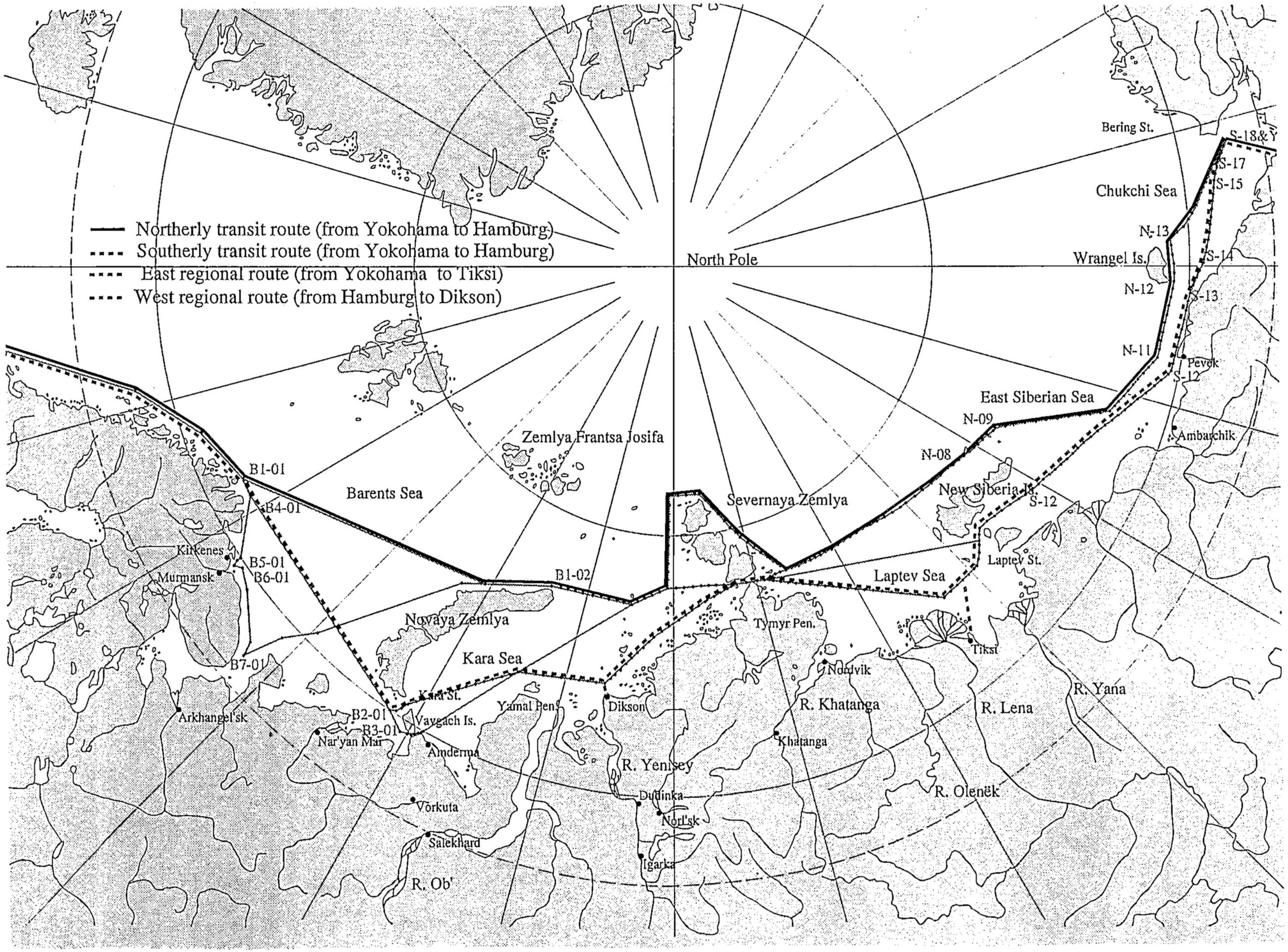


Figure 2.1.1 Schematics for four routes

2.2 Environmental condition

2.2.1 Summary of environmental condition

The environmental data supplied by the AARI (Brestkin et al.,1998) are the Russian data of the past 40 years、 which consist of eighteen parameters shown in Table 2.2.1.
The environmental data are comprised of the monthly average data which were described in each 20 nautical mile segment in specified year along the routes as noted in chapter 2.1.
The voyage route is defined from Yokohama to Hamburg, however, the environmental data were supplied only for the section of the NSR (from the Kara Sea to the Bering Sea). Those data existing out side of the NSR are excluded from the data above. Therefore, those excepted data are assumed as written in Appendix A. The data source are detailed in the following chapter. In order to indicate the approximate trends of 18 parameters in the Table 2.2.1, the yearly average, max., and min. values are shown in Table 2.2.3

Table 2.2.1 Environmental Data

No.	Parameter	Unit	No.	Parameter	Unit
1	Cold sum	°CDay	10	Wind direction	degree
2	Mean first-year ice concentration	1/10	11	Current direction	degree
3	Mean multi-year ice concentration	1/10	12	Floe size	km
4	Minimum ice concentration	1/10	13	Mean ridge size (sail height)	cm
5	Maximum ice concentration	1/10	14	Maximum ridge size	cm
6	Level ice thickness	cm	15	Maximum possible ridge size	m
7	Mean ice thickness	cm	16	Mean ridge density	1/km
8	Minimum ice thickness	cm	17	Minimum ridge density	1/km
9	Maximum ice thickness	cm	18	Maximum ridge density	1/km

Table 2.2.2 Point on the route and Segment number

	Way point		Segment number	
	N route	S route	N route	S route
Kara Sea	B1-01⇔N-04	B2-04⇔S-05	1⇔30	1⇔46
Laptev Sea	N-04⇔N-08	S-05⇔S-10	31⇔68	47⇔83
East Siberian Sea	N-08⇔N-12	S-10⇔S-13	69⇔108	84⇔120
Chukchi Sea	N-12⇔Y-01	S-13⇔Y-01	109⇔130	121⇔142

Cold sum (Parameter No. 1)

The average of monthly temperatures during 1953 to 1991, which were surveyed at fifty polar stations located along the coast of the Arctic Ocean, is used for the cold sum calculation. The value of each segment was estimated by interpolating observation data of three different polar stations.

Ice concentration (Parameter No.2 - No.5)

The ice concentration data were collected and completed based on the observation data from airplanes and satellites. Those data until 1978 were obtained from airplane observation. Satellite observation has been utilized from 1979. Mean first-year ice concentration is the average of the ice concentration in new ice, nilas, young ice, and first year ice. Mean multiyear ice concentration is the average of the ice concentration in old ice, second-year ice, and multi-year ice.

Table 2.2.3 Environmental parameter analysis

			N route				S route				Average	
No.	Parameter	Unit	Average	Max.	Min.	Stdv	Average	Max.	Min.	Stdv	Average	Stdv
1	Cold sum	°CDay	562.3	1808	0	304.6	542.3	1223	0	314.4	552.3	309.5
2	Mean first-year ice concentration	1/10	6.3	10	0	3.9	6.4	10	0	4.1	6.3	4.0
3	Mean multi-year ice concentration	1/10	1.7	10	0	2.8	1.2	10	0	2.5	1.4	2.6
4	Minimum ice concentration	1/10	7.7	10	0	3.8	7.3	10	0	4.1	7.5	4.0
5	Maximum ice concentration	1/10	8.1	10	0	3.5	7.7	10	0	3.8	7.9	3.7
6	Level ice thickness	cm	108.2	208	5	59.8	104.8	207.6	5	60.2	106.5	60.0
7	Mean ice thickness	cm	102.1	270	0	69.0	92.8	270	0	72.8	97.5	70.9
8	Minimum ice thickness	cm	95.8	270	0	70.5	87.4	270	0	74.1	91.6	72.3
9	Maximum ice thickness	cm	108.4	270	0	71.2	98.2	270	0	74.5	103.3	72.8
10	Wind direction	degree	155	359	0	90.8	157	359	0	91.7	156	91.3
11	Current direction	degree	197	359	0	107.1	196	359	0	104.6	197	105.9
12	Floe size	km	5.8	50	0	13.1	18.7	50	0	23.4	12.2	18.2
13	Mean ridge size (sail height)	cm	103.2	212	0	57.3	84.5	212	0	52.9	93.9	55.1
14	Maximum ridge size	cm	266.5	608.9	0	156.1	216.8	608.9	0	141.0	241.7	148.6
15	Maximum possible ridge size	m	3.4	8.57	0	2.1	2.8	8.57	0	1.9	3.1	2.0
16	Mean ridge density	1/km	14.8	89.2	0	13.2	13.0	88.2	0	14.6	13.9	13.9
17	Minimum ridge density	1/km	13.1	89.2	0	12.5	11.3	88.2	0	13.7	12.2	13.1
18	Maximum ridge density	1/km	16.4	89.2	0	14.8	14.7	89.2	0	16.4	15.5	15.6

Ice thickness (Parameter No.6 – No.9)

Level ice thickness was estimated by the cold sum and equation (2.2.1) (Zubov,1945) .

$$H^2 + 50H - 8\Sigma(-t) = 0 \qquad (2.2.1)$$

where, $-\Sigma(-t)$ is the cold sum. Ice thickness parameters No.7 – No.9 are different from the parameter of No.6. Taking the amount of melting and growth of ice into consideration, ice thickness parameters No.7 – No.9 were estimated based on the ice thickness data around May (the time when ices stops growing) observed by airplanes or at polar stations. The ice melting proceeds faster when the ice concentration is lower, which was also considered monthly basis. Ice thickness here indicates the whole average ice thickness including every category such as first-year ice and multi-year ice.

Wind direction (Parameter No.10)

The wind was estimated based on the surface atmospheric pressure data during 1964 to 1994. Firstly, the atmospheric pressures of primary segments were estimated by interpolating the data at polar stations. Then, the components (x, y) of the direction of wind speed were calculated by Zubov's method. By interpolating the value obtained above, the wind directions at sub-segments were calculated.

Current direction (Parameter No.11)

Using the distribution of density and the average temperature of seawater in the summer and winter of the few years, the current direction due to the density difference was calculated by the Zubov method. Based on the atmospheric pressure data, at the sea level, the current direction by the wind was calculated using the Davies calculation model. The components of total currents were calculated by means of the summation of the density and wind–driven current components.

Floe size (Parameter No.12)

The ice floe size was calculated based on visual airborne observation that was carried out during 1954 to 1985 from February to August. The ice floe size distribution was estimated using a scale of 10 units shown in Table 2.2.4.

Table 2.2.4 The scale of floe size distribution (Feb. - Aug.)

0	Cracks or leads are absent
1	Cracks or leads are more rare than every 10 km
2	Cracks or leads are observed every 5-10 km
3	Cracks or leads are observed every 3-5 km
4	Cracks or leads are observed every 2-3 km
5	Cracks or leads are more frequent than every 2 km
6	Ice pieces more than 500 m in size occupy 70-100 % of the ice area
7	Ice pieces more than 500 m in size occupy 40-60 % of the ice area
8	Ice pieces more than 500 m in size occupy 10-30 % of the ice area
9	Ice pieces more than 500 m in size are absent
10	Ice pieces more than 100 m in size are absent

The ice floe size was calculated using these scales of floe size distribution and the equation (2.2.2).

$$L = \frac{50}{1 + 1.85P + 0.7P^2} \quad (2.2.2)$$

where, P is a scale of floe size distribution. P is calculated using the equation of Apple, Gudkovich (2.2.3), when there is no observation data.

$$P = 6.5 - 0.15N + R \quad (2.2.3)$$

where, N is the ice concentration, R is the stage of melting.

<u>Determination of mean ridge height</u> (parameter 13)

The mean ridge height was estimated using the equation (2.2.4) based on Romanov's database.

$$H_S = nh_S^m \quad (2.2.4)$$

where, Hs is mean ridge sail height, hs is the mean ice thickness, for drifting ice m=0.62 and n=6.59, for land fast ice m=0.94, n=0.88

<u>Determination of the maximum ridge sail height</u> (parameter14 and 15)

Maximum ridge sail height is calculated as a value which can be exceeded with a probability of 1% ($H_{0.01}$: maximum ridge height) and 0.1% ($H_{0.001}$: maximum possible ridge height) that is shown in equation (2.2.5) and (2.2.6).

$$H_{0.01} = [\exp(In(In100) + \gamma InH_s - In\delta] \quad (2.2.5)$$

$$H_{0.001} = [\exp(In(In1000) + \gamma InH_s - In\delta] \quad (2.2.6)$$

where, Hs is the mean ridge sail height in meter, γ and δ are Weibull's parameters that was determined using ridge sail height distribution function data Romanov and Gavrilo. γ and δ are given by equation (2.2.7) and (2.2.8) .

$$\gamma = -0.67 Inh_s + 1.85 \qquad (2.2.7)$$

$$\delta = 0.97 h_s^{0.31} \qquad (2.2.8)$$

Ridge density (parameter 16-18)

Ridge density D[1/km] is obtained by equation (2.2.9).

$$D = \frac{47T^{4/3}}{5H_S} \qquad (2.2.9)$$

where, T is hummock and ridge concentration in conventional units (1 to 5), Hs is mean ridge height (parameter 13). Mean, minimum and maximum ridge density are determined using equation (2.2.9) and observed hummock and ridge concentration data.

The environmental data used for the voyage simulation

The parameters required for the ship speed calculation code from WP6 were adopted in this simulation. The selected seven parameters are cold sum, mean first-year ice concentration, mean multi-year ice concentration, floe size, mean ice thickness, mean ridge size, and mean ridge density. The cold sum data were not used directly for this simulation. Those data are used to estimate the ice bending and compressive strength. As floe size, average value of 40 years was used.

2.2.3 Fulfillment of environmental data and interpolation of lacking data

The reliability of the simulation depends on the fulfillment of the environmental data and the reliability increases with increase of the fulfillment rate. The yearly fulfillment rates of the data along the whole segments are shown in Table 2.2.5. Based on the data fulfillment analysis, the data were cut out or interpolated method as follows.

(1) As for cold sum, mean first year ice concentration, mean multi year ice concentration, mean ice thickness, floe size and mean ridge size, those data in which the data fulfillment mark lower than 50 percents are not used.

Cut out data : N route 1953-56, 61-63, 72
S route 1953-56, 62-64, 72

(2) The data of the year in which the data fulfillment was from 50 to 100 percents are interpolated in the direction of segments or months.

In the case in which the data are lacked more than five consecutive segments in the direction of segments or months, the average data of about 40 years of the segment are used. As to ridge density, the average data of 40 years of the segments are replaced for the lacked data, since the average of fulfillment is low as 27 percents.

Table 2.2.5 Fulfillment rates of the data (%)

Year	N-Route				S-Route			
	Param. 2	Param. 3	Param. 7	Param. 13	Param. 2	Param. 3	Param. 7	Param. 13
1953	48.8	40.4	7.4	7.4	42.0	42.0	6.8	6.8
1954	48.7	40.3	36.3	36.3	46.0	46.0	41.6	41.6
1955	51.7	45.3	42.8	42.8	48.2	48.2	45.7	45.7
1956	55.1	47.1	42.6	42.6	49.8	49.8	46.2	46.2
1957	63.2	54.9	52.0	52.0	57.0	57.0	52.4	52.4
1958	72.2	63.8	60.8	60.8	62.0	62.0	59.6	59.6
1959	80.8	72.4	68.0	68.0	73.7	73.7	71.1	71.1
1960	64.4	56.0	53.1	53.1	56.5	56.5	54.3	54.3
1961	60.9	52.6	49.6	49.6	52.6	52.6	50.2	50.2
1962	62.6	54.2	49.6	49.6	54.0	54.0	48.9	48.9
1963	54.1	45.8	40.8	40.8	49.3	49.3	44.8	44.8
1964	63.8	55.5	51.5	51.5	51.8	51.8	48.5	48.5
1965	73.3	64.9	61.1	61.1	67.1	67.1	63.5	63.5
1966	61.3	53.0	50.0	50.0	55.7	55.7	52.5	52.5
1967	79.6	71.2	68.7	68.7	72.4	72.4	69.6	69.6
1968	67.3	59.0	57.5	57.5	59.4	59.4	57.3	57.3
1969	64.6	56.3	52.9	52.9	59.6	59.6	57.5	57.5
1970	65.8	62.4	58.1	58.1	59.6	59.6	56.7	56.7
1971	75.4	74.4	70.8	70.8	73.9	73.9	72.3	72.3
1972	45.8	37.5	64.2	64.2	37.1	37.1	65.7	65.7
1973	66.6	61.2	60.8	60.8	61.4	61.4	61.4	61.4
1974	58.2	53.5	51.0	51.0	56.0	56.0	54.1	54.1
1975	73.0	68.5	64.8	64.8	68.9	68.9	65.8	65.8
1976	68.3	60.4	57.4	57.4	62.5	62.5	58.9	58.9
1977	65.7	59.7	58.0	58.0	64.8	64.8	63.5	63.5
1978	66.2	57.8	55.8	55.8	60.0	60.0	57.7	57.7
1979	63.6	58.2	54.6	54.6	65.8	65.8	59.9	59.9
1980	75.8	72.5	68.3	68.3	72.1	72.1	67.1	67.1
1981	64.2	61.2	58.5	58.5	67.6	67.6	65.0	65.0
1982	60.9	61.0	58.9	58.9	70.0	70.0	67.9	67.9
1983	67.5	65.8	62.7	62.7	74.3	74.3	72.2	72.2
1984	74.0	70.0	67.6	67.6	78.2	78.2	76.1	76.1
1985	72.1	72.9	72.9	72.9	75.2	75.2	73.1	73.1
1986	71.7	70.2	68.8	68.8	76.5	76.5	75.2	75.2
1987	65.9	62.7	60.6	60.6	71.6	71.6	68.5	68.5
1988	77.8	79.6	77.8	77.8	81.9	81.9	81.0	81.0
1989	70.5	71.6	72.8	72.8	74.4	74.4	75.5	75.5
1990	61.6	60.1	57.0	57.0	68.3	68.3	66.0	67.3

Determination of the environmental data for excluded from the NSR

Four different routes are considered in this simulation study as described in 2.1. However, as Figure 2.2.1 shows, segments between Hamburg and North Cape in the Barents Sea, and from the Bering Sea to Yokohama are excluded from the NSR. The environmental data along these routes were not supplied by WP1, thus they are estimated in accordance with the following assumptions.

(1) Ice exists only in a couple of segments neighboring the edge of NSR.
(2) The ice condition in a couple of segments lying next to the edge of the NSR is intermediate ice condition between ice free sea area and the edge of the NSR.

The rest of concrete determinations are detailed in Appendix A. The accuracy of these data was checked using the data produced by other INSROP study (Proshutinsky et al., 1998). Their data sources are mainly based on the US National Sea Ice Data Center. Assumed values of parameters were almost the same as their data on the average basis.

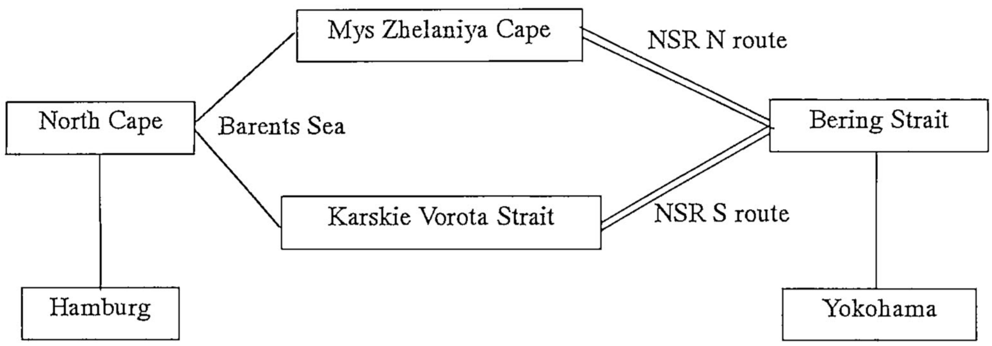


Figure 2.2.1 Exclusive routes from the NSR

2.3 Cost tables and cargo requirements

WP3 is responsible for gathering cost data necessary for the cost estimation and performing cargo analysis. WP3 report for cost table portion did not reach WP8 in time, and WP8 asked NYK Line to develop ship operation cost tables capturing recent trends. The backgrounds and assumptions to derive the cost tables are described in this chapter and the current and future cargo flow studied in WP3 is briefly summarized.

2.3.1 Cargo requirement

Three types of ships, 25,000DWT type bulk/container (25BC), 40,000DWT type bulk/container (40BC) , and also 50,000DWT type bulker (50BC), are used for this simulation. The details of ships are explained in chapter 2.4.

The kind of cargo should be assumed based on the respective cargo flow of a ship route, since it originally varies with either transit or regional route. WP3 has been investigating the recent cargo flows between Arctic regions of Russia and Far East or Asian-Pacific region. The results indicate that Russia exports a lot of ferrous metal and chemical/mineral fertilizers. They also predict the increment of the machinery and equipment exports from Russia in the future. Figure 2.3.1 is referred to "The structure of Russian export cargo flow in 1996" from WP3 discussion paper (Ivanov et al. 1998).

On the other hand, the prediction of potential cargo flows through the NSR between Pacific Asia and Europe was explained in "Northern Sea Route Reconnaissance Report (US Army Corps of Engineers, 1995)". Figure 2.3.2 summarizes the prediction of the cargo flows from Pacific Asia to Europe referred from the report, and Figure 2.3.3 summarizes the one from Europe to Pacific Asia. Their prediction was assumed for 60 day navigation in the NSR. It also predicts that the amount of the cargo flows by a container cargo and bulk cargo would be increased enormously.

Accurate prediction is not easy, hence, in reality, the kind of cargo and the cargo flows in sea trade depend on the type of ship operation or an economic trend of each country. A bulk cargo was selected for the series of simulation referring the above result, that the kind of cargo has the large amount of cargo flows at present and future, and also it is relatively general cargo in sea trades. Ferrous metal and chemical/mineral fertilizers could be assumed to be exported from Russia on the regional route. On the transit route between Europe and Pacific Asia, grain, coal, coke, and food products are considered as the cargo flow.

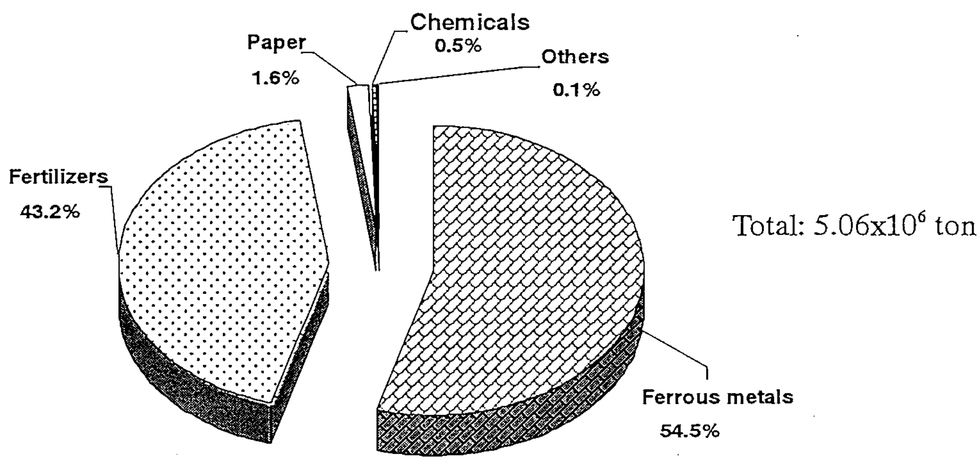


Fig.2.3.1 Structure of cargo flow exported through the ports of Baltic and Northern basins in 1996 from (Ivanov et al.,1998)

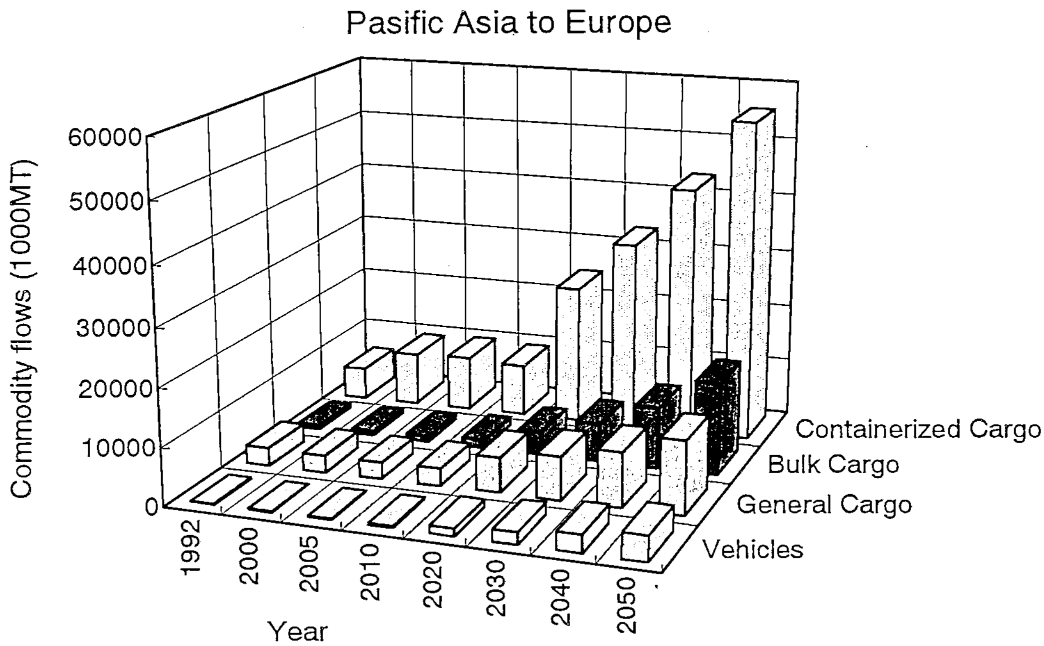


Fig.2.3.2 Potential Northern Sea Route commodity flows by cargo type, assuming 60-day navigation season (Pacific Asia to Europe)

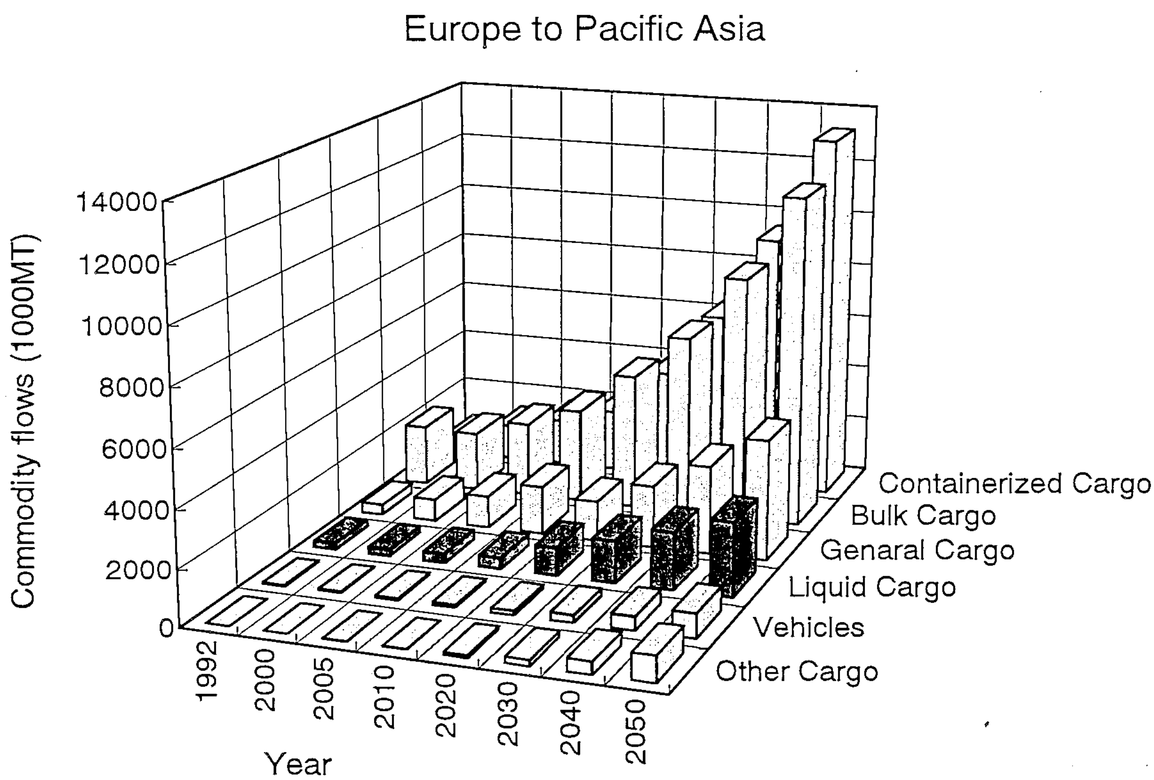


Fig.2.3.3 Potential Northern Sea Route commodity flows by cargo type, assuming 60-day navigation season (Europe to Pacific Asia)

2.3.2 Cost tables

Table 2.3.1 shows the cost tables for three cargo ships used for the simulation. The Capital cost and the following running costs are considered as cost items consisting of ship operation costs. In order to investigate the operation cost through Suez route, the tariff rates for the Suez Canal are also prepared.

Capital cost

Capital costs for a new build ship are comprised of a loan repayment of initial investments that are sum of a new build ship price and an initial miscellaneous costs. It is assumed that a ship owner amortizes these costs in 15 years at 7% interest per year with level payment. The initial miscellaneous costs are considered as additional costs for a newly built ship, and it includes interest during building stage and equipment/deposits to be newly furnished for navigation. It is predetermined as 3 percents of a ship price. This assumption is the average for the bulkers from 25,000 to 50,000DWT. The prices of 25BC and 40BC are given by WP4. The price of 50BC is decided from the SOF relevant studies (1998, SOF).

Crewing cost

A number of crews are 24 for both 25BC and 40BC, and 25 for 50BC. The average costs per month for these crews are given as crewing costs.

Maintenance costs

The averages of annual maintenance costs of five years after ship constructions are used as maintenance costs per year. These costs are based on the actual results in the last few years obtained for the same class ships. These costs include repairs, replenishment of parts and stocks and lubrication oils and other miscellaneous expenses.

Insurance costs

The ship insurance seems to be difficult to estimate properly due to the limitation of the actual results. Considering the voyage in ice infested seas, the risk is larger than that of Suez route. The ship insurance is usually assigned to P&I (Protection and Indemnity) and H&M (Hull and Machinery). P&I insurance that includes cargo insurance depends on a ship size and a type of cargo. H&M insurance depends on the ship price. P&I insurance is decided as 8$/GT based on the report from WP7. Also, H&M insurance complies with the ship price taking account for the damage rate in the NSR. There is no official data of the rate of damages, so that we roughly estimate H&M insurance assuming the annual sinking rate in the NSR as 0.1%. Thus, H&M insurance ranging from 1.0 to 2.9$/GT are obtained. Adding P&I of 8$/GT to this H&M insurance ranges, we reached an insurance of 10$/GT in round number as the package insurance covering both H&M and P&I. On the other hands, there are many actual data of the ship insurance through Suez route. Consequently, this insurance turned twice as much as that of the Suez route as listed in Table 2.3.1.

Fuel cost

In the last few years, the banker prices were fluctuated. The heavy fuel oil of 380cSt are assumed as a fuel, and the average prices for the last five years were adopted.

Icebreaker escort fee

The icebreaker escort fee is referenced in Table 2.3.2 that is cited from the WP7 report. The fee is as a function of gross tonnage, season and area and specified up to 20,000GT. The actual prices will be decided after negotiation with MSCO operating icebreakers. The icebreaker fee includes ice-forecast and route recommendation services. The fee per GT decreases as increasing GT, and the fees for the three simulated ships are extrapolated from Table 2.3.2. Figure 2.3.1 illustrates the relation between gross tonnage and tariff rate per GT. The tariff rate of 50,000 DWT bulker is raised by 10% from the extrapolated value, considering the inferiority of ship performance in comparison with other ships. The escort fee is charged per voyage and regarded as flat rate, thus the frequency of icebreaker escort does not affect it. As the miscellaneous costs, ice pilot costs per day are added when the ships stay within the NSR. One ice pilot is assumed in Regional West routes and two ice pilots are mandate in the other three routes. The working hours of ice pilot is assumed as 12 hours per day.

Port costs

The port costs are needed at each call for port for the use of tag boat, harbor facilities, and loading/unloading costs. This cost considerably varies with each port and a type of cargoes. As it is explained in 2.3.1, the kind of cargo is assumed as a bulk cargo of grain, plastic and the like. Four ports, Yokohama, Hamburg, Tiksi, Dikson are selected as departure/arrival ports. The port costs at Hamburg and Yokohama are based on the data studied by NYK and those of Tiksi and Dikson were refereed from the WP report.

Table 2.3.1 Cost tables for the simulated three ships

cos	UNIT	25,000 DWT type BULK/CONTAINER	40,000 DWT type BULK/CONTAINER	50,000 DWT type BULKER
BUILD PRICE	M$	57	66	30
CAPITAL COSTS	M$/year	6.45	7.46	3.39
ICEBREAKER FEE				
* Summer N-route	$/GT	-	7.11	6.83
* Summer S-route	$/GT	7.36	-	-
* Summer E-route	$/GT	7.36	-	-
* Summer W-route	$/GT	4.78	-	-
* Winter N-route	$/GT	-	6.89	6.56
* Winter S-route	$/GT	7.14	-	-
* Winter E-route, W-route	$/GT	7.14	-	-
ICE PILOT FEE				
* N-route	$/day	-	672	672
* S-route	$/day	672	-	-
* E-route	$/day	672	-	-
* W-route	$/day	336	-	-
ROUTE RECOMMENDATION		included in IB fee	included in IB fee	included in IB fee
CREWING COST	K$/day	4.21	4.21	4.38
MAINTENANCE COST	K$/year	473	493	560
INSURANCE				
* NSR	$/GT/year	10.0	10.0	10.0
	K$/year	210.0	226.0	310.0
* SUEZ route	$/GT/year	5.7	5.5	4.8
	K$/year	119.7	124.3	148.8
FUEL UNIT COST (380 cSt)	$/ton	91	91	91
PORT DUES				
* Hambrug (6days)	K$/stop	78.2	84.2	113.1
* Dikson (4days)	K$/stop	19.2	-	-
* Tiksi (4days)	K$/stop	19.2	-	-
* Yokohama (6days)	K$/stop	44.5	47.4	59.7
SUEZ canal transit tolls	K$/transit	122	127	139
Number of crew	person	24	24	25
Gross tonnage	GT	21,000	22,600	31,000

Table 2.3.2 Icebreaker Tariff from WP7 report (Semanov et.al, 1998)

Ice class of vessle	Regisiter tonnage(GT)		Cost of leading USD/GT		
			Summer		Winter
	From	to	Entire NSR	Part of NSR	
Icebreaker	5001	6000	7.26	4.36	6.53
	10001	11000	6.58	3.95	5.92
	19001	20000	5.49	3.29	4.94
ULA	5001	6000	9.98	6.49	9.73
	10001	11000	9.04	5.88	8.82
	19001	20000	7.54	4.90	7.36
UL	5001	6000	18.15	11.80	17.70
	10001	11000	16.44	10.68	16.03
	19001	20000	13.72	8.92	13.37
L1	5001	6000	22.69	15.88	23.82
	10001	11000	20.55	14.38	21.58
	19001	20000	17.15	12.00	18.00

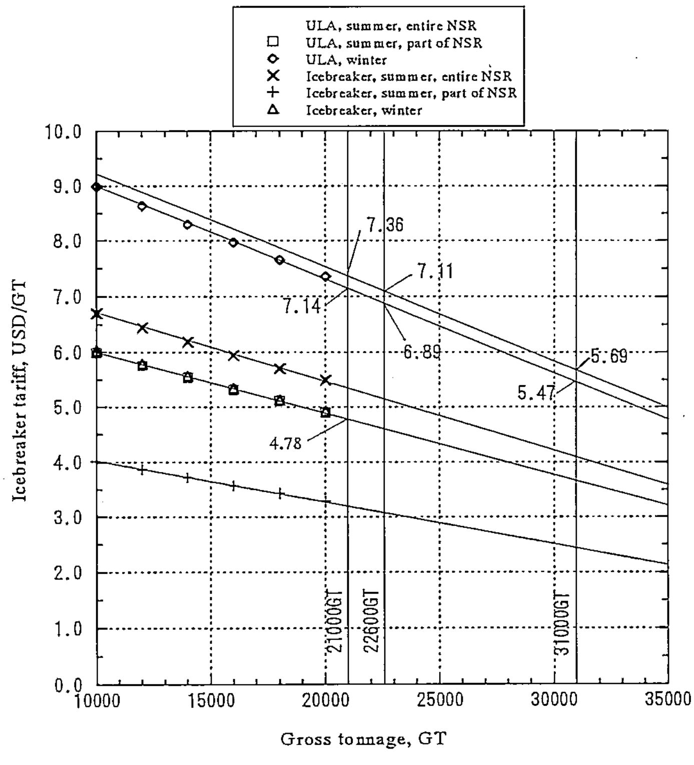


Figure 2.3.1 Icebreaker Tariff extrapolated from Table 2.3.2

2.4 Service ships

Three service ships were used for the simulation. They are all hypothetical ships, although their performance and principle dimensions were confirmed employing ice tank tests and past design data. WP4 conducted the preliminary design for two icebreaking bulk/container ships with 40,000 and 25,000 dead weight tons (Juurmma et al., 1998). A type of ships should have been selected following cargo flow analysis in current and future, although the whole phase II project are running in parallel and not allowed to wait for the result of cargo flow analysis done in WP3. Currently, there is little demand for specified cargoes in the NSR, and it also makes difficult to select an optimum type of ships for the simulation. Thus, a sort of open bulk carriers is selected as a type of ships to comply with multi cargo demand in future as a compromised solution. These two ships are able to carry dry bulk including ore, timber and containers.

The Ship and Ocean Foundation provided 50,000DWT bulk carrier design that was developed by the NSR steering committee in Japan (SOF, 1998). This ship enhances open water performance and cargo volume rather than icebreaking capability. It would be suitable to examine the effects of less powered ship and larger cargo volume.

Table 2.4.1 summarizes the principal dimensions for three ships and Arctic class selected as an escort icebreaker.

40,000 DWT Icebreaking Bulk/Container Carrier

The design was aimed to enhance both icebreaking capability and dead weight up to 8 month independent navigation and 40,000DWT respectively. This ship is assumed to deploy in Northerly route and has a draft of 12.5m. Figure 2.4.1 shows the general arrangement and rough body plan. This ship features the DAS (Double-Acting Azipod Ship) with Azipod as well as adopted by MT Lunni. The Azipod rotates 360° and realize the full DAS concept, therefore the Azipod works as pulling mode (the propeller comes first). The propulsion is provided with two full rotating Azipod-units podded syncrhronous AC motors rating 14MW each. Four medium-speed engines rating 7.92MW each generate the AC electricity. The motors are controlled by cycloconverters. The schematics of diesel electric systems are depicted in Figure 2.4.2. The going astern mode is usual employed in moderate ice conditions without multi-year ice to preclude multi-year fragments from hitting against Azipods that are unable to bear high ice load. Therefore, the conventional icebreaking bow form is adopted in order to go ahead in heavy ice condition including multi-year fragments. The cargo ship has 8 cargo holds and 6 of them are divided in upper and lower holds. The cargo holds are protected with double bottom and double sides along the whole cargo length. The upper and lower holds are suitable for timber and ore respectively. When containers are laden, pivot type hatches in the middle of cargo holds will be kept open. The ship carries 825 TEU in cargo holds, 846 TEU on deck, and 1671 TEU in total when used as a container ship.

The icebreaking capability was estimated by the ice tank test using 1/30 scale model. From the ice tank test results, it is estimated that the vessel breaks 1.2m thick level ice at 3 m/sec. with ahead mode, and also 1.8m and 1.85m thick ice at 1.1m/sec. and 1.0m/sec. with astern mode respectively. As for ridge, tests astern were made in two ridges with thickness corresponding to 15 to 20m and length to 180m in full scale. According to the tests, the vessel is capable to penetrate the ridge continuously by turning the Azipod to and fro. However, when going ahead, the vessel was not able to move continuously, and three rammings were necessary to break through a ridge of 15m thickness in full scale. In open water, service speed is 14.5 knots with 15% sea margin and required power will be 15.8MW that are supplied by two engines.

25,000 DWT Icebreaking Bulk/Container Carrier

This 25,000DWT ship was designed to keep the same icebreaking capability as 40,000DWT ship with 9m draft limitation, and aimed to be deployed in the Southerly route and regional routes. The configuration and cargoes are similar to 40,000DWT ship. Icebreaking capabilities are interpolated from the results of 40,000DWT. Figure 2.4.3 shows the general arrangement and rough body plan. Lpp is approximately 2m shorter and D is 1m smaller than those of 40,000DWT in order to maintain cargo capacity requirement and hull girder strength.

50,000 DWT Icebreaking Bulk Carrier

The design studies were performed in the Ship and Ocean Foundation as the relevant project of the INSROP to improve capabilities of the vessel employed in the NSR, especially economical viewpoints. Before this vessel was developed, the extensive studies were carried out to select an optimum bow and stern form for 8m draft ship, 25,620 ton in displacement (Kitagawa, H., 1995). As first step, three typical bow and two stern forms were selected to grasp basic performance, and Figure 2.4.4 shows their configuration. Bow form A so-called "conventional", represents relatively simple V type frame lines, large flare angles, and stem angle close to 25°. Bow form B " Spoon " represents close to spoon-bow form, large flare angle of bow at water line, and stem angle of 19°. Bow form C "Concave" has concave frame line of bow at the load water line, constant large flare angle from bow to shoulder. As for stern forms, Stern form "a" has U-shape frame lines, mariner type stern profile, and Stern form "b" has U-shape frame line accentuated near the bottom.

The extensive series test both in ice tanks and open water tank were performed including maneuvering tests in ice tank and sea keeping tests in wave. Then, the new bow form named Bow form D was derived as an optimum bow form incorporating the advantages of Bow form A that was superior in open water performance as well as the advantages of Bow form B that exhibited less ice resistance. As for stern form, a new stern form "d" was proposed, that has shorten parallel portion and smaller inclination angles at frame lines from SS.1/2 to 3 in order to improve maneuvering performance. The bow and stern form developed for this 8m-draft vessel extended to 12.5m draft vessel with approximately 50,000 DWT. The performance of newly designed ship was confirmed by also extensive ice and open water tank tests. Figure 2.4.5 shows the general arrangement and body plan and principal particulars. The vessel has 7 holds, navigates 17 knots in open water and breaks 1.2m level ice at 3 knots.

Table 2.4.1 Principal dimensions for the service ships and escorted icebreaker

Parameter	Unit	Ship			
		25000 DWT bulk/container	40000 DWT bulk/container	50000DWT bulk	Arktika
Loa	m	199.9	206.5	252.0	148.0
Lpp	m	184.1	186.1	240.0	136.0
Length of bow region	m	36.8	51.1	24.6	35.5
Length of parallel part	m	86.1	50.0	62.6	65.0
B	m	25.1	27.5	30.0	28.0
D	m	15.0	16.0	18.8	17.2
d	m	9.0	12.5	12.5	11.0
Stem angle	deg	30.0	30.0	25.0	24.0
Waterline entrance angle	deg	52.0	50.0	43.0	40.0
Cb		0.813	0.751	0.767	0.546
Cm		0.995	0.998	0.978	0.900
Cp		0.817	0.751	0.784	0.607
Cwp		0.949	0.932	0.847	0.701
Speed in open water	knot	14.50	14.50	17.00	20.80
Number of propellers		2	2	1	3
Propeller diameter	m	5.2	5.8	7.1	5.3
Shaft power	kw	24000	28000	16578	49000
Lcb from midship (+ forward)	m	2.94	3.44	0.34	0.00
Displacement	MT	35700	52000	70960	23460
Gross tonnage	GT	21000	22600	31000	-
Cargo tonnage	MT	21500	36000	47000	-
Fuel consumption of main engine	g/ps/hour	187.1	187.1	171.2	-
Fuel consumption of generator (sea going)	MT/day	-	-	1.54	-
Fuel consumption of generator (port)	MT/day	3.81	3.81	3.08	-

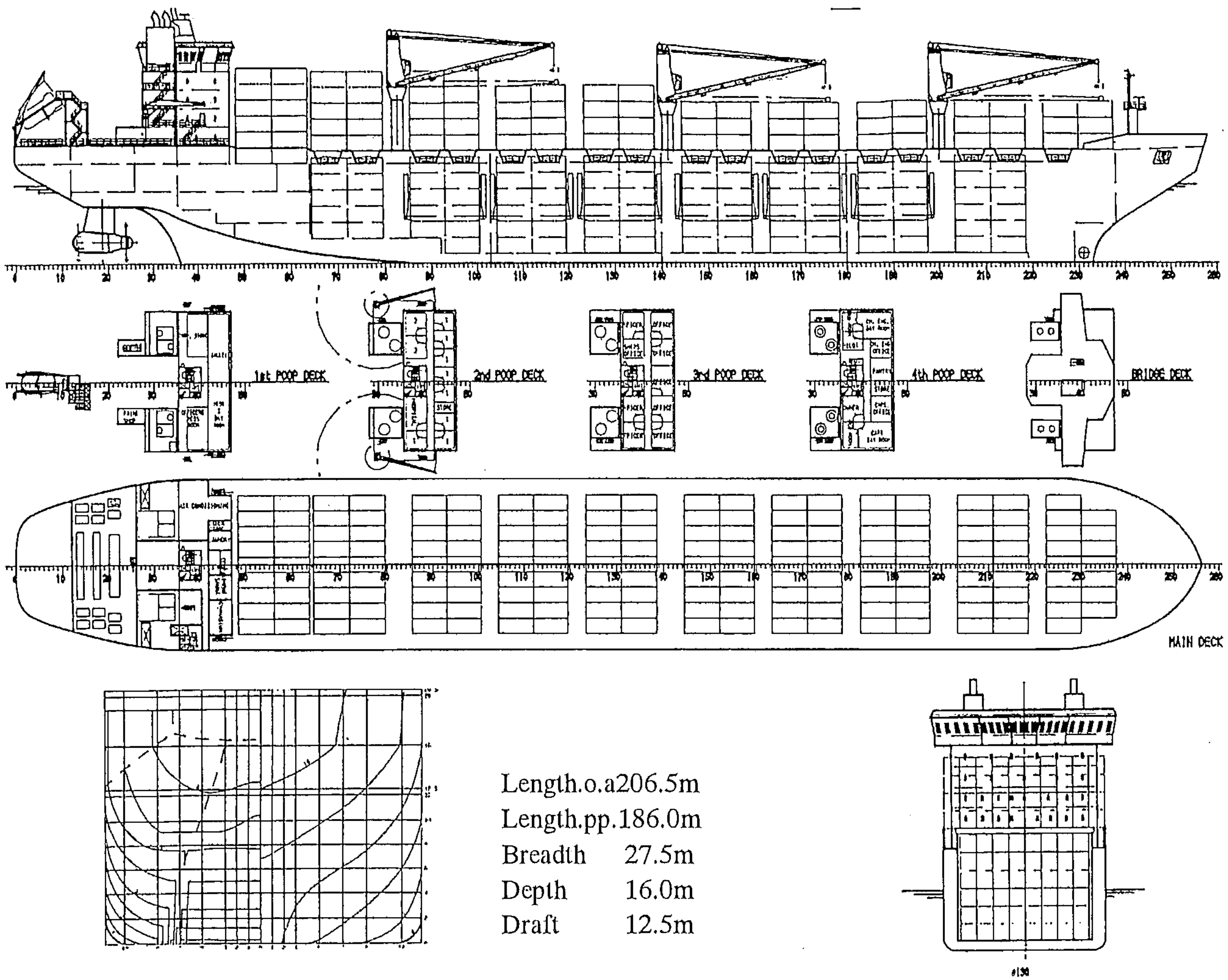


Figure 2.4.1 40,000DWT DAS Icebreaking Bulk/Container Ship

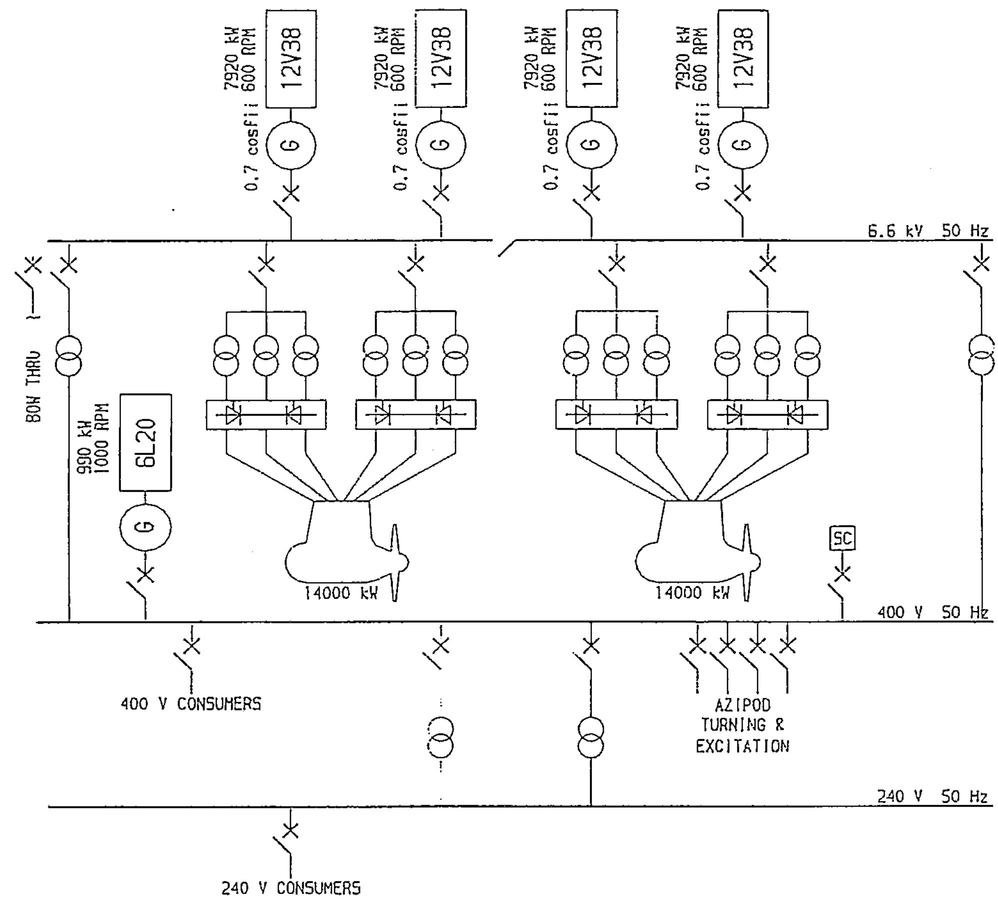


Figure 2.4.2 Schematic of Diesel Electric System

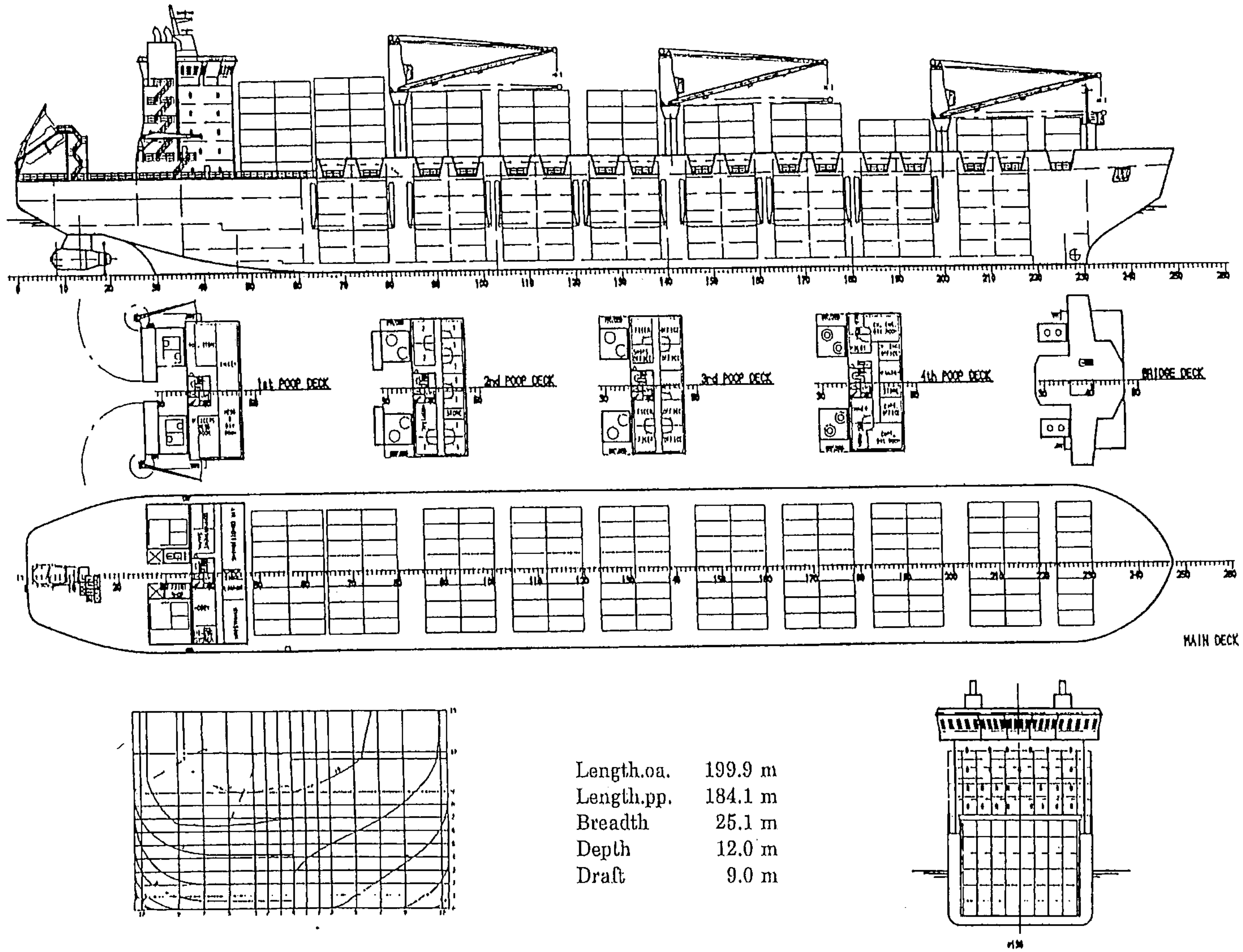


Figure 2.4.3 25,000dwt DAS Icebreaking Bulk/Container Ship

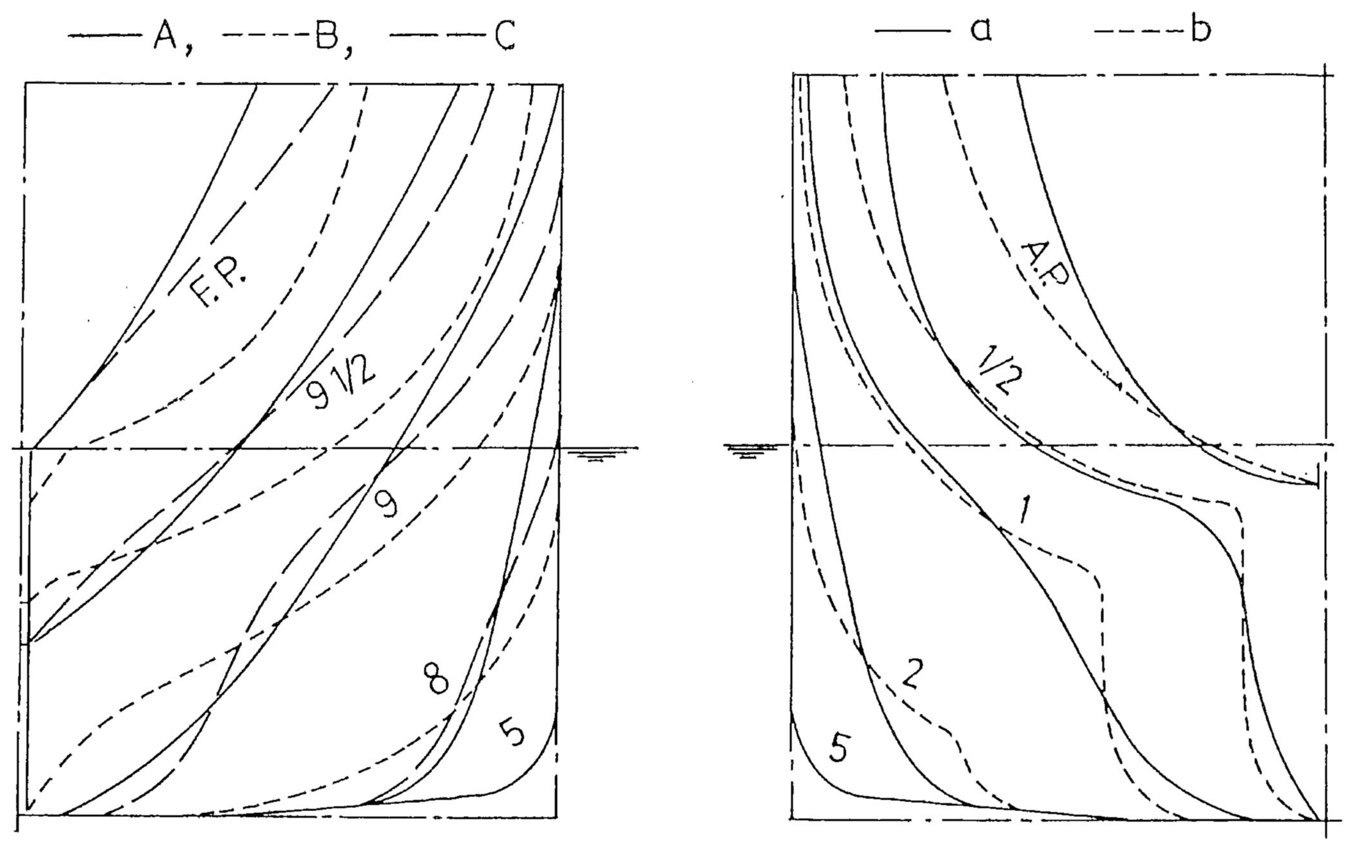
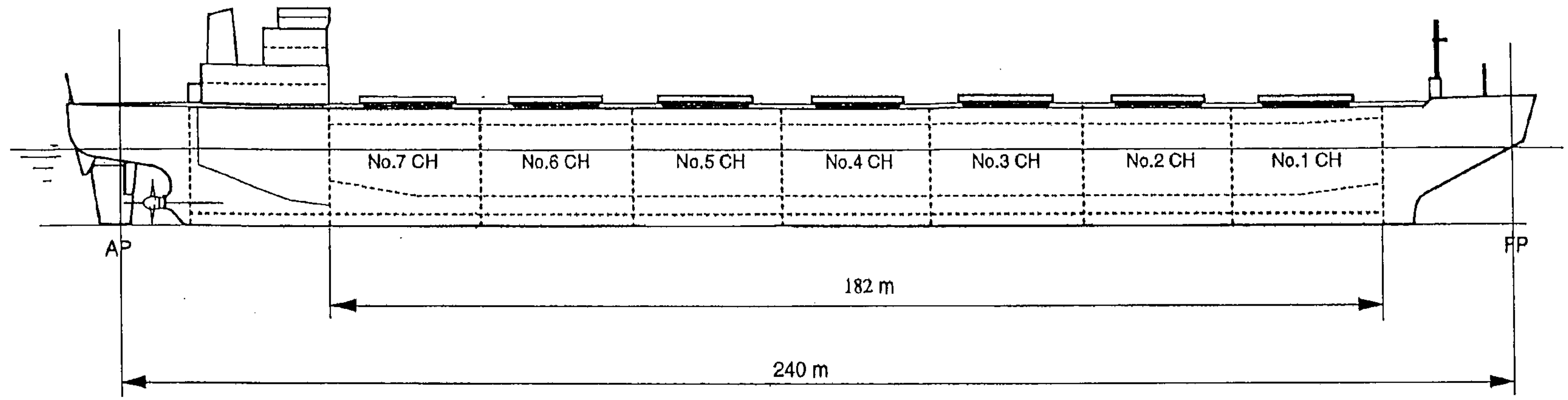
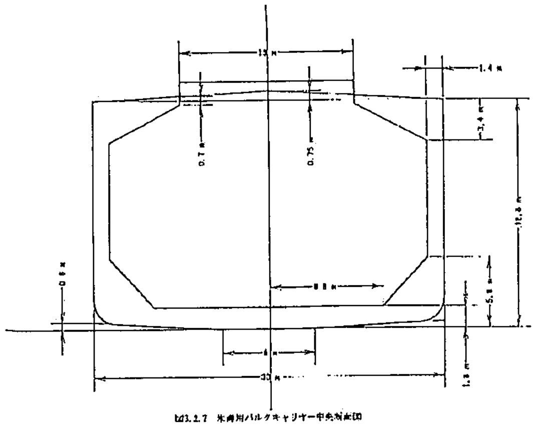


Figure 2.4.4 Bow Forms A,B,C and Stern Form a,b





Principal Particulars for
50,000 DWT Icebreaking Bulk Carrier

Length O.A.	252.2m
Length P.P.	240.0m
Breadth	30.0m
Depth	18.8m
Draft	12.5m
Block Coefficient	0.767
Displacement	70,900MT
Dead Weight	50,900MT
Cargo Capacity	abt. 70,000M3
Velocity in open water	17.0 knots at NSO with 15% S.M.
Velocity in level ice	3 knots in 1.2m thick level ice
Engine power, MCO	18.02 MW
Engine power, NSO	16.21 MW, 90% MCO
Propeller	7.1m Dia. x 1 (Fixed)

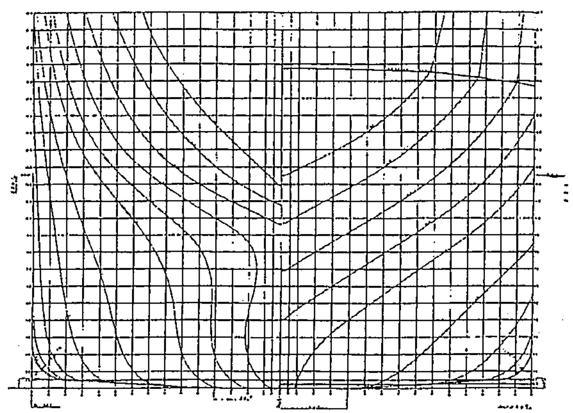


Figure 2.4.5 50,000DWT Icebreaking Bulk Carrier

2.5 SA-15 Operation data

WP5 collected SA-15 data as to icebreaking capability and hull damages in order to calibrate the ship transit velocity simulation code developed by WP6 and refered to the service ship designed by WP4. In this chapter, the icebreaking capabilities are briefly summarized. The details are refereed to WP1 report (Tsoy et al., 1998).

General Features

SA-15 was the designation for the Finnish/Russian development for 15,000 ton multipurpose cargo ships whose purpose was to improve delivery of various cargoes to the ports of the western NSR on an year round basis. In total, 19 ships were built in the two shipyards, Wärtsilä and Valmet in Finland during the period of 1982 to 1987. The general arrangement is shown in Figure 2.5.1. The SA-15 class equipped a roll-on roll-off deck with the stern ramp to discharge cargo directly on the land fast ices off the arctic ports in the winter season. The ship was designed to meet the requirement for ULA class of Russian register of shipping to attain sufficient ice performance both in summer with independent operation and in winter period with escort by the Arktica class icebreakers.

Several innovative systems were aboard the SA-15s. An air bubbling system was adopted to reduce friction and accretion between a hull and snow/ice at low air temperature in winter, and a hull was coated with low friction paint, Inerta-160. The SA-15 power plant comprises two medium speed engines of 7.72 MW output per each at 560 revolution per minute. Fluid couplings and friction couplings were installed between the main engines and the reduction gear. The former is mainly employed in navigating in ice to protect the propulsion system from ice torque. The latter is used for open water or light ice conditions. A controllable pitch propeller with four blades was adopted to attain a quick thrust change in ice. It measures 5.6 m in diameter and 0.42 in hub/blade ratio. The principal particulars of the SA-15s are listed in Table 2.5.1.

Icebreaking Capability

Ship speed in level ice and pack ice

Extensive tests were performed in the Yenisei Gulf at the beginning of May in 1983 as the ice trial of SA-15 m/s *Igarka.* The tests were run to confirm the icebreaking capability in various conditions and to assess the performance of air bubbling systems. The design specifications requested continuous icebreaking capability in 1m thick ice with 20cm-snow cover at a speed of 1 knot. Figure 2.5.2 shows the power speed relation in 0.7 to 0.8m compact level ice with 5 to 10cm thick snow covers. Figure 2.5.3 plotted the relation between speed and ice thickness at a power of 90% of the maximum continuous output.
The test showed far better icebreaking capability than the specifications and m/s *Igarka* recorded a minimum steady speed of 0.5 knot against 1.3m thick fast level ice with 20cm snow cover. A far better velocity is obtained when transiting pack ice, and Figure 2.5.4 shows the velocity as a function of ice concentration in tenth class of ice cake.

Ship Speed in various ice conditions

In reality, an icebreaking ship encounters various ice conditions and ship operators have to estimate a ship velocity as a function of ice regime in order to predict a transit time. Figure 2.5.5 illustrates a ship velocity against mixed ice concentrations with different ice ages containing hummocking fields ranging from 1/5 to 2/5. This figure clearly demonstrates that the ship transit velocity decreases considerably when encountering the heavier the ice conditions. The severity is expressed as a function of multiples of ice concentration and its category such as ice free water, gray-white ice, first-year ice, second-year ice and multi-year ice occupies. In order to develop the ice numeral, we need the data as depicted in Figure 2.5.5

that shows the ice conditions including ice categories, their ice concentrations and average navigation velocity. The data like Figure 2.5.5 are useful to verify the relation between ice index and velocities. CASPPR adopted ice numerals that are calculated from ice class and ice conditions. An icebreaking vessel does not allow to enter into area that ice numeral is negative.

Ship Speed in escorted navigation

An icebreaking cargo ship has to maintain a sufficient speed in a broken channel made by a leading icebreaker. When selecting the power level of the SA-15 class, they were designed to attain the most efficient icebreaking capability when escorted by the Arktika class icebreakers that are the major ships in the NSR icebreaker fleet. Figure 2.5.6 indicates the dependence of speed moving through the broken channel made by the Arktika class icebreakers. The Arktika class icebreakers can navigate at approximately 2 knots in the 2m thick compact ice. While the SA-15 class can navigate slightly over 2 knots and thus the compatibility to the icebreaker can be well balanced. The data stored for 15-year operation enables to derive possible navigation days as a function of ice breaking capability. Figure 2.5.7 represents the relation between independent navigation days and icebreaking capability escorting the SA-15 while ensuring safety operation against a relative heavier ice condition with four year return periods. The SA-15 class can continuously break ice approximately one meter thick. Thus, the SA-15s can independently navigate for: one month in transit navigation and in the eastern navigation; 2.5 months in the western Arctic area; 3 months in the western Kara Sea and 6 months in the Pechora Sea.

Table 2.5.1
Principal particulars of icebreaking cargo ships of the SA-15 type

Characteristics	Value
Type of ship	Multipurpose
Number of units in the series	19
Year of construction	1982-1987
Ice class	ULA
Length, m	
• overall	174
• between perpendiculars	159.6
Breadth, m	24.5
Depth, m	15.2
Draft, m	
• loaded	10.5
• arctic	9
• specified	8.5
Displacement, t	
• loadline	31200
• arctic	25900
• specified	24100
Deadweight, t	
• loadline	20000
• arctic	14700
• specified	12900
Cargo-carrying capacity, t	
• loadline	15700
• arctic	10345
• specified	8555
Register tonnage, reg.t	
• gross	16500
• net	11000
Number of holds/tweendecks	5 / 5
Container capacity, units	532 × 20′ or 240 × 40′
Number and lifting capacity of cranes, units × t	3 × 20 and 1 × double 40
Type of propulsion plant	Medium speed engine
Main engine	*Wärtsilä-Sulzer* 14ZV 40/48
Number and power of main engines, kW	
• maximum	2 × 7700
• service	2 × 6930
Engine room location	Intermediate
Number and type of propellers	1 × CPP
Icebreaking capability at 2 kn speed, m	1.0
Open water speed (at the maximum load), kn	18.1
Endurance, miles	12000
Number of crew, person	39

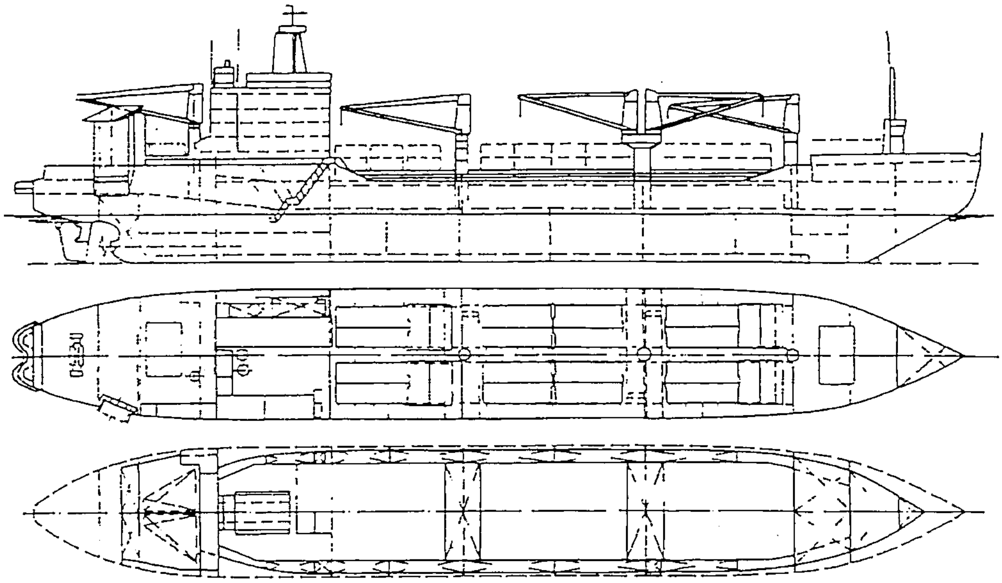


Fig.2.5.1 General arrangement plan of SA-*15* class

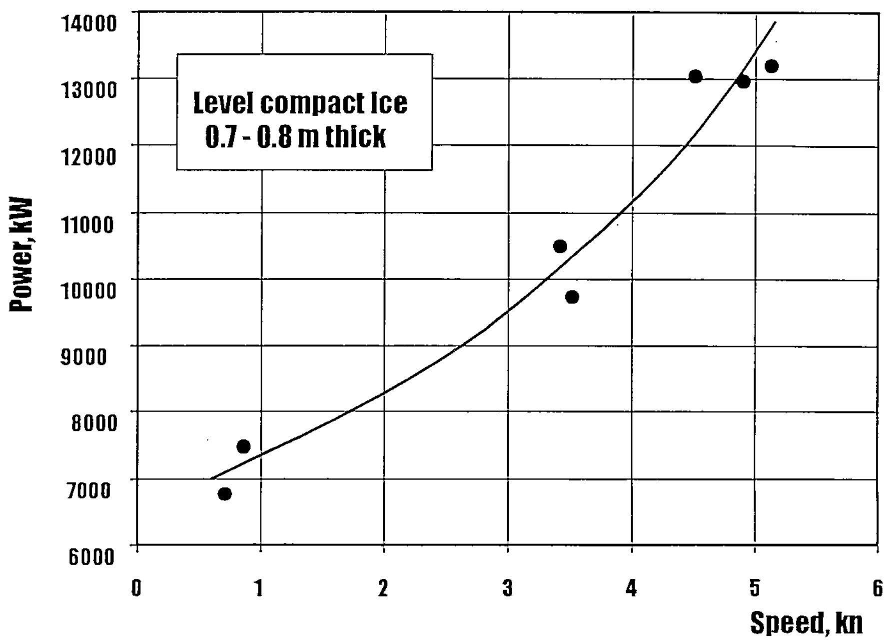


Fig.2.5.2 Relationship between speed and main engines power of m/s *Igarka*

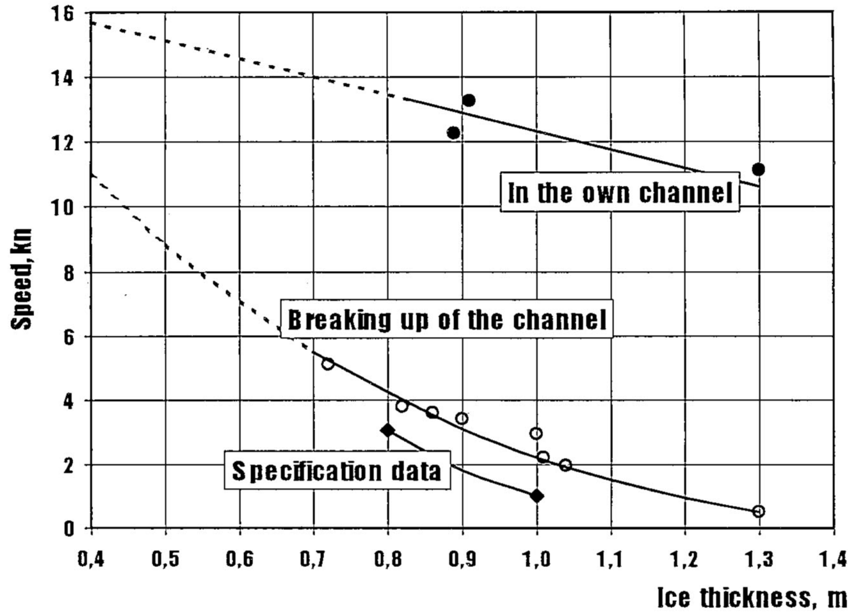


Fig.2.5.3 Propulsion of m/s *Igarka* in the level compact ice
(Snow cover 10 to 15 cm deep) ice conditions

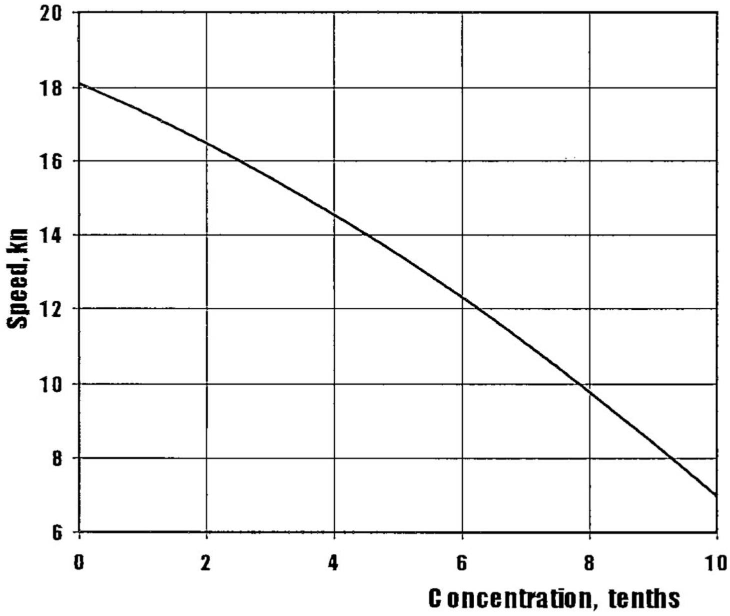


Fig.2.5.4 Influence of the concentration of ice on speed of the *SA-15* type ships
during their navigation independently through the ice cake

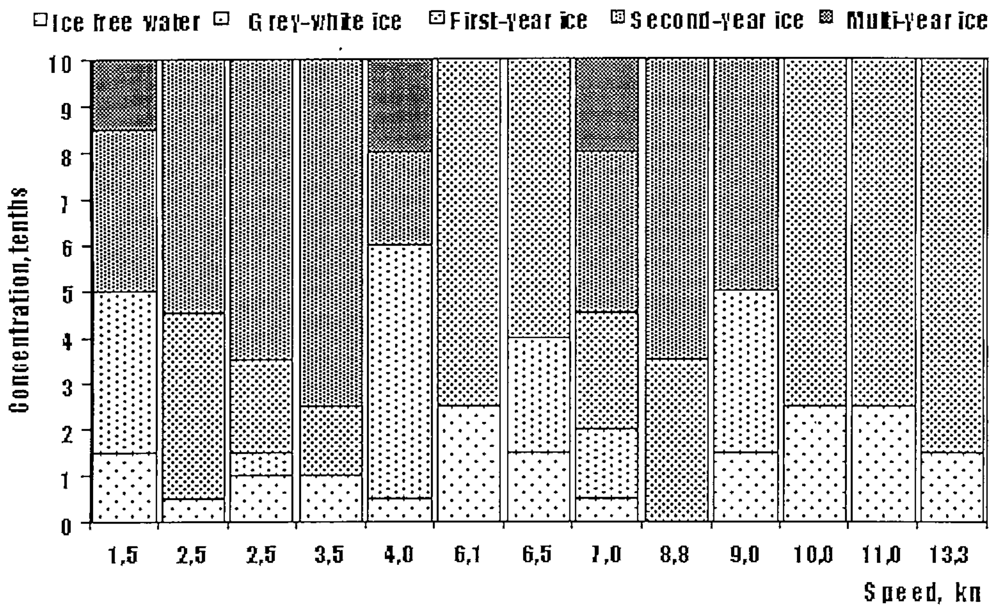


Fig.2.5.5 Variations in speed of ship of the *SA-15* type navigating in drifting ice of different concentration (hummocking 1/5 to 2/5)

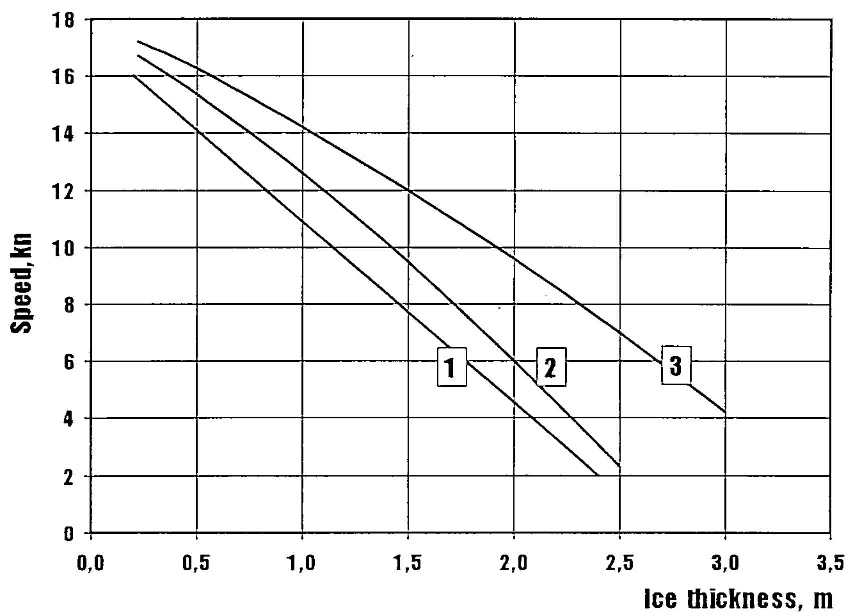


Fig.2.5.6 Propulsion of ships of the *SA-15* type during the navigation under assistance of icebreaker of the *Arktika* type in the fast ice and vast giant (1), medium and small floes with a concentration of 9/10 from 10/10 (2) and 7/10 from 8/10 (3)

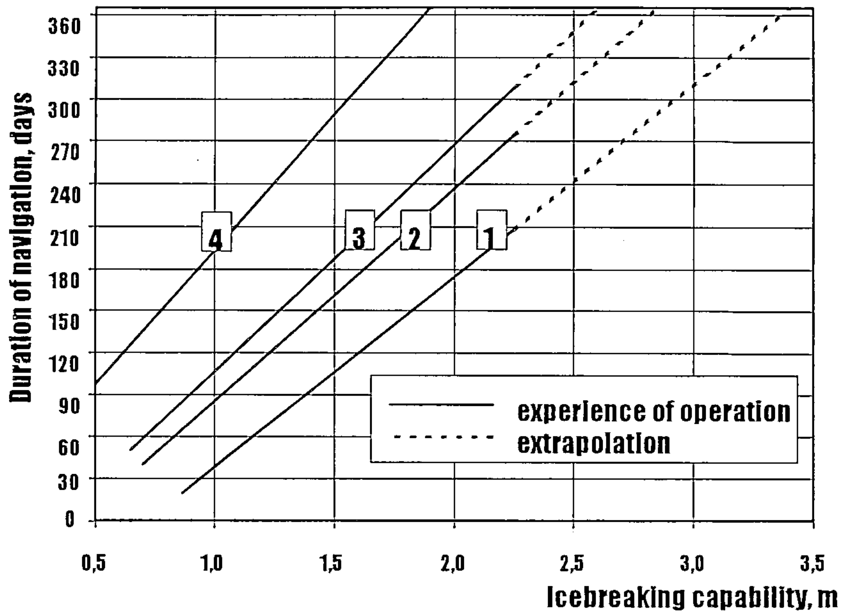


Fig.2.5.7 Relationship between the duration of navigational period in the Arctic and the icebreaking capability of icebreakers:

1 – transit navigation along the NSR and in the eastern area of the Arctic,

2 – western area of the Arctic,

3 – western part of the Kara Sea,

2.6 Transit ship speed simulation code

2.6.1 Summary of the development for transit ship speed code

Transit ship speed code: NEWSIM2

The ship velocity simulation code named NEWSIM has been developed by the Helsinki University of Technology (Lensu et al., 1996) in INSROP phase 1 in order to calculate ship transit velocity in ice infested waters. However, NEWSIM dealt with too simple ice condition, and NEWSIM2 is newly developed (Riska et al., 1998) for this simulation to incorporate parameters prepared by WP2. NEWSIM2 is the code using FORTRAN, and it enables to calculate ship speed in five different types of ice conditions;

Open water
Channel ice
Level ice
Ridged ice
Pack ice

Table 2.6.1 shows input parameters of NEWSIM 2.

Table 2.6.1 Input parameters

Ship Parameters (Units)	Symbol	Ice Parameters	Symbol
Length between Perpendiculars (m)	L_{PP}	Ice Density (kg/m^3)	P_t
Length of Bow Region (m)	L_{BOW}	Ice Bending Strength (MPa)	σ_B
Length of Parallel Midbody (m)	L_{par}	Ice Compressive Strength (MPa)	σ_C
Beam (m)	B	Ice Elastic Modulus (MPa)	E
Draught (m)	T	Ship-Ice Friction Coefficient	μ
Maximum Open Water Speed (m/sec)	V_{max}	Speed of Converging Ice between Ridges (m/sec)	V_{ice}
		Open Water Distance (km)	OW
Stem Angle (deg.)	Φ	Channel Ice Distance (km)	CI
Waterline Entrance Angle (deg.)	α	Mean Channel Ice Depth (km)	H_M
Propeller Diameter (m)	D_P	Level Ice Distance (km)	LI
Shaft Power (kW)	P_D	Level Ice Thickness (m)	h_i
Longitudinal Center of Buoyancy (positive forward of amidships)	LCB	Ridge Field Distance (km)	RF
Block Coefficient	C_B	Mean Ridge Density (#/km)	μ
Midship Coefficient	C_M	Mean Ridge Sail Height (m)	h_s
Prismatic Coefficient	C_P	Ratio of Consolidated Layer in Ridges to Level Ice Thickness	h_{con}/h_i
Water Plane Coefficient	C_{WP}	Ridge Keel-to-Sail Ratio	h_{ic}/h_s
		Pack Ice Distance (km)	PI
		Pack Ice Coverage (% : 0 to 100)	CI
		Pack Ice Mean Floe Diameter (m)	D

The equation in which a net thrust is equal to the resistance is adopted as calculation method for the ship speed. Figure 2.6.1 represents the calculation method schematically. The equation (2.6.2) (Riska, 1997) is used to calculate the net thrust.

$$T_{net} = T_{pull} \times \left[1 - \frac{v}{3v_{max}} - \frac{2}{3} \times \left[\frac{v}{v_{max}}\right]^2\right] = R_i \quad (2.6.1)$$

$$T_{pull} = K_e \times (D_p \times P_D)^{\frac{2}{3}} \quad (2.6.2)$$

where, v is ship speed, v_{max} is maximum open water speed as defined in the figure., T_{net} is the net thrust (kN), T_{pull} is the bollard pull thrust (kN), Ke is the coefficient: 0.728 for single screw, 0.98 for twin screw, and 1.12 for triple screw. P_D is the propeller diameter (m), P_D is the ice resistance (kW), and Ri is the resistance of icebreaker in each ice condition.

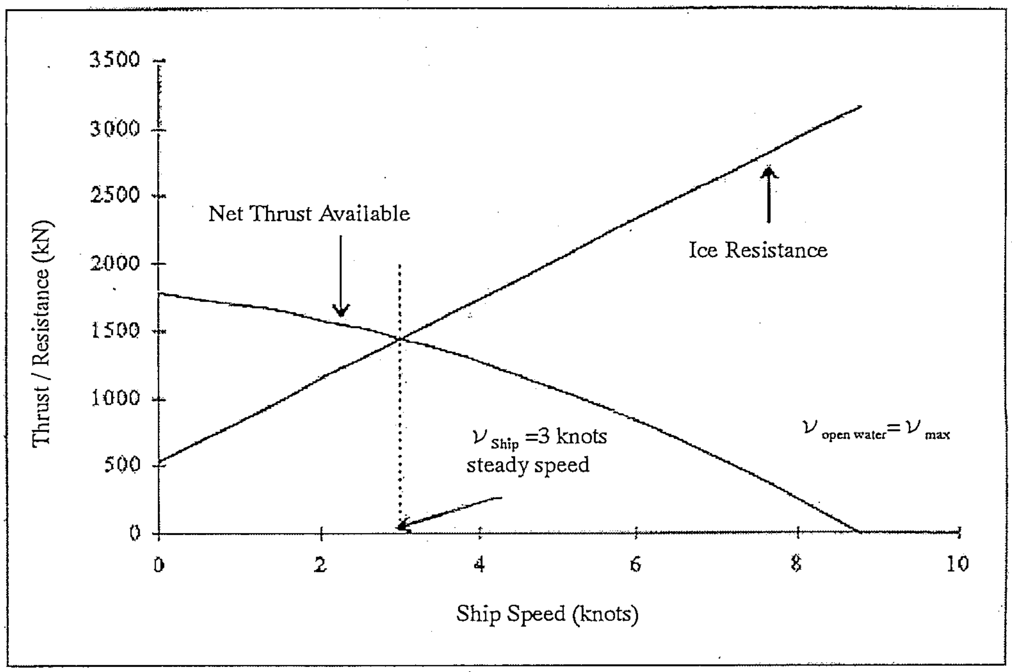


Figure 2.6.1 Schematic of the solution for ship speed

Ship speed in open water

The ship speed in open water is equal to the navigation speed of input data; $V_{max.}$.

Ship speed in channel ice

$R_{CH,}$ the resistance of channel ice, is given by the equation (2.6.3).
The voyage speed is calculated by equation (2.6.1) in which R_{CH} is assumed to be equal to T_{NET} in the equation (2.6.1).

$$R_{CH} = \frac{1}{2} \times \mu_B \times \rho_\Delta \times g \times H_F^2 \times K_P \times \left[\frac{1}{2} + \frac{H_M}{2H_F}\right]^2 \times \left[B + 2 \times H_F \times \left(\cos\delta - \frac{1}{\tan\phi}\right)\right] \times$$

$$(\mu_h \times \cos\phi + \sin\phi \times \sin\alpha) + \mu_B \times \rho_\Delta \times g \times K_o \times \mu_h \times L_{PAR} \times H_F^2 + \rho_\Delta \times g \times \left[\frac{L \times T}{B^2}\right]^3$$

$$\times H_M \times A_{WF} \times F_n^2 \quad (2.6.3)$$

where, μ_B is the constant value 0.8~0.9, ρ_Δ is the density difference between ice and sea water, g is the acceleration of gravity, K_P is the coefficient of passive stress, H_M is the mean channel ice depth, δ is 22.6 degree, μ_H is the friction coefficient of vessel and ice, ϕ is the waterline entrance angle at the point of B/4 from the centerline, K_O is the coefficient of lateral stress, L_{PAR} is the length of parallel midbody, A_{WF} is the water line area of foreship, F_n is the Froude number, H_F is the term describing the thickness of the brash ice layer. Channel ice is a refrozen broken channel, and it is not used for this simulation.

<u>Ship speed at level ice</u>

The resistance in level ice, R_{LEVEL} is calculated using Lindqvist (Lindqvist, 1989) in equation (2.6.4). This resistance consists of three resistant components: the crushing resistance, the bending resistance, and the resistance of buoyancy force of ice pieces.

$$R_{LEVEL} = (R_C + R_B) \times \left[1 + 1{,}4 \times \frac{v}{\sqrt{g \times h_i}}\right] + R_S \times \left[1 + 9.4 \times \frac{v}{\sqrt{g \times L_{PAR}}}\right] \quad (2.6.4)$$

where, R_C is the resistance due to crushing, R_B is the resistance due to bending, R_S is the submergence resistance. On the assumption that R_{LEVEL} is equal to T_{net} in the equation (2.6.1), the ship speed was calculated.

<u>Ship speed in ridged ice</u>

As shown in Figure 2.6.2, pressure ridge is modeled with sail height, consolidated layer, and spacing. A ridged ice, as shown in Figure 2.6.2, is modeled as isosceles triangles with two 20 degree angles、 where keel depth = 5× ridge height、 ridge width = 27.5× ridge height.

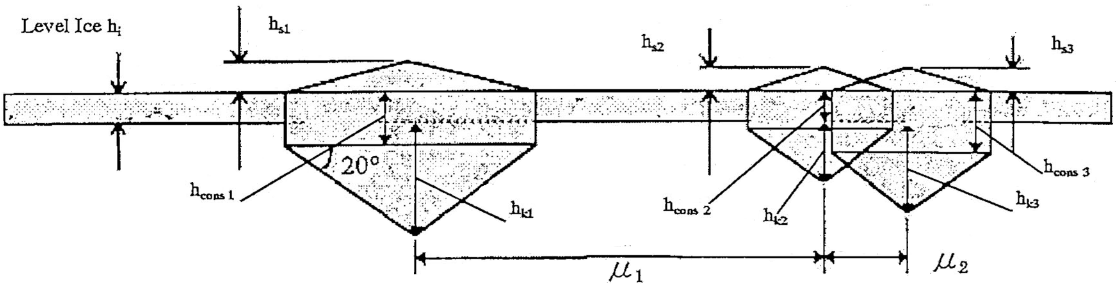


Figure 2.6.2 Geometry of ridge fields

The ridge spacing x is calculated using the following exponential distribution equation (2.6.5):

$$p(x) = 1 - \exp(-\frac{x}{\mu}) \ : \ x = -\mu\, In(1 - p(x)) \quad (2.6.5)$$

where, p(x) : CDF (cumulative distribution function) of ridge space.
μ : mean value of ridge space

The ridge sail height is also expressed using an exponential function of the form:

$$p(h) = 1 - \exp(-\frac{h}{h_s}) \quad : \quad x = -h_s \, In(1 - p(h)) \qquad (2.6.6)$$

where p(h) is CDF of the ridge sail height and h_s is the mean ridge sail height.

The thickness of the consolidated layer in a ridge is distributed using the following equation:

$$h_{cons} = h_i \times (1 + 0.8x) \qquad (2.6.7)$$

where, h_{cons} is the thickness of the consolidated layer, h_i is the mean ice thickness and x is the random number 0~1.

For the calculation of ridge resistance, the method (Malmberg, 1983) is again used. The ridge resistance is comprised of resistance at the ship's bow, resistance of parallel midbody.

$$R_{Ridge} = -R_{Bow} + R_{Par} \qquad (2.6.8)$$

$$R_{BOW} = C_1 \times T \times H \times \left(\frac{B}{2} + H \times \tan\phi \times \cos\alpha \right) \times (0.15 \times \cos\alpha + \sin\phi \times \sin\alpha) \qquad (2.6.9)$$

where C_1 is constant value determined according to the soil mechanics. T is the draft, H is the keel depth, B is the breadth, α is the waterline entrance angle at stem, and ϕ is the stem angle. R_{par} is somewhat lengthy and referred to the original paper (Lindquist, 1989).

In the ridged ice, the resistance of compressive ice is considered more carefully. A compressive ice field increases the ice resistance of the ship due to the convergence of the ice. In the program the direction of the compression is assumed to be 90 degree to the ship centerline. The additional resistance in the compressive ice; ΔR is given in the equation (2.6.10) and equation (2.6.11).

$$\Delta R = P_n(\mu + n(\sin(\arctan(v_{ship} / v_{ice})))) \qquad (2.6.10)$$

$$P_n = P_0(1 - (mchv_{ship}^{2/3} / (L_{par} v_{ice}))((E / \rho)^{1/2} \sigma_t / \sigma_c)^{1/3}) \qquad (2.6.11)$$

where v_{ship} is ship speed, v_{ice} is the speed of the converging ice field, L_{par} is the length of the parallel midbody, H_i is the level ice thickness, E is the elastic modulus, ρ is the density of ice, σ_t is the bending strength, σ_c is the compressive strength, μ is the friction coefficient, m = 1.5, n = 2.5, c = 0.65 and P_0= 1

Based on the assumption that the sum of the resistance of level ice, consolidated layer, ridged ice and compressive ice is equal to T_{NET} in the equation (2.6.1). Making use of the probabilistic technique and the repetitive calculation, the distribution of the ship speed is obtained.

Ship speed in pack ice

The pack ice field consists of individual ice floes separated by stretches of open water, as shown in the Figure 2.6.3. Ice floes have thickness equal to that of the level ice of the route.

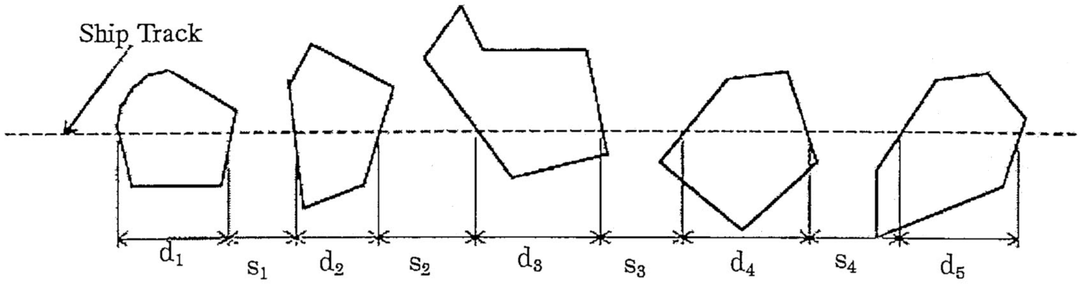


Figure 2.6.3 Geometry of pack ice field showing track of ship

The floe size is given as probability distribution shown in the equation (2.6.12) similar to the situation of ridged ice.

$$p(D) = 1 - \exp(-\frac{D}{D_m}) \tag{2.6.12}$$

where p (D) is a cumulative probability distribution function, D_m is a mean ice size. The equation (2.6.13) is used to calculate ice spacing.

$$s = \frac{1-C}{C} \times D \tag{2.6.13}$$

where C is a total ice concentration, D is an ice size given in the equation (2.6.12). The resistance is obtained by the Lindqvist resistance formula. The ship speed can be estimated on the assumption of that the resistance in pack ice is equal to T_{NET} in the equation (2.6.1). The ship speed is obtained as the distribution, hence the Pack ice calculation uses a probabilistic technique the same as the ridged ice calculation.

2.6.2 Ice index

Ice index is a parameter that quantitatively represents ice navigation difficulties with one value, which is introduced in order to run the simulation efficiently. The purpose of introducing ice index is to develop the chart showing the relation between ice index and the ship speed distribution. The chart is obtained based on the environmental data of WP2 and the code developed by WP6. The chart is put into the simulation code of WP8 as a lookup table. Ice index is a concept originally introduced in the CASPPR, however, it is different in the following points: considering not only ice type, ice thickness, and ice concentration, but also the influence of ice bending strength, compressive strength, ridge size, ridge distribution.

Components of ice index

Ice index: I consists of the three types of ice index: I_A, I_B, I_C as assumed in equation (2.6.14). These components are shown in the Figure 2.6.4.

$$I=I_A+I_B+I_C \qquad (2.6.14)$$

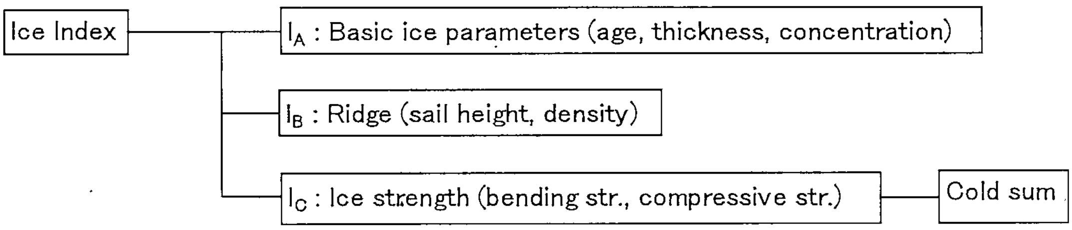


Figure 2.6.4 Components of Ice Index

-I_A-

The calculation technique of I_A is almost the same as the Canadian ice numeral. The first year ice is categorized into four levels by ice thickness as shown in Table 2.6.2. Multipliers of multi-year ice and first year ice using ice class are assigned referring to Table 2.6.3. A part of ice multipliers given by the CASPPR is revised as Table 2.6.3. There is no difference between multi-year ice and second-year ice in the environmental data of WP2; therefore, the mean value of multi-year ice and second-year ice given in the CASPPR is used as an ice multiplier of MY.

Table 2.6.2 Type of first year ice

Type of FY	Ice thickness
TFY	120cm≦hi
MFY	70cm≦hi<120cm
THFY2	50cm≦hi<70cm
THFY1	30cm≦hi<50cm

Table 2.6.3 Ice Multiplier

	Ship category				
Ice type	TYPEA	CAC4	CAC3	CAC2	CAC1
MY	-3.5	-2.5	0	2	2
TFY	-1	1	2	2	2
MFY	1	2	2	2	2
THFY2	2	2	2	2	2
THFY1	2	2	2	2	2
OW	2	2	2	2	2

Finally, using the mean first-year ice concentration C_f, mean multi-year ice concentration C_m, and a multiplier that are given in Table 2.6.3, ice index I_A is calculated by the equation (2.6.15).

I_A= first-year ice concentration multiplier x C_f + multi-year ice concentration multiplier x C_m

$+2 \times (10 - C_f - C_m)$ (2.6.15)

I_B

The similar method used for level ice is adapted to calculate I_B. Ridge concentration corresponding to ice concentration in level ice was introduced for the calculation. The ice index I_B was calculated in the following way.

First, based on the assumption of the equation (2.6.16), the ridge width is calculated using the sail height.

$$W_k=4H_k, \quad H_k=5H_s, \quad W_k=20H_s \qquad (2.6.16)$$

where, W_k is ridge width, H_k is the keel depth, H_s is the sail height as shown in Figure 2.6.5

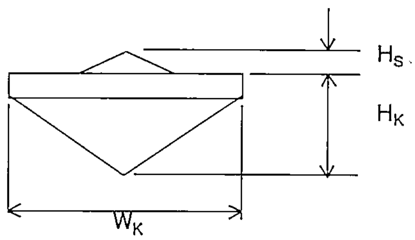


Figure 2.6.5 Ridge profile

Next, the newly introduced parameter; the ridge concentration: Cr, is obtained using the ridge width and the ridge density Dr (1/km). The ridge concentration takes scale 0~10: 0 is used the level ice having no ridged at all, and 10 represents the condition in which the ice floe is fully covered with ridges. Ridge concentration is assumed as equation (2.6.17).

$$C_r = W_K \times \frac{D_r}{1000} \times 10 \qquad (2.6.17)$$

Replacing the equation (2.6.16) to equation (2.6.17), we obtain equation (2.6.18) representing the ridge concentration with the keel depth and ridge density.

$$Cr = \frac{HsDr}{5} \qquad (2.6.18)$$

At the end, I_B was calculated same as the calculation method that computes I_A. On this calculation, the influence of the ridge concentration is defined as a function F (Cr), and it is shown in equation (2.6.19) as a multiplier.

$$I_B=F(C_r) \times (C_f+C_m) \qquad (2.6.19)$$

On the definition of the Canadian Ice Numeral, the influence of ridged ice is obtained by diminishing 1 from the multiplier in the Table 2.6.2, only in the case where ice floe is covered with ridge more than one third and the total ice concentration is more than 6. Accordingly, it is equal to $F(C_r) = -1$ under the condition in which ice concentration $C_r > 10/3$ and also $C_f + C_m > 6$. Here, the influence of ridge is assumed in detail in equation (2.6.20) by the use of the ridge concentration: C_r

$$F(C_r) = -2 \times \frac{C_r}{10} \tag{2.6.20}$$

The influence of ridge is assumed not only limiting the case in which the ice concentration is more than 6, but also including influences against all ice concentration. The comparison for $F(C_r)$ between Canadian Ice Numeral and present method is shown in Figure 2.6.6.

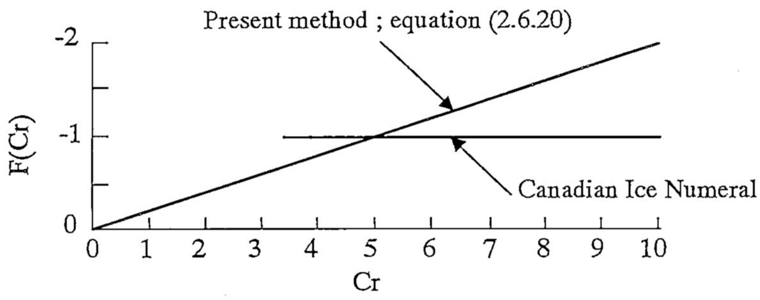


Figure 2.6.6 Comparison for $F(C_r)$ between Canadian Ice Numeral and present method

I_C

Ice index I_C indicates the influence of the ice strength. Firstly, the mean monthly temperature was calculated by taking the monthly difference of the cold sum. Hence the ice strength highly depends on the temperature and salinity of ice, the ice strength which corresponds to the mean of monthly temperature is defined shown in Table 2.6.4 (Riska ,1996). Utilizing M_{CS}, I_C is obtained as the equation (2.6.21).

Table 2.6.4 The multiplier for ice strength, M_{CS}

Ice type	FY			MY		
T : Monthly average temp.	T≦-10	-10<T≦-2	-2<T≦-0	T≦-10	-10<T≦-2	-2<T≦-0
Bending str.(KPa)	600	450	300	1600	1200	800
Compressive str.(KPa)	6000	4500	3000	9000	6500	4000
M_{CS}	-0.12	0	0.12	-0.44	0	0.44

$$I_C = M_{CS}(\text{first-year ice}) \times C_f + M_{CS}(\text{multi-year}) \times C_m \tag{2.6.21}$$

where, M_{CS} is a multiplier. After the parametric study by NEWSIM2 in which the bending strength value and the compressive strength value were varied, the value of M_{CS} was calibrated using the relation between ice index and the ship speed.

Example for calculating Ice Index

For example, Ice index: I is calculated as follows in case of the next condition.

Ice thickness : 1.0 m (MFY)
First year ice concentration : 6
Multi year ice concentration : 1
Ridge sail height : 0.5 m
Ridge density : 20 /km
Monthly average temperature : -5 °C
Ice class : Type A

$I_A = 1 \times 6 + 1 \times (-3.5) + 2 \times (10 - 6 - 1) = 8.5$

$C_r = 0.5 \times 20/5 = 2.0$
$I_B = -2 \times 2.0/10 \times (6 + 1) = -2.8$
$I_C = 0 \times 6 + 0 \times 1 = 0.0$
$I = I_A + I_B + I_C = 8.5-2.8+0.0=5.7$

2.6.3 Ice index v.s. ship speed

The flow to develop the chart for ice index v.s. ship speed

To develop an ice index v.s. ship speed chart, the environmental data supplied by WP2 and the ship speed code NEWSIM2 are used. The flow is shown in Figure 2.6.7.

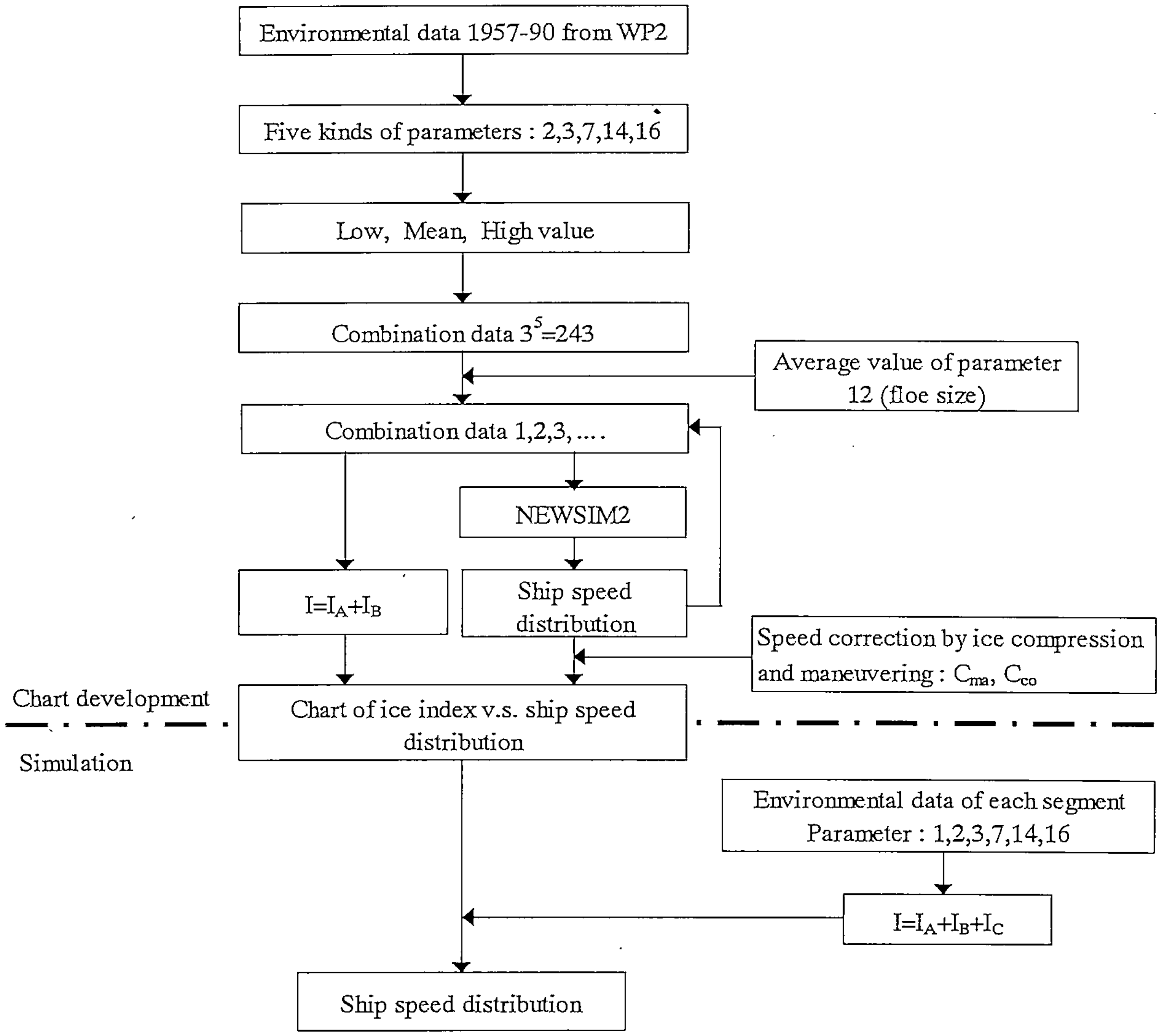


Figure 2.6.7 Flow of developing the chart for ice index v.s. ship speed

Combination data

If all environmental data supplied by WP2 are used, it will take enormous amount of time to develop charts. Therefore, the mean first-year ice concentration (para.2), the mean multi-year ice concentration (para.3), the mean ice thickness (para.7), the mean ridge size (para.14), and the mean ridge density (para.16) that are construction components of I_A and I_B covering most part of ice index, were selected as representative parameters.

After the analysis of the environmental data supplied WP2, the data (mean-standard deviation (low value), mean, mean + standard deviation (high value)) shown in the Table 2.6.5 were selected as the basic environmental data.

Table 2.6.5 Basic environmental data

Parameter	Unit	Low value	Mean	High value
Mean first-year ice concentration	1/10	2.3	6.3	10.0
Mean multi-year ice concentration	1/10	0.0	1.4	4.0
Mean ice thickness	cm	27	97	168
Mean ridge size (sail height)	cm	39	94	149
Mean ridge density	1/km	0.0	13.9	27.7

Finally, the total of 3^5=243 combinations of environmental data were produced from the basic environmental data. However, the data combinations under the following conditions were cut out.

- The combination of data in which the total ice concentration >10
- The combination of environmental data which does not exist in the real situation (for example, data in which mean ice thickness is 27 cm, the mean sail height is 149cm or 94cm, and the ridge density is 27.7 /km.)

The combination data and the ice index obtained by the method that we discussed in chapter 2.6.2 were presented in Tables in Appendix B. When the ice index was calculated, I_C is not considered because its value is very small compared with I_A or I_B.

Ship speed distribution for each type of vessels

Using the code NEWSIM2, the ship speed distribution was obtained for three service ships and Arctica type escort icebreaker. As the data of floe size (para.12), the average data (12.2 m) was used. The input data of the ships are shown in Table 2.6.6. The ice multipliers for TYPE A and CAC1 in Table 2.6.3 were applied for the three icebreaking cargo ships and the escort icebreaker respectively. The combination data in the Appendix B were used as the environmental data.

Then, the ship speed was corrected by both maneuvering factor and ice compression effect, as described below.

2.6.4 Speed correction factors

Correction of ship speed by maneuvering factor in severe ice condition

On the navigation in the ice covered waters, a master of the icebreaking cargo ship tends to avoid severe ice condition and chooses open leads. The decision of the operation is made depending on the condition of ice thickness and concentration. If he avoids the severe ice condition, the navigation distance becomes longer, although the ship speed appears to be increased. Consequently, the transit time in one segment tends to be shorten in less concentrated ice. C_{ma} is defined as the adjust parameter for maneuvering referring to the model porposed by the CRREL (Mulherin, 1996) as shown in the Table 2.6.7. The maneuvering effect is 3-5% of the ship speed. Here, the adjust parameter C_{ma} is multiplied to the ship speed from NEWSIM2.

Table 2.6.7. Adjust parameter Cma for the maneuvering

Total ice concentration	Cma
10/10 – 6/10	0.95
5/10 – 1/10	0.97

Correction of ship speed by ice compression effect

Ice pressure is exerted on a ship when ice floe is compacted due to wind and current. That will prevent ship progress and maneuvering. Ice pressure acts as side force when the ice-breaking vessel breaks the ice sheet. The side force causes frictional force between ship hull and ice and decreases the ship speed. The influence of ice pressure against the ship speed is incorporated in NEWSIM2 and then the relation between ice index and the influence was investigated.

The influence of ice pressure is considered when the total ice concentration equals 10. The adjust parameter C_{co} is shown in Table 2.6.8. The friction coefficient between ship and ice is assumed 0.1, and the speed of ice flow is assumed 0.3m/sec. Here, the adjust parameter Cco is multiplied to the ship speed.

Table 2.6.8 Adjust parameter Cco for ice compression effect

Ship	Cco
Arktika	0.95
25,000DWT & 40,000DWT Cargo	0.88
50,000DWT Cargo	0.80

2.6.5 Development for the charts of ice index v.s. ship speed

Figure 2.6.8 to 2.6.11 shows the relations between the ice index and the ship speed of each service ship and escort icebreaker. Table 2.6.8 summarizes the input data set for NEWSIM2. Tables corresponding to Figure 2.6.8 to 2.6.11 are listed in the Appendix B. Ship speeds corresponding to arbitrary width of ice index were distributed within some range of speeds, thus the discrete probability distribution of the ship speed responding to every two pitches of ice index was developed as shown in Table 2.6.9. The ship speed distributions for the three service ships and escort icebreaker are summarized in Table 2.6.10 and Table 2.6.11.

In the voyage simulations mentioned in chapter 3, I_A, I_B and I_C are calculated for each segment in the selected route. Then the ship speed is calculated using the charts obtained here.

Table 2.6.6 Input data summaries

No.	Parameter	Unit	Ship			
			40000 DWT type	25000 DWT type	50000DWT type	Arktika
1	Lpp	m	186.07	184.06	240.00	136.00
2	Length of bow	m	51.07	36.78	24.60	35.50
3	Length of parallel part	m	50.00	86.05	62.60	65.00
4	B	m	27.50	25.10	30.00	28.00
5	d	m	12.50	9.00	12.50	11.00
6	Stem angle	deg	30	30	25	24
7	Waterline entrance angle	deg	50	52	43	40
8	Speed in open water	m/sec	7.46	7.46	8.74	10.70
9	Number of propellers		2	2	1	3
10	Propeller diameter	m	5.8	5.2	7.1	5.3
11	Shaft power	kw	28000	24000	18375	49000
12	Lcb from midship (+ forward)	m	3.44	2.94	0.34	0.00
13	Cb		0.751	0.813	0.7674	0.546
14	Cm		0.998	0.995	0.978	0.900
15	Cp		0.751	0.817	0.784	0.607
16	Cwp		0.932	0.949	0.847	0.701
17	Ice density	kg/m^3	880	880	880	880
18	Bending strength	Pa, N/m^2				
19	Compressive strength	Pa, N/m^2				
20	Elastic modulus	Pa, N/m^2	5.00E+09	5.00E+09	5.00E+09	5.00E+09
21	Friction coefficient		0.1	0.1	0.1	0.1
22	Speed of converging ice field between ridges	m/sec	0.3	0.3	0.3	0.3
23	Open water distance	km				
24	Channel ice distance	km	0.0	0.0	0.0	0.0
25	Mean channel ice depth	m	0.0	0.0	0.0	0.0
26	Level ice distance	km				
27	Level ice thickness	m				
28	Ridge field distance	km				
29	Pack ice distance	km				
30	Ridge sail height	m				
31	Average number of ridges (Ridge density)	1/km				
32	Average floe diameter (Floe size)	m	12.22	12.22	12.22	12.22
33	Pack ice coverage(Total concentration)	%:0-100				
34	Ridge depth to sail ratio		5	5	5	5

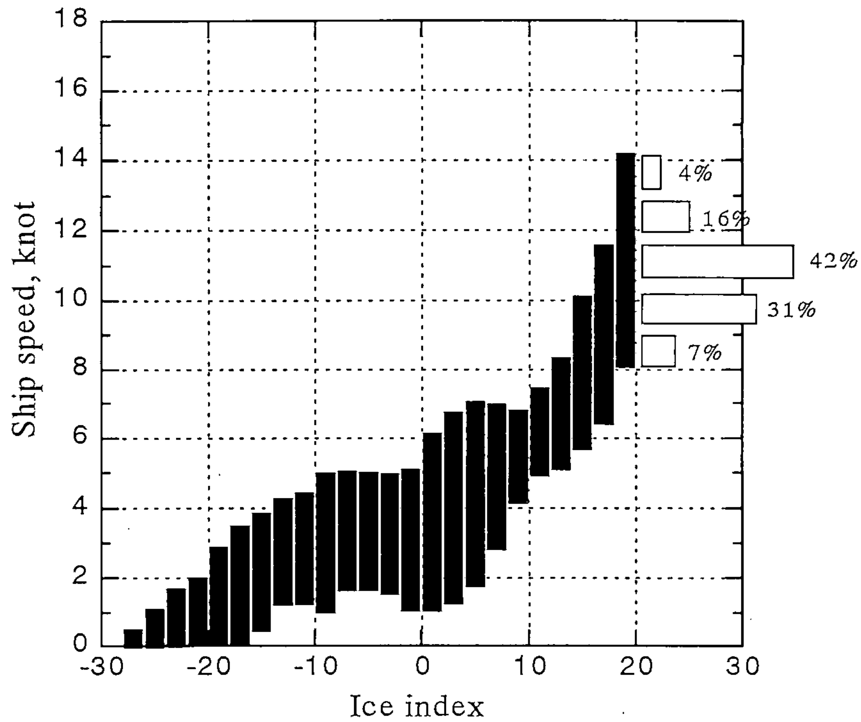


Figure 2.6.8 Ice index v.s. ship speed for 40000DWT Bulk/Container Carrier

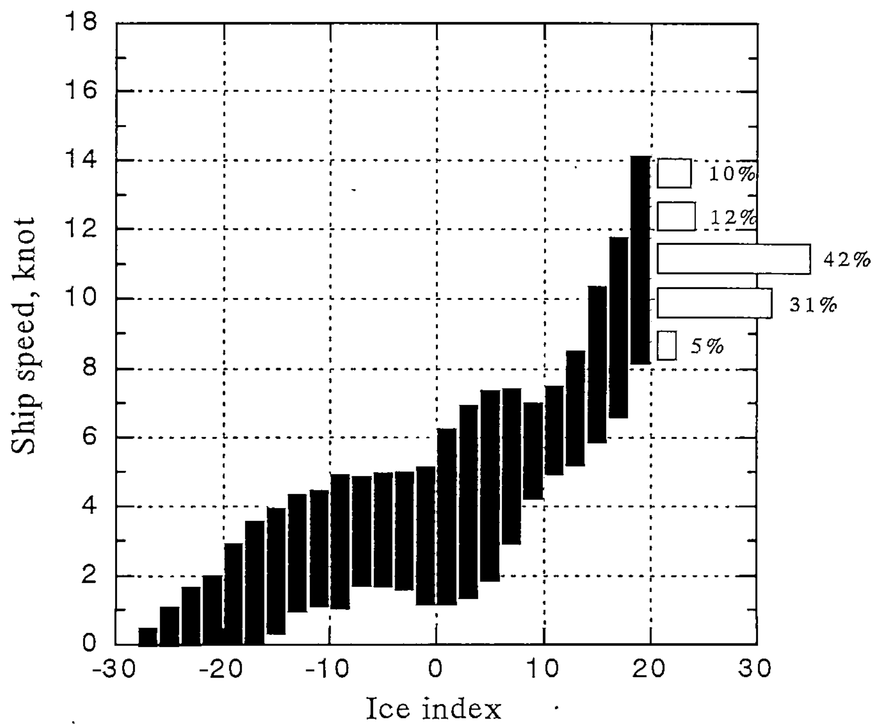


Figure 2.6.9 Ice index v.s. ship speed for 25000DWT Bulk/Container Carrier

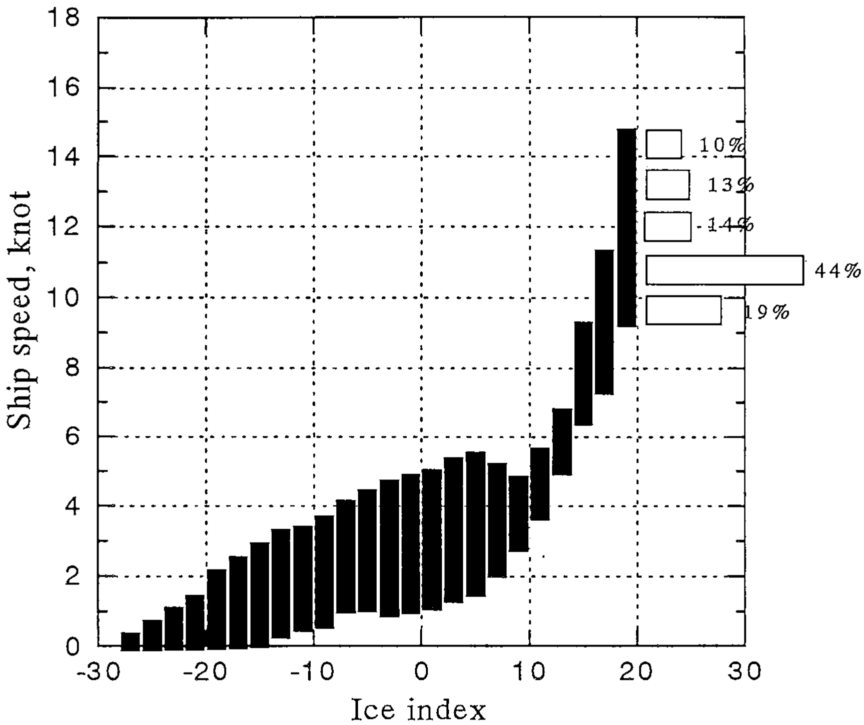


Figure 2.6.10 Ice index v.s. ship speed for 50000DWT Bulk/Container Carrier

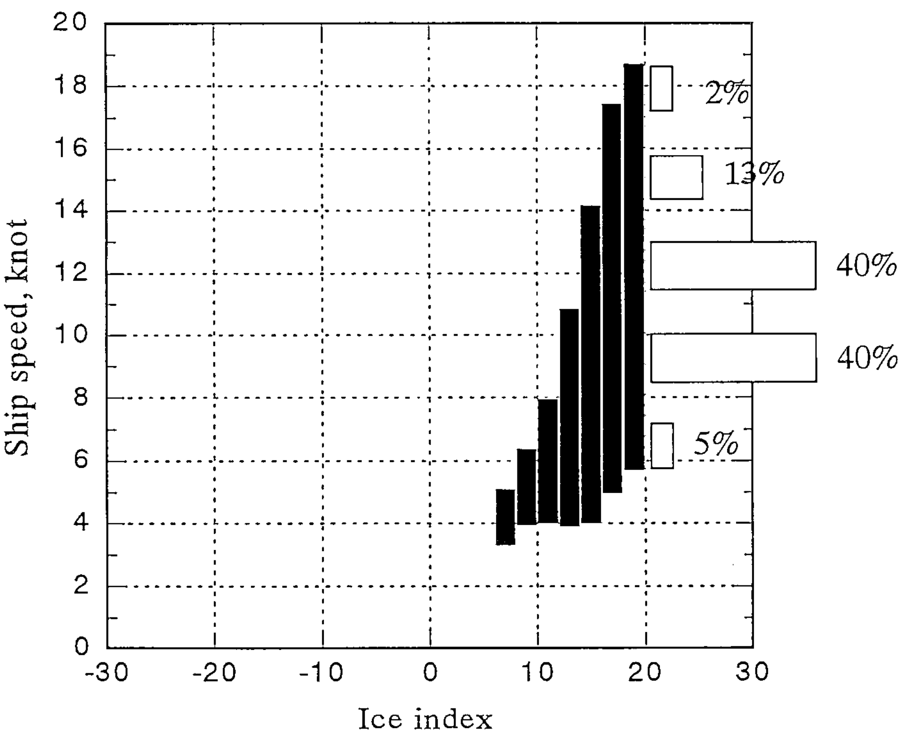


Figure 2.6.11 Ice index v.s. ship speed for Escort icebreaker (Arktika)

Table 2.6.9 Probability distribution for ship speed of 40000DWT Bulk/Container Carrier

Ice index	Ship speed	Probability distribution (%)	
-26≦Ice index<16	Max.	p1	7
		p2	23
	Mean	p3	27
		p4	32
	Min.	p5	11
16≦Ice index≦20	Max.	p1	4
		p2	16
	Mean	p3	42
		p4	31
	Min.	p5	7

Table 2.6.10 Probability distribution for ship speed for service ships

Ice index	Ship speed	Probability distribution		
		25000DWT	40000DWT	50000DWT
-30<I<16	Max.	0.06	0.07	0.01
		0.22	0.23	0.13
	Mean	0.29	0.27	0.24
		0.31	0.32	0.48
	Min.	0.12	0.11	0.14
16≦I≦20	Max.	0.10	0.04	0.10
		0.12	0.16	0.13
	Mean	0.42	0.42	0.14
		0.31	0.31	0.44
	Min.	0.05	0.07	0.19

Table 2.6.11 Probability distribution for escort icebreaker

Ice index	Ship speed	Probability distribution
0<I<16	Max.	0.03
		0.08
	Mean	0.27
		0.57
	Min.	0.05
16≦I≦20	Max.	0.02
		0.13
	Mean	0.40
		0.40
	Min.	0.05

2.7 Legal assessment and Environmental Impact Assessment

WP7, Part 1 identified the applicable documents for the routes selected by WP1. As shown in Table 2.7.1, the lengths of the routes are categorized into internal waters, territorial sea and economic zone. The details are referred to the original report (Semanov et al.,- 1998). The report described some cost tables for icebreaker tariffs, ice pilots and pot dues. Some of them were adopted as the cost data in this simulation. However, the other legal items affecting the voyage cost are not identified. The details are referred to the WP7 original report (Semanov et al., 1998).

Table 2.7.1 Length of internal waters, territorial sea and economic zone for the selected routes

Sea areas	Southerly route	Northerly route	
		Throuth Vil'kitskogo straight (2108 NM)	North Severnaya Zemlya islands (2446 NM)
Internal waters	7	5	0
Territorial sea	22	1	0
Economic zone	71	94	100

WP7, part II performed the environmental impact assessment for the selected routes. However the assumed ship is 40,000dwt container carrier as depicted in Table 2.7.2, and it should be noted that the type of the ship is different from the service ships used in this simulation study. The corresponding wasted material is calculated in Table 2.7.3. Also, the navigation period is limited from July to September in accordance with L2 class limitation.

Table 2.7.2 Particulars of container ship

Particulars	values
Length overall (m)	236.0
Breadth (m)	32.0
Displacement (cu.m)	55200
Container Capacity, pcs	1990/2664
Deadweight (metric ton)	38,850
Type of propulsion machinery	Low-speed diesel engine
Power of main engine (kw)	21700
Load speed (knots)	20.7
Ice class	L2
Fuel tank capacity (cu.m)	3800
Fuel consumption (ton/day)	123.6
Complements	34

Table 2.7.3 Quantities of waste produced on board in the process of normal operation

Characteristics	Unit	value
Bildge water	Cu.m / day	7
Sewage water/Black water	L/day	3400
Sewage water/Gray water	L/day	5700
Garbage/domestic waste	Kg/day	100
Garbage/operational waste	Kg/day	15
Garbage/cargo waste	Kg/day	1.5

Forty voyages were assumed in the analysis. The report stated that the accident probability for sinking is one case out of 300000 voyages, and the accidental pollution seems to be quite low.
Following the study in Phase 1, The followings are identified as VECs (valued ecosystem components) ;

- Benthic invertebrates
- Marine estuaries and anadromoùs fish
- Plant and animal life in polynyas
- Seabirds
- Marine wildfowl
- Waders in resting and feeding areas
- Polar bear
- Walrus
- Bearded seal
- Ringed seal
- Ringed seal
- White whale
- Gray whale
- Bowhead whale
- Protected areas

56 VECs (valued ecosystem components) are detailed from above categories to implement the environmental impact assessment. The impact hypotheses with four categories (A, B, C, D) are assigned to 56VECs. The model scenario does not provide oil spill and waste dumping, the 22 hypotheses are rejected. Thus, due to shortness of duration and small intensity, impacts on benthos, ichthyofauna and life activity in polynyas are quantitatively minor, and impacts on sea birds and mammals would be disturbance. Analysis and adaptation of environmental impact scenarios have identified some meaningful hypotheses classed as Category C that proves the requirement for further studies and observations for final verification. The impact assessment was performed against two operational conditions. The report concluded that the preliminary impact assessment obtained for the NSR area gives ground for conclusion of minor negative impact from the assessed activities in case of observation of conventional practice and due account for the features characteristics for the specific areas. Also the report recommended that the first step for proper environmental damage assessment shall be the arrangement of ecological monitoring in most vulnerable points or sites along the NSR including protected territories. The report does not discuss the year round transit scenarios implemented in this simulation, however the environmental impact may be low as far as the applicable regulations to the NSR are kept. In this simulation, the cost parameters affected by the environmental assessment are not identified as well as the legal part.

3. Simulation code

3.1 Features and assumptions

This simulation features;

- Sufficient long-term historical environmental data to examine the trend of cost
- Short segment of 20NM to describe the route
- Service ships with much larger size to improve the cost efficiency expecting the future trend
- Reasonable relation between ice condition and ship speed
- Two type of cost descriptions to meet technical and shipping industry aspects.

Some of assumptions adopted from other work packages are already mentioned in chapter 2, although summarized as follows for clarification purpose.

Routes

Four routes are selected. Each route is plotted in every 20 nautical mile within the NSR.
Northerly route : Transit route between Yokohama and Hamburg, draft for 12.5m
Southerly route : Transit route between Yokohama and Hamburg, draft for 9.0 m
Regional East route: Regional routes between Tiksi and Yokohama, draft for 9.0m
Regional West route: Regional routes between Dikson and Hamburg, draft for 9.0m

Ice data

Seven parameters, namely, cold sum, mean first year ice concentration, mean multi year ice concentration, mean ice thickness, floe size, mean ridge sail height and mean ridge density are used. The data are described for each 20 NM segment by month and year from 1953 to 1990.

Cost data

The data are comprised of capital, crewing, maintenance, insurance, fuel, port and icebreaker escort costs as summarized in Table 2.3.1. WP4, 7 and NYK line reports are referenced.

Service ships and escort icebreaker

Three service ships are not existing ships and newly prepared for the simulation. They are larger than existing ships and feature new propulsion system. Two of them are bulk/container ship with the capacity of 25,000DWT and 40,000 DWT, and the other is bulk carrier of 50,000 DWT. Their icebreaking capabilities are confirmed by ice tank tests. Arctica class is selected as escorted icebreaker.

Ship speed algorithms

WP 6 provided sophisticated computer code capable of predicting ship velocity in ice taking account for various ice conditions. However it takes too long time to run the code in each segment. Therefore, an ice condition each segment is expressed in the form of index, and the relations between index and speed are created using WP6 code. One index gives several ice features, therefore a ship speed corresponding to arbitrary index distributes some ranges of speed. These scatter ranges are expressed in the form of discrete probability as shown from Figure 2.6.6 to 2.6.10.

<u>Decision of icebreaker escort</u>

Icebreaker escort is decided by referring ice index. The minimum effective ship speed for this simulation is set as 3knots. Fig.3.1.1 shows the relation between the mean ship speed and ice index of 25BC, 40BC, and 50BC. From the relationship, the Ice indexes to operations that need an escort of icebreakers (IN_C) are defined as -4, -4, and -1 to the cargo ship 25BC, 40BC, and 50BC respectively. If the ice index for a cargo ship in the route segment is more than IN_C, then a cargo ship can navigate independently (named Independent voyage mode). On the other hand, if the ice index is less than IN_C, it is supposed that the cargo ship cannot navigate independently and needs icebreaker support (named Escort mode).

It is assumed that an icebreaker can escort a cargo ship without any standby time at the starting point of the segment. In recent years, observation technology for sea ice including satellite has made remarkable progress, so it is plausible to predict the ice condition and to set up an icebreaker arrangement at the appropriate destination. The decision for terminating icebreaker escort is assumed. Even though a cargo ship can voyage in the segment next to the escort mode segment, it is realistic to make the judgement considering predictable ice condition at precedent segments. Accordingly, we assumed a cargo ship might have icebreakers' escort maximum for one day even if ice condition betters. About 10 knots of voyage speed is assumed as a proper average speed referring from WP5 report to the voyage speed of SA-15 class when she has escort by the *Arktika*–class icebreaker in the moderate ice condition. The simulation code search the existence of other escort mode segments among the next 12 segments (the distance of 240NM), when the voyage is judged to be independent mode from escort mode only by ice-index. If it finds any difficulty to make an independent voyage within the next 12 segments, the assistance of icebreakers is continued (named Watching Mode). When it does not find any problematic segment within the neat 12 segments, escort mode would be switched to independent mode at the next segment. Fig. 3.1.2 summarizes the decision of algorithms used to judge the mode. Also, Figure 3.1.3 shows the example of escort decision.

Assumption for ship speed and required engine power

Ship speed is estimated using the calculation model corresponding to three types of voyage modes (Independent voyage/ Escort / Watching). At an independent voyage mode segment, the ship speed distribution is estimated based on the relation between ice index and ship speed. The distribution of fuel consumption, which is necessary to calculate fuel cost, can be calculated based on fuel consumption rate, required power, and voyage time. In order to obtain the distribution of required power to the distribution of ship speed ; 1) speed-power curve at open water is referred when the ice concentration of the segment is zero, 2) speed – power curve at ice covered water when the ice concentration is greater than zero respectively.

The distribution of navigation speed in the segment of escort mode or watching mode is coincident with the distribution of icebreaker speed. It is estimated using the relation between ice index and ship speed for icebreaker. A distribution of fuel consumption is estimated based on a fuel consumption rate and a required power in broken channel for a cargo ship and a navigation time. The power of cargo ship in broken cannel following the leading icebreaker is estimated as 10 % increase of one in open water, considering the friction and interaction of ice pieces.

Cost description methods

The following two ways of cost evaluation are attempted.

Monthly Voyage Simulation (MVS)

A ship operation cost may vary considerably by season and year. A cost required for one voyage is calculated as the first step to examine the trends for navigation days, icebreaker escort times and costs etc. In this calculation, it is assumed that voyages are always in a westbound direction and a voyage starts at the beginning of a month. Therefore, a voyage starts in Yokohama and terminates in Hamburg on transit voyage, and Dikson and Yokohama are the starting points on regional routes. When navigation days require over one month, the next month data should be used, because the segment data are given on a monthly basis. However in this simulation, the environmental data for the starting month is maintained to avoid discontinuities between segments as to ice conditions. These one voyage simulations based on monthly environmental data of each year is named as Monthly Voyage Simulation (MVS).

Annual Serial Voyage Simulation (ASVS)

Freight cost is commonly accepted as an index to express the cost efficiently. The freight cost is calculated from the required costs over a specified period by dividing the total transporting cargo capacity and described by $/ton. For this purpose, a serial voyage operation between Yokohama and Hamburg for one year is simulated. A voyage starts on Jan.1st from Yokohama and a number of voyages is calculated. The anchoring days at each port are selected from the actual results. The simulation can also take account of route switching between the NSR and SUEZ route by judging ice conditions. As the results of this simulation, the whole costs and annual amounts of transportation can be calculated. Consequently, they provide us a comparative freight performance by the NSR to year round operation by the SUEZ route. This series of simulation is named as Annual Serial Voyage Simulation (ASVS).

Cost calculation procedure

In the cost calculation, capital cost, escort cost, ship operation cost, fuel cost, and port cost are considered as noted in chapter 2.3. They depend on different units i.e. one-year; one-voyage, escort days, and required power etc. The cost, which depends on the voyage or escort days, can be calculated by multiplying a distribution of days by a unit cost shown in the cost table in chapter 2.3. The fuel cost is one of the costs that depend on the ship performance. It is obtained by multiplying a distribution of the fuel consumption to one voyage, which is a total of fuel consumption of each segment, by bunker price.

In annual simulation, each voyage cost influenced seasonally is totaled to obtain the total annual cost.

The following shows each of cost calculation :

Capital cost: Repayment of the loan for new build ship. A fixed amount per year (CCa) would be charged. For one-voyage simulation, multiply CCa by the ratio of voyage-day (Tm) to annual operation days (Ta).

MVS : $CCm = CCa \times Tm/Ta$

ASVS : CCa

Ship operating costs: cost to maintain a cargo ship, which considers a crewing cost, a maintenance cost, and insurance cost in this simulation.

- Crewing cost; cost depends on voyage days, which is calculated by multiplying crew charge for one day (CCRd) by voyage days (Tm).

  MVS : $CCRm = CCRd \times Tm$

  ASVS : $CCRa = \Sigma_j CCRj$

  where, CCRj is a crewing cost for the j time of voyage.
- Maintenance cost; Cost to maintain a ship for one year (CMa). In one voyage simulation, multiply the maintenance cost per year by the ratio of voyage days (Tm) to operation days per year (Ta).

MVS : $CMm = CMa \times Tm/Ta$
ASVS : CMa

- Insurance costs; costs are charged per year (CIa). In one voyage simulation, multiply CIa by the ratio of voyage days (Tm) to operation days per year (Ta).

MVS : $CLm = CIa \times Tm/Ta$
ASVS : CIa

Escort costs: costs related to icebreaker escort, icebreaker fees (Tariff) and ice pilot fees are considered.

- Tariff; calculate to every one voyage (CTRv).

MVS : CTRm , it is CTRv in m-month of certain year.
ASVS : $CTRa = \Sigma_j CTRj$
where, CTRj is tariff of voyage for the j-time of voyage.

- Ice pilot fee; depends on the navigation days in the NSR. Multiply ice pilot charge par day (CIPd) by the navigation days (Te).

MVS : $CIPm = CIPd \times Te$
ASVS : $CIPa = \Sigma_j CIPj$
where, CIPj is ice pilot fee for the j-time of voyage.

Fuel costs: fuel consumption at a route segment (QFi) is calculated by multiplying a fuel consumption rate by a voyage time and a required power from speed-power curve, which meets the ice condition of a segment. Costs for one voyage (CFv) are estimated by multiplying the entire fuel consumption totaling the QFi over the route by a bunker price (cf).

$CFv = cf \times \Sigma_i QFi$, QFi is fuel consumption for I-segment
MVS : CFm , it is CFv for m-month of certain year ,
ASVS : $CFa = \Sigma_j CFj$, CFj is CFv for the j-time of voyage.

Port costs: a different port cost (CP) is required at every stop of port to use of equipment and so on. For one voyage simulation, a cost (CPDi) related to loading and preparing departure at departure port (i-port), a cost (CPAj) at arrival port (j-port) related to entering port and unloading are considered.

MVS : $CPm = CPDi + CPAj$
ASVS : $CPa = \Sigma_k (CPDik + CPAjk)$
where, CPDik is CPD at departure port of the k-time of voyage.
CPAjk is CPA at arrival port of the k-time of voyage.

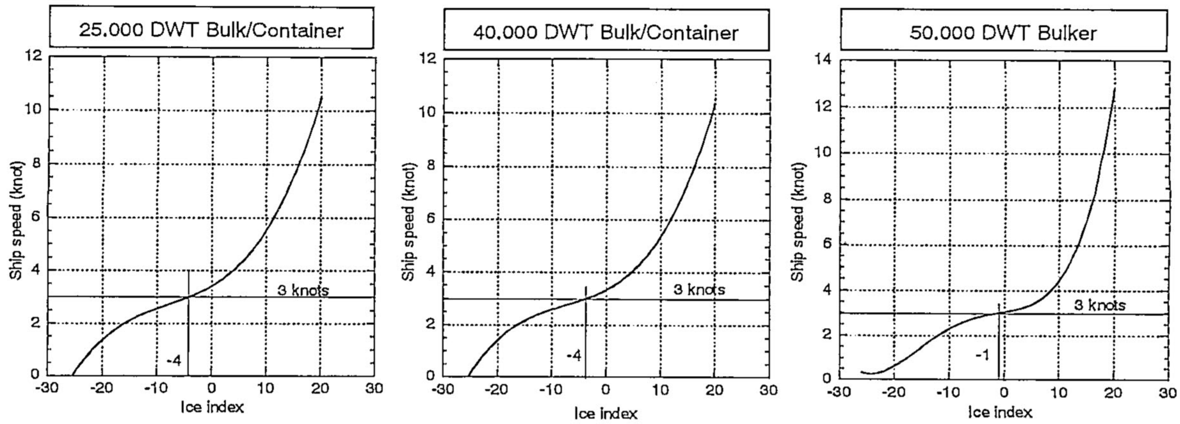


Fig.3.1.1 Ice index at minimum effective ship speed

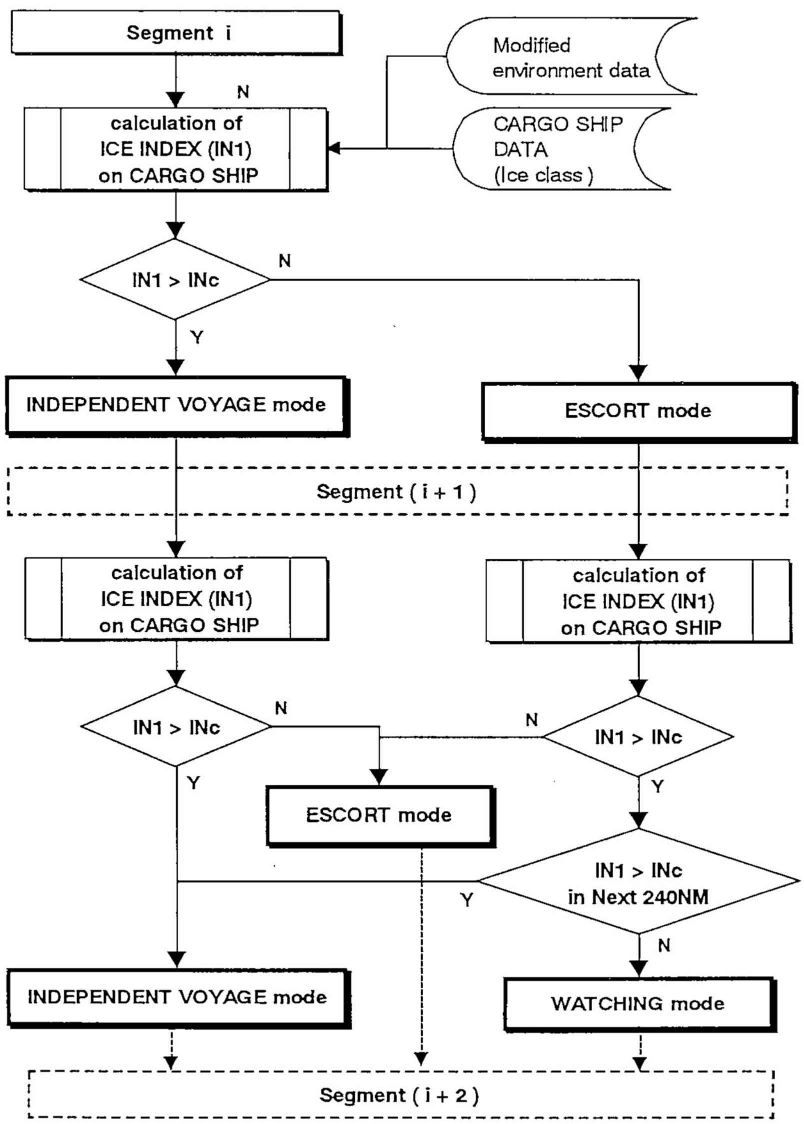


Figure 3.1.2 Algorithm for decision of icebreaker escort

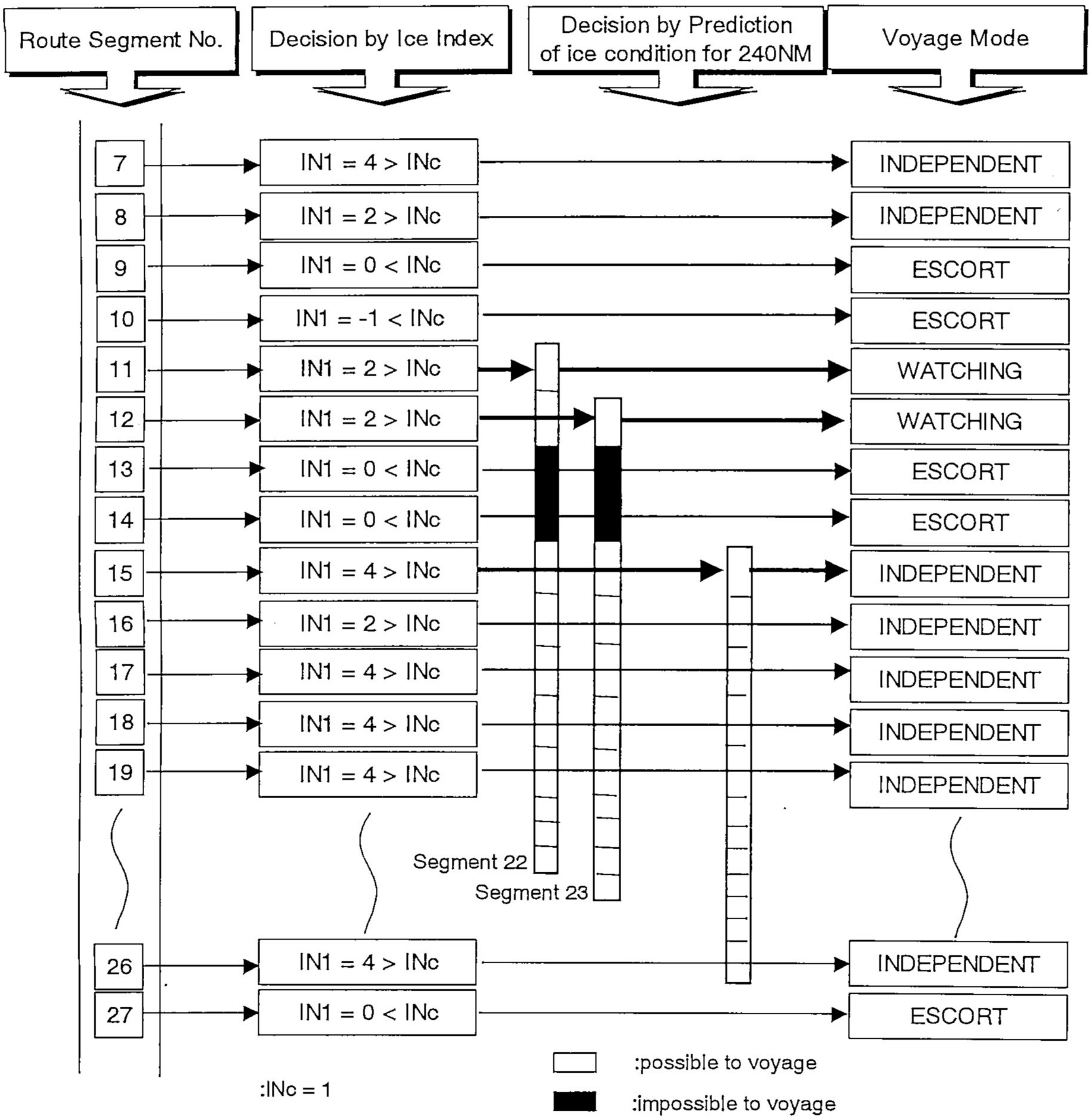


Figure 3.1.3 Example of escort decision along route segments

3.2 Monthly voyage simulation (MVS)

Main flow

The monthly calculation over for forty years is possible at one run. It makes possible to study the trend of the operation feature by month and/or year.

Figure 3.2.1 shows the main flow of the simulation. The whole simulation consists of four prime modules: *DATA READ* module, *VOYAGE SIMULATION* module, *COST CALCULATION* module, and *RESULTS OUTPUT* module. *DATA READ* module is common to the annual serial voyage simulation (ASVS).

Data input and reading

Figure 3.2.2 shows the flow of *DATA READ* module. The all data needed in the NSR simulation is read or input from the data file.

Control data and condition data

Control data and condition data for the simulation are read from data files. The control data specify a simulation mode, output formats, conditions for judging escort, conditions of probability calculation etc. As the condition data, a type of cargo ship, a route, a departure port, an arrival port, the month and year of the operation are selected. Also cost parameters such as icebreaker tariffs and crewing costs are input from this file. Relationships between ice index and ship speed, and port data, are also input.

Route data

From the data files for voyage routes supplied by WP1, Route data selected by the above condition data are loaded. Referred data are route point No., latitude and longitude of the way points, and distances of segments between adjacent points.

Environmental data

Among the environmental data file supplied by WP2, data sets related to referred route, year, and month selected by the above condition data are loaded. The sorts of reference data are stated in chapter 2.2.

Ship data

A ship data file contain data specifying ship performance . The ship data selected in the condition data is loaded from this file.

One-voyage simulation

Figure 3.2.3 illustrates the flow of one voyage simulation. The ship speed and the voyage time at each segment is estimated in order along a route. As for MVS, the simulation starts on the first day of that month. However, it is not the day when the ship departures the port but is defined as the day when cargo-loading begins at a selected port. For instance, if it takes three days to prepare a departure, the departure of the ship would be the fourth day of that month.

Thus, there is no difference in the both results of westward and eastward. Here, the direction of voyage is determined from Far East to Europe in all cases.

Cost for one-voyage

Figure 3.2.4 shows the flow of the cost calculation in MVS mode in *COST CALCULATION* module. The items of one-voyage cost and their calculation methods had been explained in the chapter 3.1.

Output results

The principal items of output results from MVS are listed below.

-Stochastic value of voyage speed by month (mean, maximum, minimum, standard deviation, expected value)
-Ship speed change along voyage route by month.
-Stochastic value of voyage-day for one voyage by month (mean, maximum, minimum, standard deviation, expected value)
-Stochastic value of escort-day for one voyage by month (mean, maximum, minimum, standard deviation, expected value)
-Stochastic value of voyage-cost for one voyage by month (mean, maximum, minimum, standard deviation, expected value)

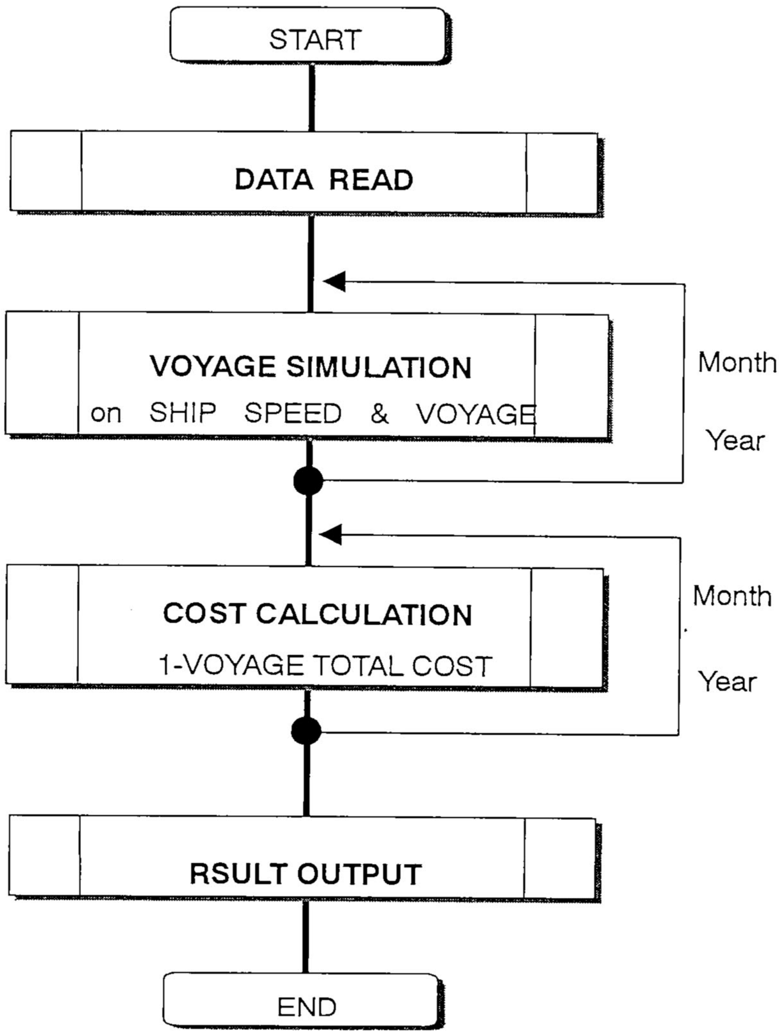


Fig.3.2.1 Main flow of Monthly Voyage Simulation (MVS)

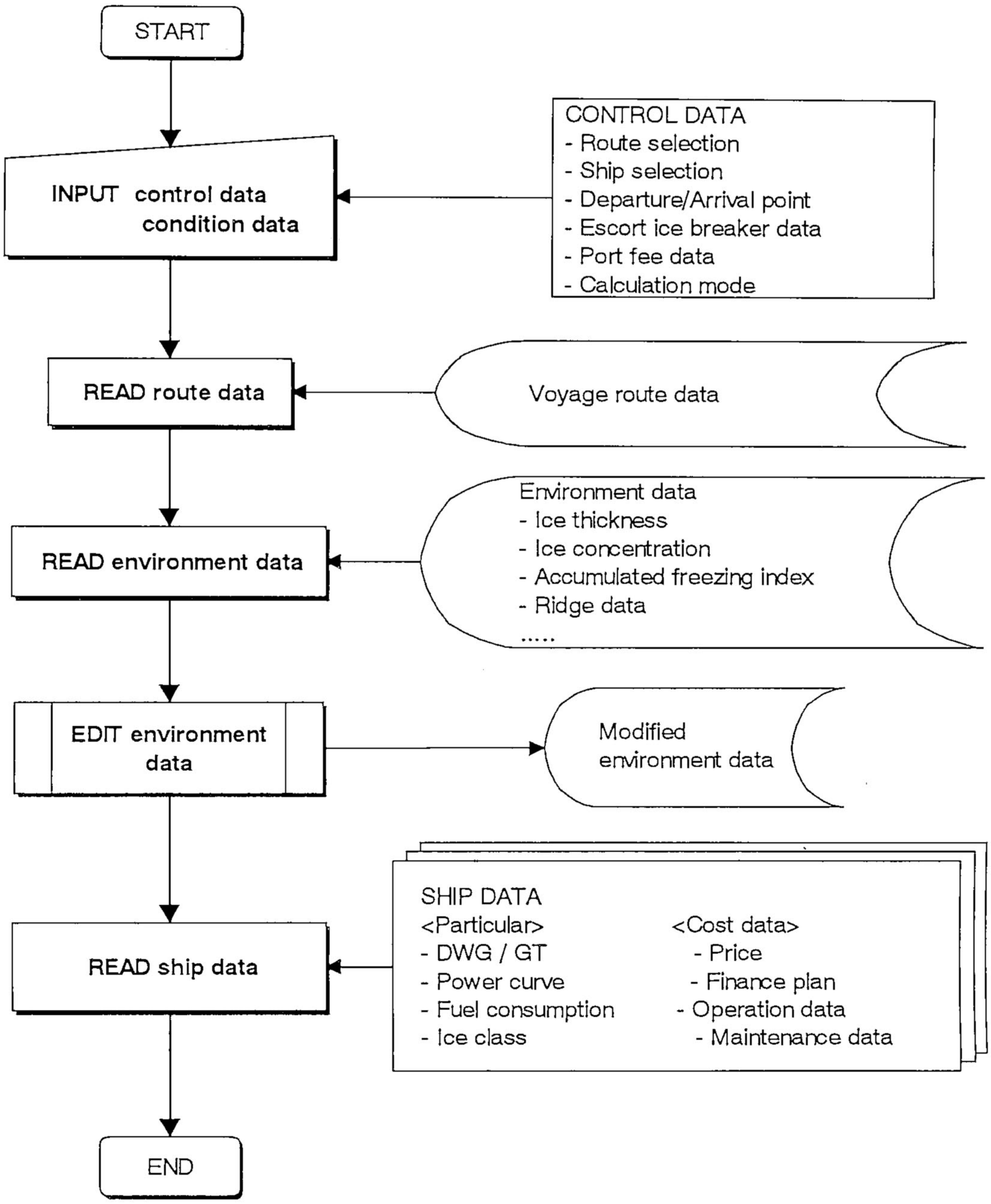


Fig.3.2.2 DATA READ module in the NSR simulation

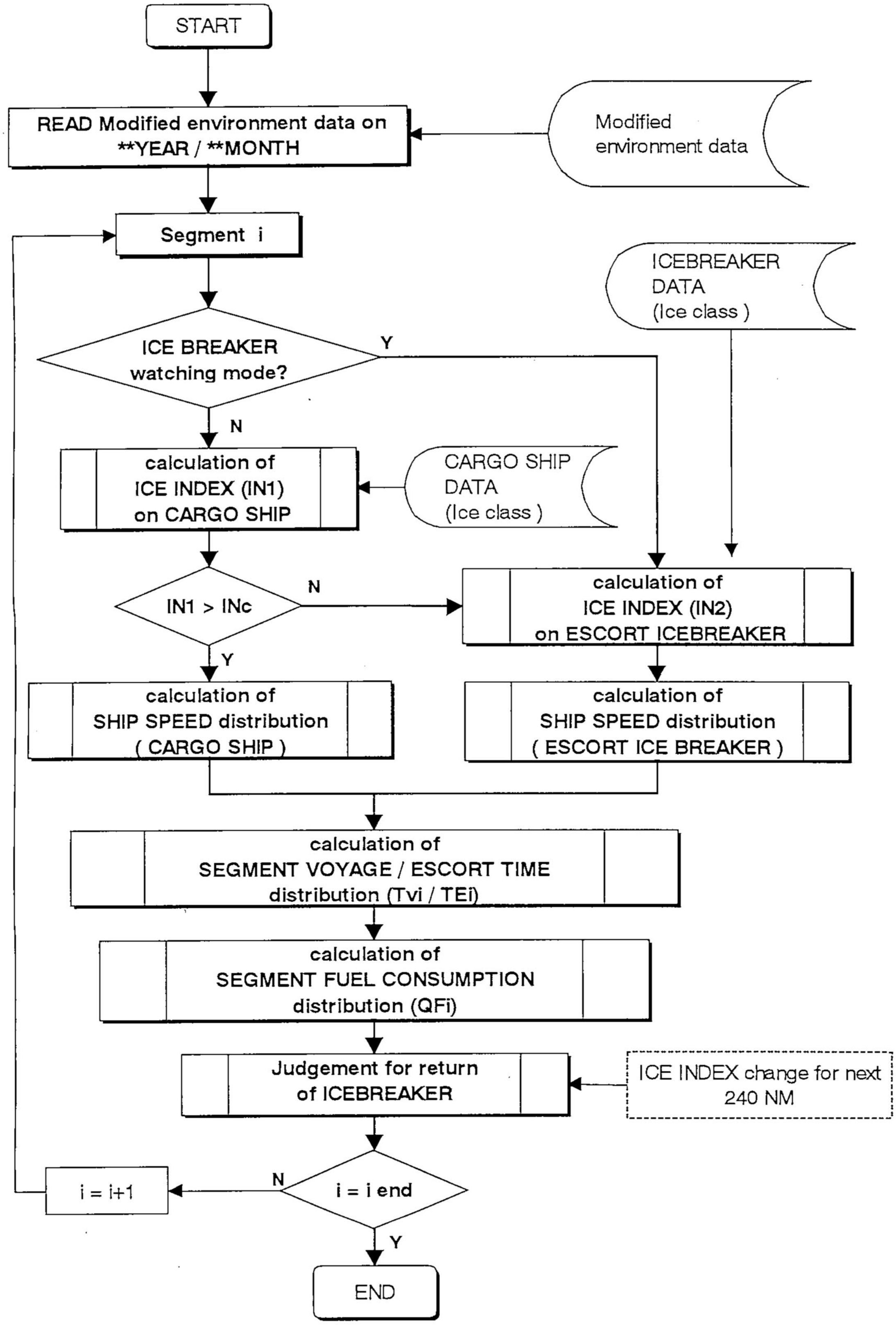


Fig.3.2.3 One-voyage simulation flow in *VOYAGE SIMULATION* module

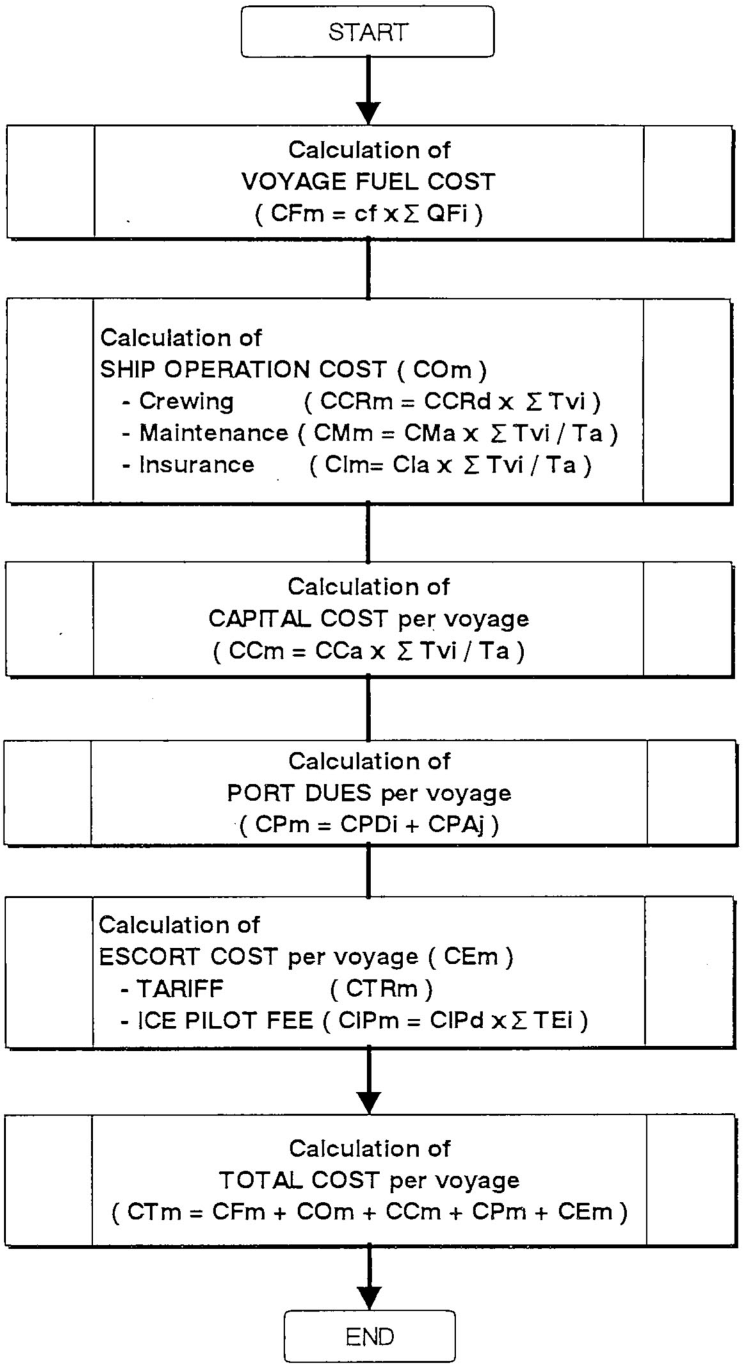


Fig.3.2.4 Voyage cost calculation for *Monthly Voyage Simulation*

3.3 Annual serial voyage simulation (ASVS)

Main flow

In the annual serial voyage simulation (ASVS), the total cargo amounts and freight cost for serial operation running between transit route throughout the year are calculated when the serial operation is performed in the transit routes for the period of one year. The total cargo amounts and freight costs is compared with those through the Suez route. Fig.3.3.1 represents the main flow of ASVS.

Serial voyage simulation

The major difference between ASVS and MVS is the calculation method in the *VOYAGE SIMULATION* module. In MVS, operation performance for one-voyage is calculated separately in each month and in the same direction. On the other hand, in ASVS, each operation is started from the next day of the end of the previous voyage and in the opposite direction, which is repeated for one year. The beginning of the voyage is assumed the first of January, and a voyage simulation is repeated until the arrival is 31st of December or after the day. The direction of first voyage is assumed from Yokohama to Hamburg. The flow of one-voyage simulation is same as one of MSV, which is represented in Figure 3.2.3.

In ASVS, the voyage is likely started in the middle of month, so the shift of month during one voyage occurs frequently. In such a case of ASVS, also the environmental data is renewed to one of the next month at the route segment where the month changes.

Annual cost

Figure 3.3.2 illustrates the flow of ASVS cost calculation. In ASVS, the one-voyage cost is totaled separately in each cost component throughout the year. The calculation methods for cost component have been explained in chapter 3.1.

As the explanation in chapter 3.2.2, the last voyage in that year would be extended over the next year. Therefore, the cost and cargo capacity are converted to one year basis, and the freight rate and a number of voyages are derived.

Results output

The output results of the calculation in ASVS are listed below.

- Stochastic value of annual cargo amount
- Change of voyage-days for one year
- Stochastic value of annual total cost
- Stochastic value of cost component for one year
- Stochastic value of freight cost
- Stochastic value of cost component for one year

Each stochastic values above are output by the mean value combination of each voyage, the upper expected value combination of each voyage, and the lower expected value combination of each voyage respectively. Where, the upper expected value is defined as the value under which the probability of occurrence is 90 %. The lower expected value is defined as the value under which the probability is 10 %.

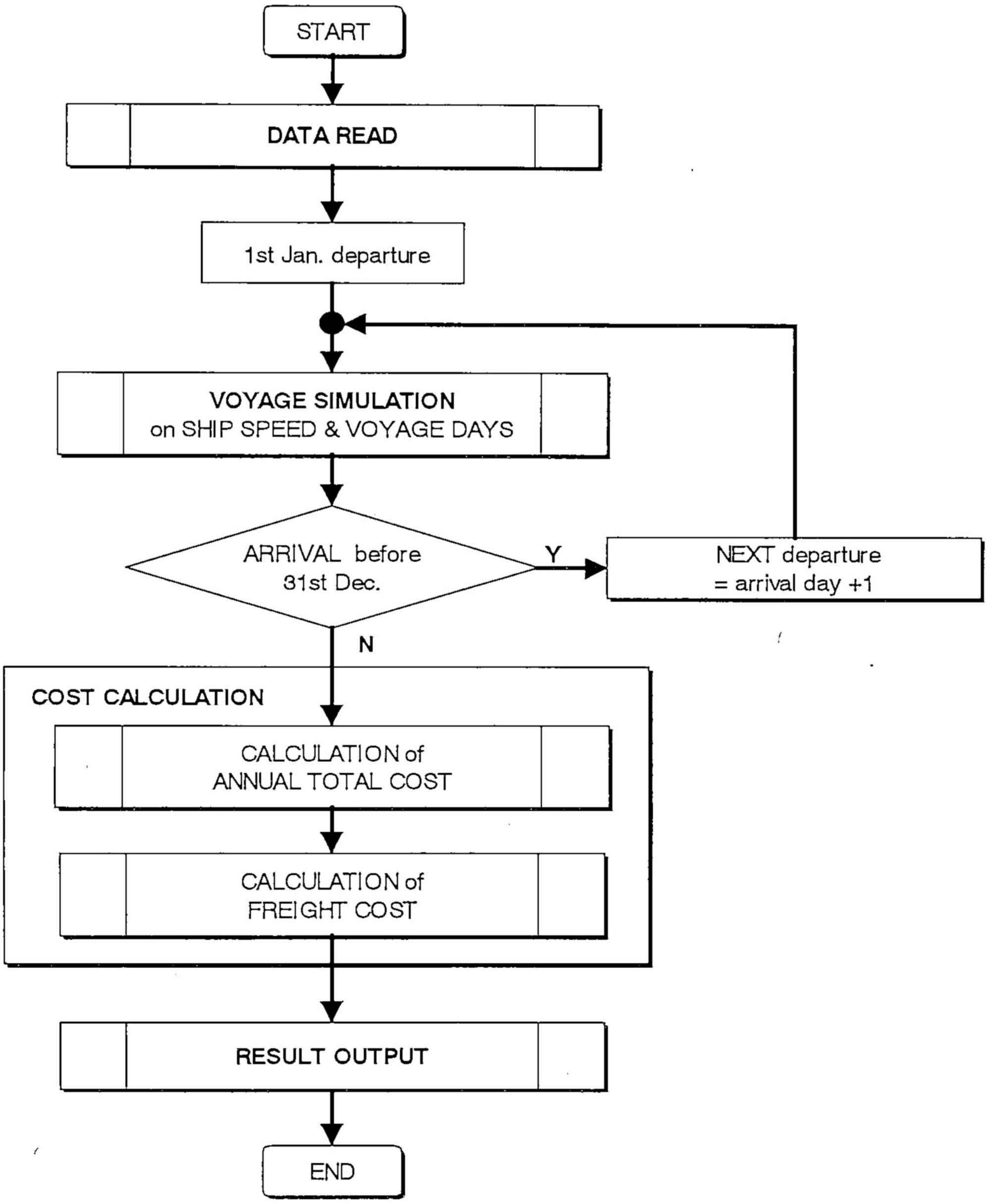


Fig.3.3.1 Main flow of ***Annual Serial Voyage Simulation***

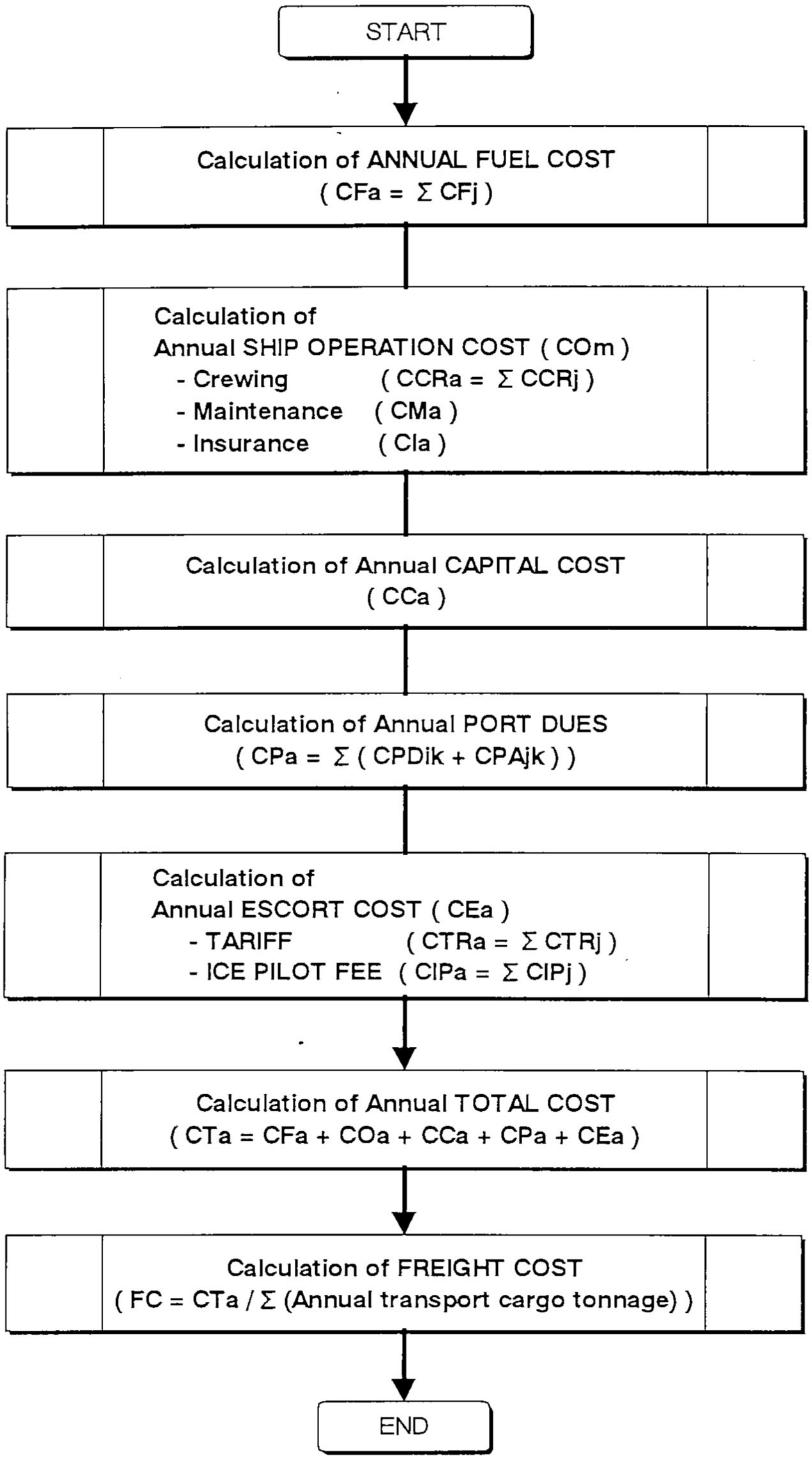


Fig.3.3.2 Voyage cost calculation for *Annual Serial Voyage Simulation*

4. RESULTS

4.1 Evaluation of Monthly Voyage Simulation

4.1.1 Sensitivity Analysis on Icebreaker Tariff

The profitability of the NSR operation must meet or exceed that of the Suez route in order to use the NSR commercially. The icebreaker tariff is considered as the most significant factor among the cost parameters, although it is not rigorously regulated and the final fee will be decided after the negotiation with MSCO (Murmansk Shipping Company) that is operating the NSR icebreaker fleet. The icebreaker tariff rates in the cost table are extrapolated value from the tariff rate published. Before proceeding the cost simulation, the icebreaker tariff is discussed to set reasonable one to be used throughout the simulation.

It is assumed that the NSR has to keep advantage to the Suez route for at least 6 months in terms of the operation cost as rationale. Thus, it is studied whether the extrapolated icebreaker tariff is suitable to fulfill these premises, an d how low the tariff should be set if it is unfeasible. The sensitivity analysis for icebreaker tariff was performed applying MVS (the monthly voyage simulation) and it proved that the tariff should be cut by 26% as shown in Table 4.1.1.

Table 4.1.1 Assumption of the Icebreaker Tariff

Entire NSR			Extrapolated value	26% off value
			$/GT	$/GT
25BC	Summer	(Jul.-Oct.)	7.36	5.45
	Winter	(Nov.-Jun)	7.14	5.28
40BC	Summer	(Jul.-Oct.)	7.11	5.26
	Winter	(Nov.-Jun)	6.89	5.10
50BC	Summer	(Jul.-Oct.)	6.83	5.05
	Winter	(Nov.-Jun)	6.56	4.86
West part of NSR			**Extrapolated value**	**26% off value**
			$/GT	$/GT
25BC	Summer	(Jul.-Oct.)	4.78	3.54
	Winter	(Nov.-Jun)	7.14	5.28

The voyage costs for 40,000 DWT type bulk/container (40BC) that is calculated by using these two different tariff rates are shown in Table 4.1.2 and 4.1.3. In these cases, the freight costs are calculated by dividing one voyage cost by cargo tonnage in Table 2.4.
The ship route is set as high latitude transit route (N-route). The calculation results for 25,000 DWT type bulk/container (25BC) and 50,000 DWT type bulker (50BC) were shown in Appendix C. The freight cost for the ship route via the Suez Canal is also shown below the Tables. Also the calculation conditions for the Suez route are indicated the Appendix C.

The mean values of environment data from 1957 through 1990 (except 1961,1963 and 1972) are used for the calculation. As Table 4.1.2, Table C.1 and Table C.3 show, the result using the extrapolated tariff rate indicates that the average freight cost for a year is higher than that of Suez route and the freight cost of the NSR is lower during the period of six or four months. If using the tariff cut by 26%, the average freight cost becomes lower or nearly equal as indicated in Table 4.1.3, Table C.2 and Table C.4. Setting more than 30% off value would be unrealistic and unfeasible. Thus, the tariffs of 26% off value are used throughout the simulation.

Table 4.1.2 Freight cost by month for 40BC (using extrapolated tariff)

Tariff ($/GT)	Summer (7-10)	7.11	Winter (11-6)	6.89

Month	1 voyage cost	Icebreaker fee	1voyage days	Freight cost
	k$	k$	days	$/t
1	1537	172	44.1	42.7
2	1538	175	45.4	42.7
3	1541	176	45.5	42.8
4	1527	175	45.0	42.4
5	1481	174	43.3	41.1
6	1341	170	38.5	37.2
7	1407	176	40.0	39.1
8	1317	166	33.3	36.6
9	1300	166	32.9	36.1
10	1252	168	32.8	34.8
11	1390	161	35.2	38.6
12	1652	164	42.9	45.9
via SUEZ	1429	0	40.3	39.7

Table 4.1.3 Freight cost by month for 40BC (using 26% off tariff)

Tariff ($/GT)	Summer (7-10)	5.26	Winter (11-6)	5.10

Month	1 voyage cost	Icebreaker fee	1voyage days	Freight cost
	k$	k$	days	$/t
1	1497	132	44.1	41.6
2	1497	134	45.4	41.6
3	1499	134	45.5	41.6
4	1487	134	45.0	41.3
5	1440	133	43.3	40.0
6	1301	130	38.5	36.1
7	1365	134	40.0	37.9
8	1276	125	33.3	35.4
9	1258	125	32.9	34.9
10	1211	127	32.8	33.6
11	1349	120	35.2	37.5
12	1611	124	42.9	44.8
via SUEZ	1429	0	40.3	39.7

4.1.2 Simulation for transit route operation

The monthly voyage simulation (MVS) linking Yokohama and Hamburg was executed in order to investigate the trends for transit voyages. 40BC and 50BC were used for N-route voyage, 25BC was used for S-route voyage. The simulation series was executed using the environment data from 1957 to 1990, however, those years in which the data did not satisfy the fulfillment of 50% were excluded from our database as noted in chapter 2.2.

Figure 4.1.1 to 4.1.3 show the voyage-days and Figure 4.1.4 to 4.1.6 indicate the escorted days by icebreaker by month for 25BC, 40BC and 50BC in both 1979 and 1980 as one of the results. The notations, 1% max. in the figures means the value corresponding the probability of occurrence at 99%. Another notation, 1% min. means the value under which the probability at 1%. However the difference between 1% and 99% is small, and that demonstrates that the ice index is reasonable. Figures 4.1.7 to 4.1.9 show the components of one-voyage cost. The results in the other years are summarized in the Appendix C.

Table 4.1.4 to 4.1.6 and Figure 4.1.10 to 4.1.12 show the monthly tendency of the voyage-days and the escort days for 25BC, 40BC and 50BC respectively. Each data of them represents the average of 1957 to 1990. The monthly tendency indicates that the voyage-days decrease from June to October. The ratio of escort-days to the voyage-days in the NSR tends to exceed over 50% from February to June. As for a comparison between the cargo ships, the ratio of 50BC is greater than the other ships. These results for the escort-days are reasonable. 50BC needs longer escort-days than 40BC in the N-route, since 50BC is inferior in the icebreaking capability. 40BC in the N-route, where the ice condition is more severe, needs longer escort-days than 25BC in the S-route as both 40BC and 25BC has the same icebreaking capability.

Figure 4.1.13 to 4.1.15 show the monthly tendency of the average navigation speed by sea area. On the whole, the navigation speed ranges between 4 to 7knots in the winter from December to May. In the summer season from August to October, it ranges between 9 to 13knots for 25BC and 40BC, between 9 to 14knots for 50BC. The tendency indicates that the speed of 40BC and 50BC in the winter season is slightly greater at the Laptěv Sea than the other area, but in summer season one at the Chukchi Sea is greater. On the other hand, as for 25BC in the summer season, the superiority at the Chukchi Sea is not recognized. As a whole, the speed in the East Siberian Sea is relatively slower than other areas.

Table 4.1.7 to 4.1.9 and Figure 4.1.16 to 4.1.18 show the monthly tendency of the cost components, as the average of 1957 to 1990. The operating and fuel costs slightly vary, although the capital cost greatly changes in season. The escort days increase from January to July, and decreased from August to December, nevertheless the icebreaker fee is almost constant because the flat rate charge is adopted. The difference among ship types is that 50BC requires more expenses on icebreaker fee, fuel fee and port fee than that of 40BC and 25BC but capital cost for 50BC is relatively low. As the results, the total costs for 50BC is less than those of other two ships. The detailed data are listed in Appendix C.

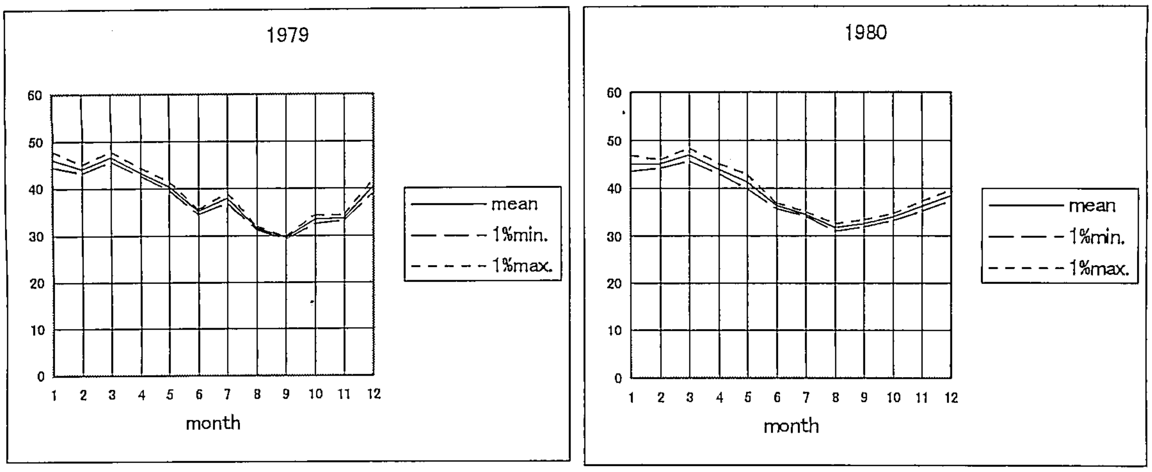


Figure 4.1.1 Voyage days for 25BC

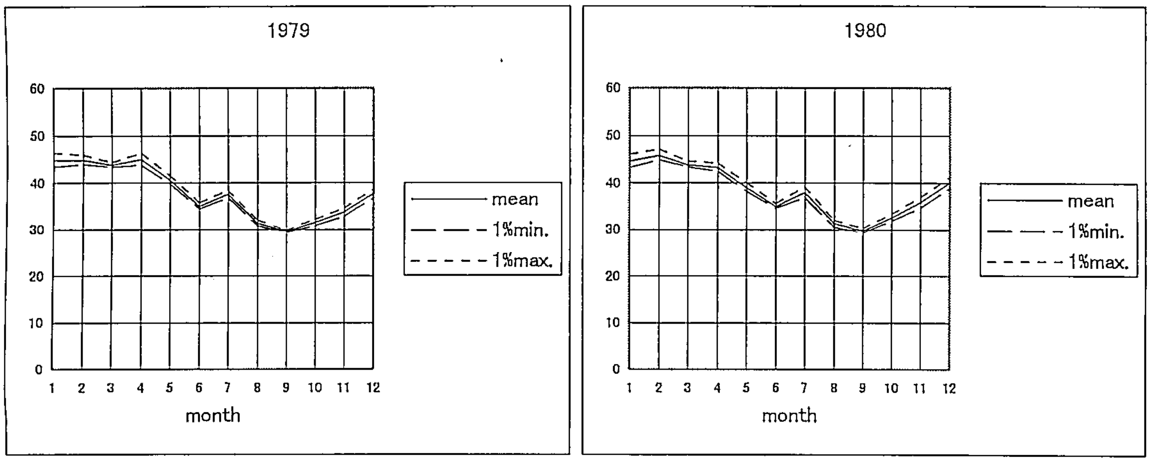


Figure 4.1.2 Voyage days for 40BC

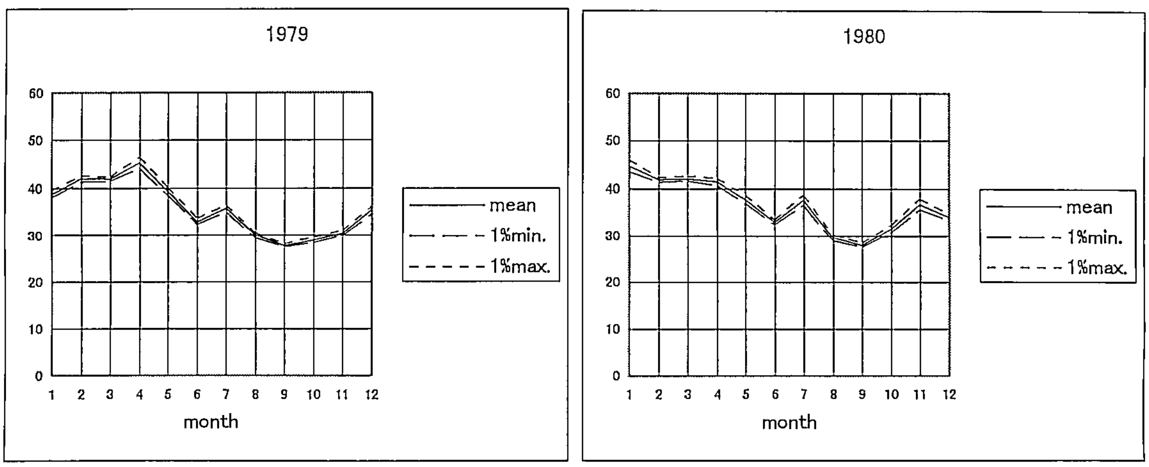


Figure 4.1.3 Voyage days for 50BC

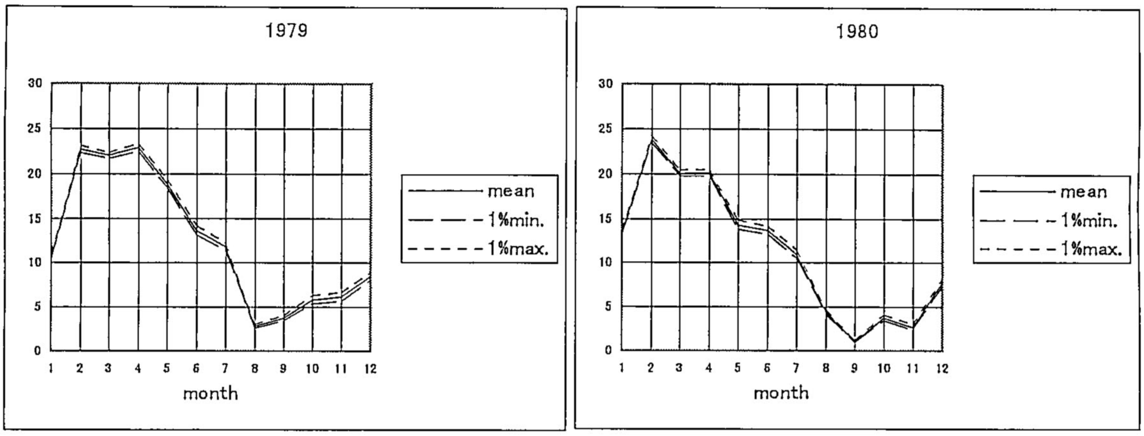


Figure 4.1.4 Escorted days by icebreaker for 25BC

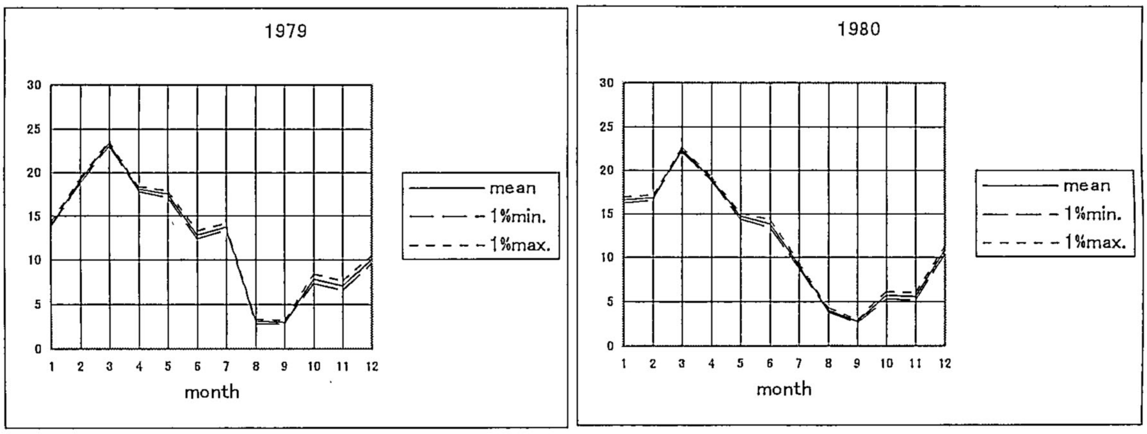


Figure 4.1.5 Escorted days by icebreaker for 40BC

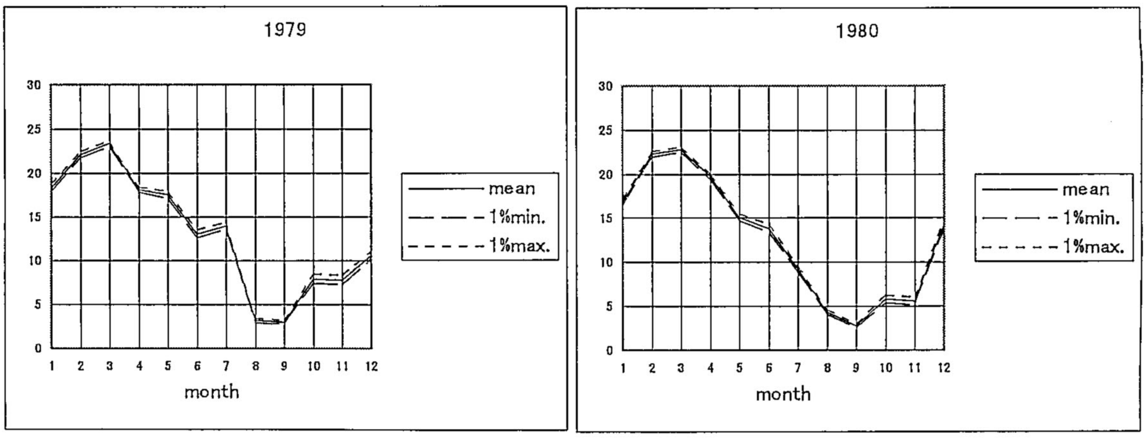


Figure 4.1.6 Escorted days by icebreaker for 50BC

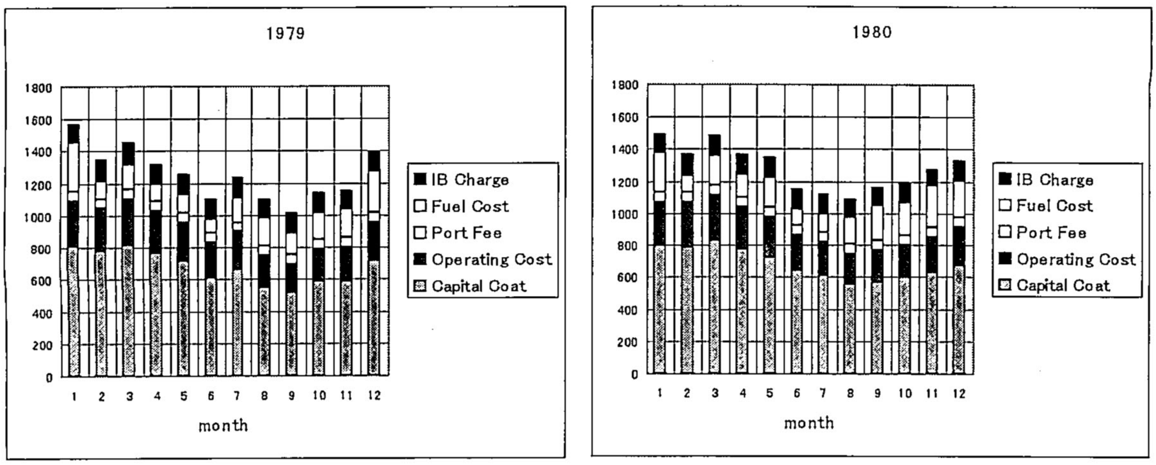


Figure 4.1.7 The voyage cost component for 25BC

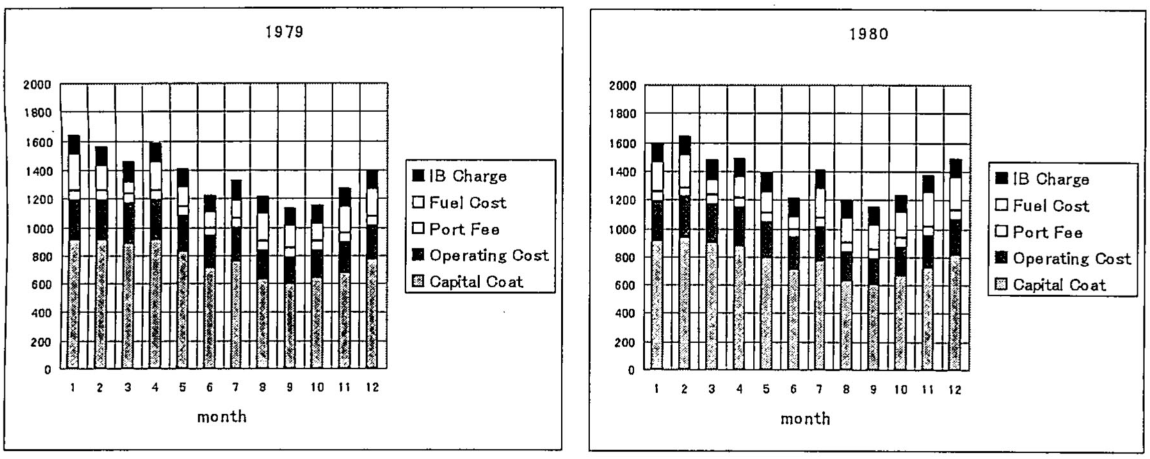


Figure 4.1.8 The voyage cost component for 40BC

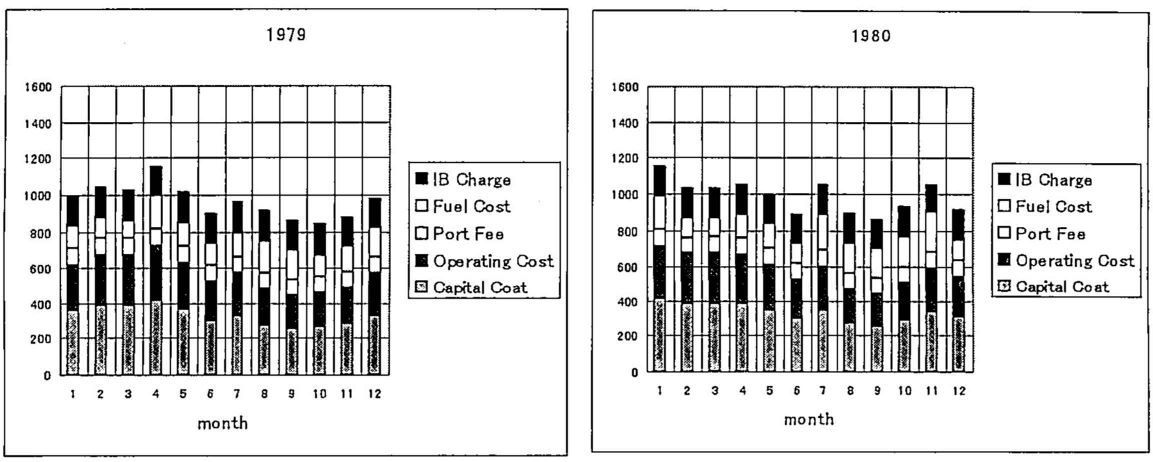


Figure 4.1.9 The voyage cost component for 50BC

Table 4.1.4 Voyage days and Escort days for the 25BC as statistical value for 1957 – 1990 at S-route; 7330NM

	Voyage days			Escort days		Escort ratio
month	Entire ave.	NSR ave.	NSR S.Dev.	Average	Standard dev.	at NSR
Jan	43.0	27.8	1.9	10.8	2.5	38.9%
Feb	45.2	30.0	1.3	17.9	2.7	59.5%
Mar	45.7	30.5	1.3	19.6	2.3	64.5%
Apr	44.2	29.0	1.2	19.3	2.7	66.5%
May	40.5	25.3	1.5	16.1	2.8	63.6%
Jun	35.5	21.9	1.2	12.4	2.2	56.7%
Jul	35.9	22.3	1.6	9.8	2.8	43.8%
Aug	31.2	17.6	1.1	1.6	1.1	9.2%
Sep	30.4	16.8	1.0	1.4	1.3	8.1%
Oct	32.7	19.1	1.2	2.3	1.4	12.0%
Nov	37.7	24.1	4.0	1.6	1.7	6.5%
Dec	40.2	25.0	1.1	4.8	1.7	19.3%
Year	38.5	24.1	4.8	9.8	7.3	40.6%

Table 4.1.5 Voyage days and Escort days for the 40BC as statistical value for 1957 – 1990 at N-route; 7196NM

	Voyage days			Escort days		Escort ratio
month	Entire ave.	NSR ave.	NSR S.Dev.	Average	Standard dev.	at NSR
Jan	43.9	26.6	2.5	10.2	2.7	38.5%
Feb	44.3	27.0	1.4	15.4	3.7	56.9%
Mar	44.1	26.8	1.2	17.0	3.1	63.5%
Apr	43.1	25.8	1.0	17.2	2.5	66.5%
May	40.2	22.9	1.7	14.0	2.0	61.2%
Jun	35.2	20.2	1.4	12.6	1.6	62.3%
Jul	35.9	20.9	1.3	10.2	2.9	48.7%
Aug	31.7	16.7	1.5	2.2	1.1	13.1%
Sep	30.7	15.7	1.5	2.0	1.5	13.0%
Oct	32.3	17.3	1.4	3.9	1.6	22.4%
Nov	35.6	20.6	2.4	3.5	1.0	16.9%
Dec	39.8	22.5	1.6	4.1	1.6	18.3%
Year	38.1	21.9	4.2	9.4	6.1	42.7%

Table 4.1.6 Voyage days and Escort days for the 50BC as statistical value for 1957 – 1990 at N-route; 7196NM

	Voyage days			Escort days		Escort ratio
month	Entire ave.	NSR ave.	NSR S.Dev.	Average	Standard dev.	at NSR
Jan	41.2	25.8	4.0	12.6	2.8	48.7%
Feb	42.2	26.8	1.7	17.5	3.0	65.2%
Mar	42.7	27.3	2.0	17.8	2.6	65.2%
Apr	41.6	26.2	1.5	17.5	2.4	66.7%
May	38.9	23.5	2.2	14.2	1.9	60.6%
Jun	33.4	20.7	1.8	13.0	1.5	62.8%
Jul	34.4	21.7	1.8	10.7	2.9	49.2%
Aug	30.2	17.5	1.9	2.7	1.0	15.4%
Sep	28.8	16.1	2.2	2.4	1.5	15.2%
Oct	30.6	17.9	2.0	4.4	1.7	24.7%
Nov	35.5	22.8	3.9	4.1	1.1	17.8%
Dec	37.2	21.8	3.2	5.8	2.4	26.7%
Year	36.4	22.3	4.4	10.2	6.2	45.7%

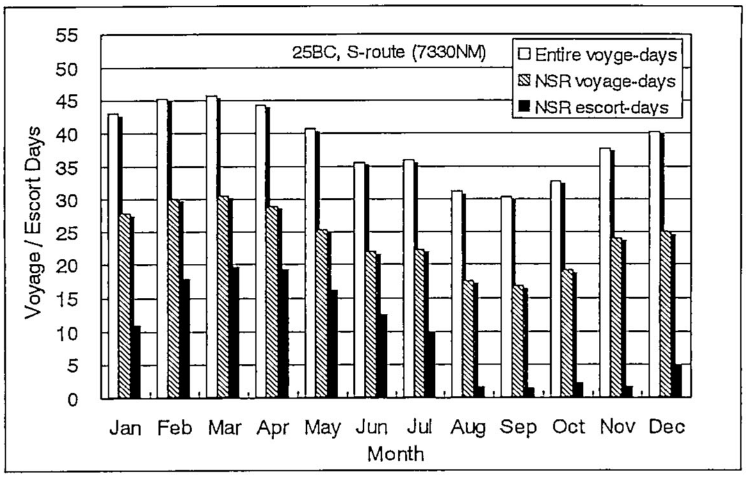


Figure 4.1.10 Voyage days and Escort days for the 25BC as average of 1957 – 1990 at S-route; 7330NM

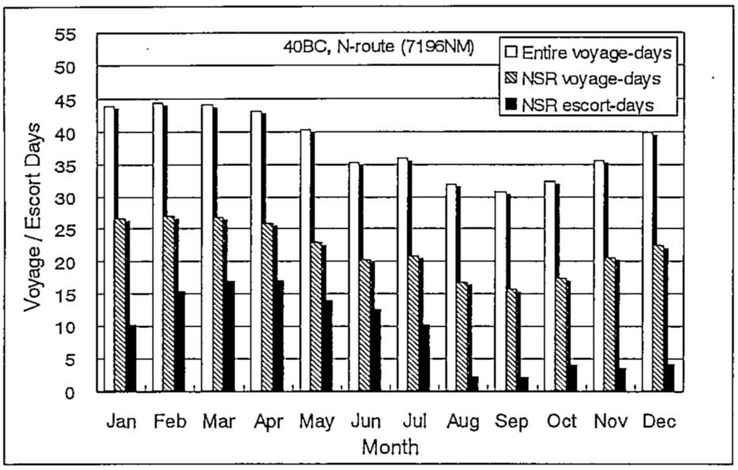


Figure 4.1.11 Voyage days and Escort days for the 40BC as average of 1957 - 1990 at N-route; 7196NM

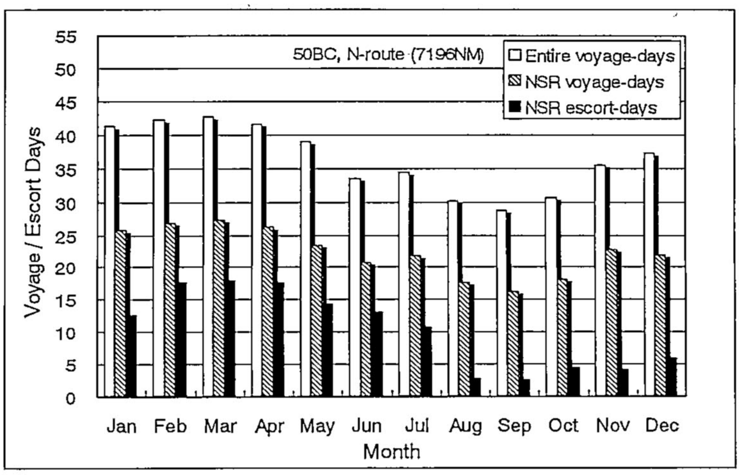


Figure 4.1.12 Voyage days and Escort days for the 50BC as average of 1957 - 1990 at N-route; 7196NM

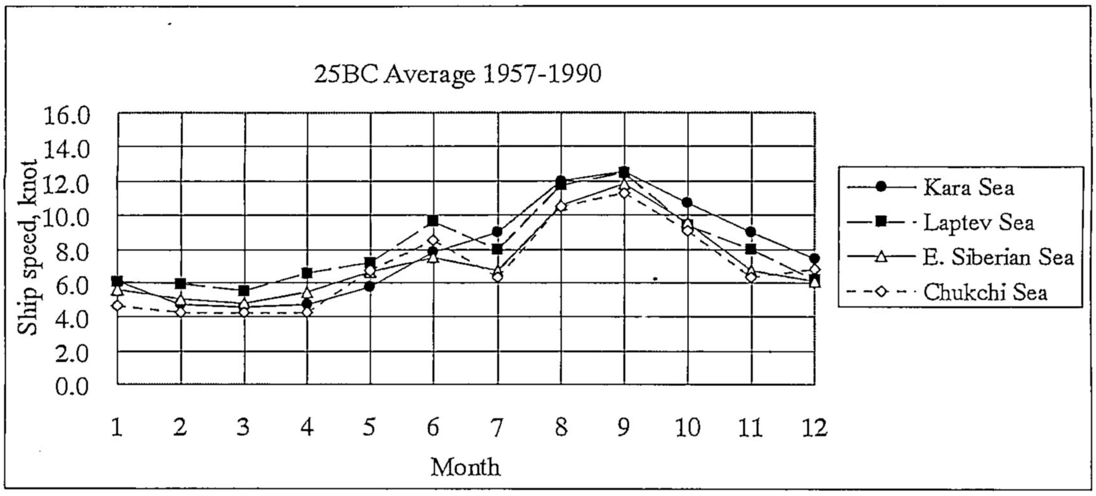


Figure 4.1.13 Navigation speed for the 25BC by the sea area, as an average of 1957-1990

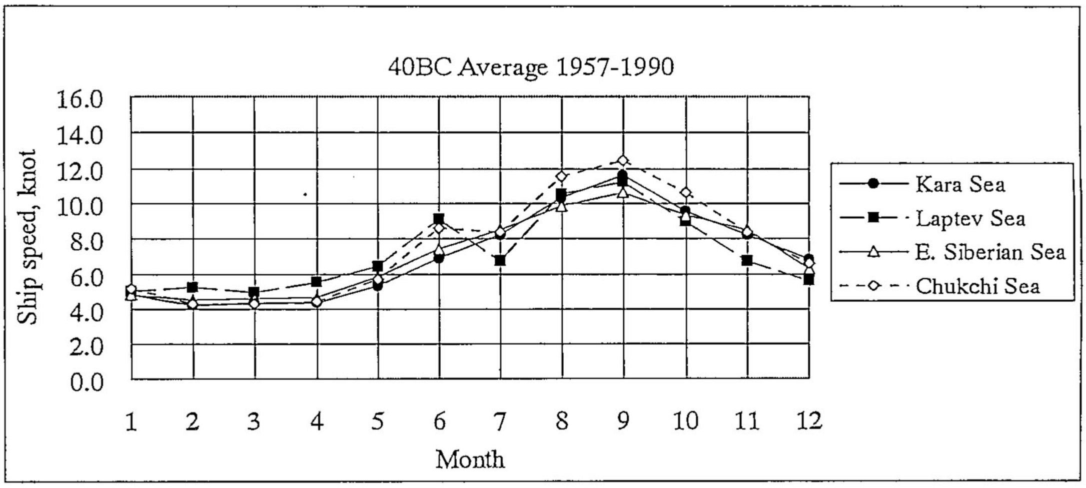


Figure 4.1.14 Navigation speed for the 40BC by the sea area, as an average of 1957-1990

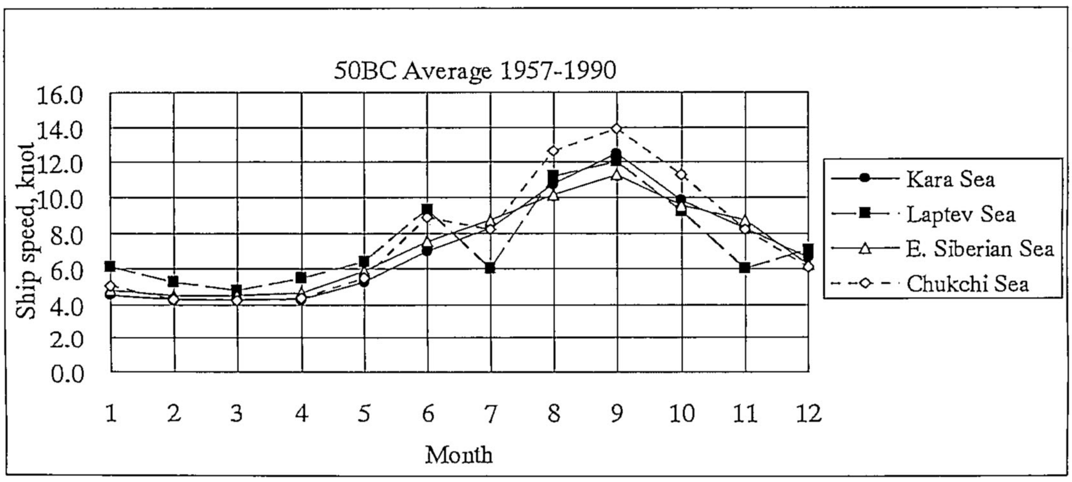


Figure 4.1.15 Navigation speed for the 50BC by the sea area, as an average of 1957-1990

Table 4.1.7 Cost components for 25BC as the average of 1957-1990

Month	Capital Cost	Operating Cost	Port Fee	Fuel Cost	IB Charge	Total Cost	St. dev. of total cost
	k$	k$	k$	k$	k$	k$	k$
Jan.	754	260	61	237	121	1433	61
Feb.	799	275	61	183	126	1444	44
Mar.	806	278	61	165	127	1438	61
Apr.	780	269	61	150	127	1388	49
May	716	247	61	143	125	1292	50
Jun	628	216	61	113	122	1140	38
Jul.	634	218	61	148	122	1184	60
Aug.	551	190	61	182	116	1100	43
Sep.	536	185	61	168	116	1067	39
Oct.	577	199	61	205	117	1159	49
Nov.	666	229	61	287	113	1357	166
Dec.	711	245	61	291	116	1423	52

Table 4.1.8 Cost components for 40BC as the average of 1957-1990

Month	Capital Cost	Operating Cost	Port Fee	Fuel Cost	IB Charge	Total Cost	St. dev. of total cost
	k$	k$	k$	k$	k$	k$	k$
Jan.	894	270	67	242	126	1599	120
Feb.	907	274	67	174	130	1552	93
Mar.	901	273	67	145	131	1517	79
Apr.	882	267	67	128	131	1474	59
May	823	249	67	131	129	1399	79
Jun	720	218	67	110	126	1241	54
Jul.	733	222	67	152	128	1302	65
Aug.	649	196	67	207	122	1242	71
Sep.	629	190	67	186	121	1194	67
Oct.	661	200	67	198	123	1250	69
Nov.	728	220	67	265	118	1399	104
Dec.	813	246	67	279	121	1527	74

Table 4.1.9 Cost components for 50BC as the average of 1957-1990

Month	Capital Cost	Operating Cost	Port Fee	Fuel Cost	IB Charge	Total Cost	St. dev. of total cost
	k$	k$	k$	k$	k$	k$	k$
Jan.	384	279	92	164	163	1082	119
Feb.	393	286	92	127	167	1064	60
Mar.	397	289	92	128	167	1074	65
Apr.	387	282	92	122	167	1049	51
May	361	263	92	127	164	1008	62
Jun	310	226	92	118	161	907	43
Jul.	320	233	92	149	166	959	56
Aug.	281	205	92	185	160	923	51
Sep.	268	195	92	175	160	890	56
Oct.	285	207	92	172	162	918	54
Nov.	330	240	92	224	154	1041	101
Dec.	346	252	92	190	158	1039	96

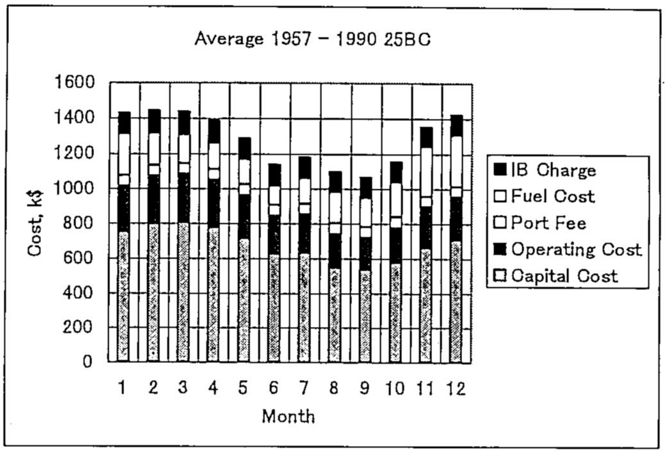


Figure 4.1.16 Cost components for the 25BC as the average of 1957-1990

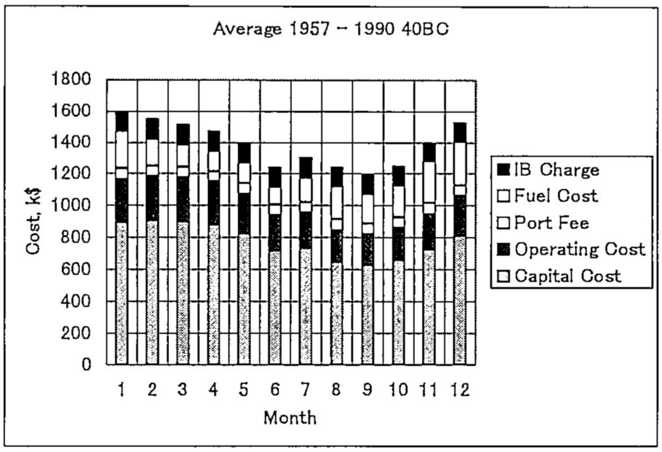


Figure 4.1.17 Cost components for the 40BC as the average of 1957-1990

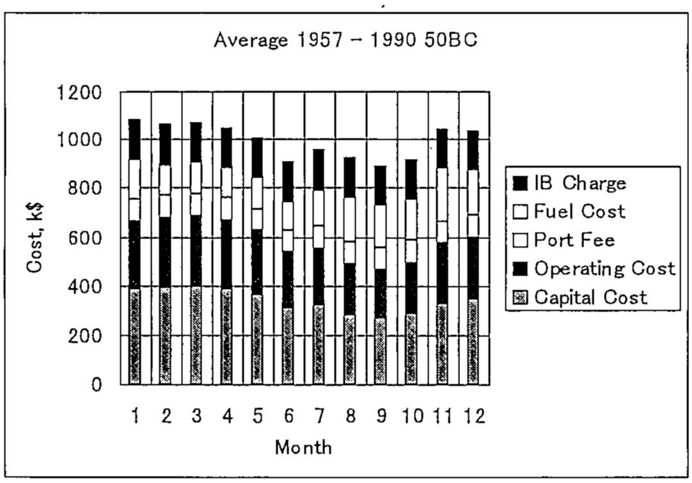


Figure 4.1.18 Cost components for the 50BC as the average of 1957-1990

Based on the results above, the relation between the freight cost and ice index in the NSR is investigated. Table 4.1.10 shows the freight cost of 40BC by month in 1964 as an example and the cumulative ice index which means the sum of a multiplier of the segment distance by an ice index of the segment along the N-route from Yokohama to Hamburg.

Table 4.1.10 Integrating ice index and the freight cost (1964)

	Freight cost ($/t)	Integrating ice index (mile)
Jan.	45.1	-19800
Feb.	41.9	-42800
Mar.	42.3	-47300
Apr.	42.0	-38200
May	36.1	-34300
Jun.	35.1	-31700
Jul.	34.2	-13100
Aug.	34.2	28400
Sep.	33.5	35600
Oct.	38.1	17700
Nov.	41.7	13800
Dec.	42.0	-300

The ice index represents the quantitative difficulty of navigation. The freight cost decreases with increasing the ice index. The freight costs and the cumulative ice index in each month for 10 years from 1980 to 1989 were calculated to reveal the relation between those, as shown in Figure 4.1.19. Figure 4.1.20 shows that of 50BC during the same term.

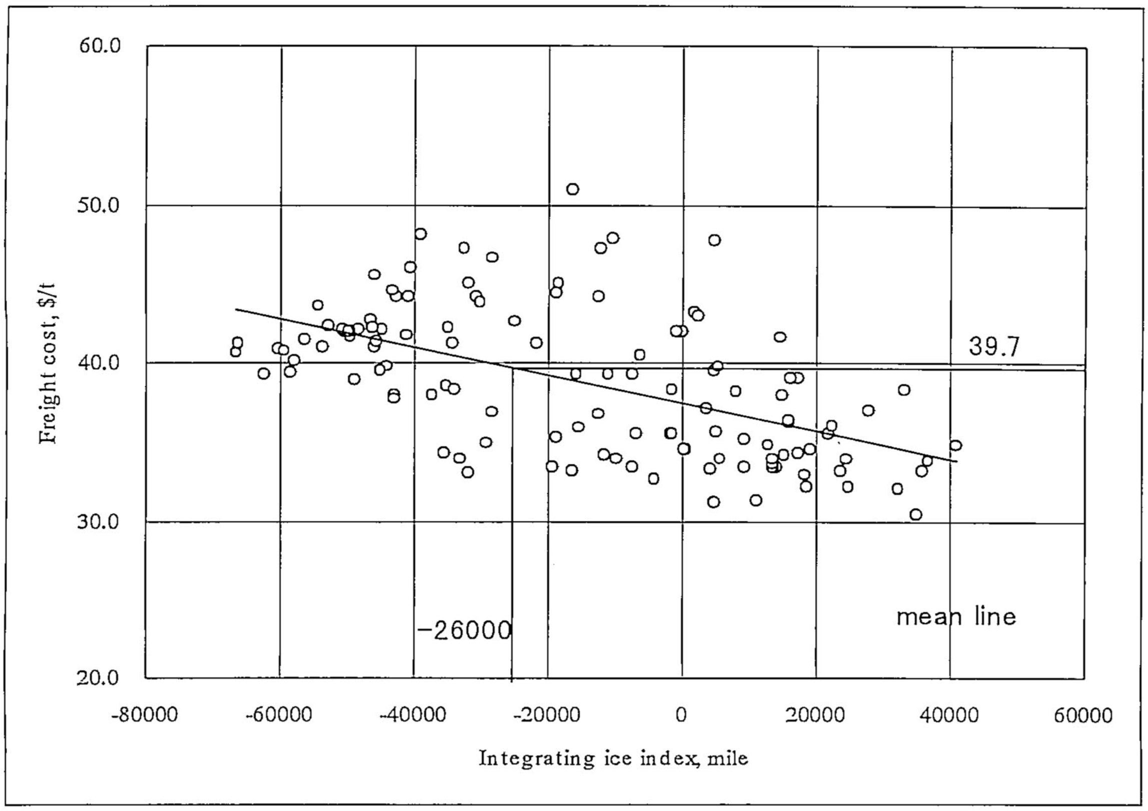


Figure 4.1.19 Integrating ice index v.s. freight cost of 40BC

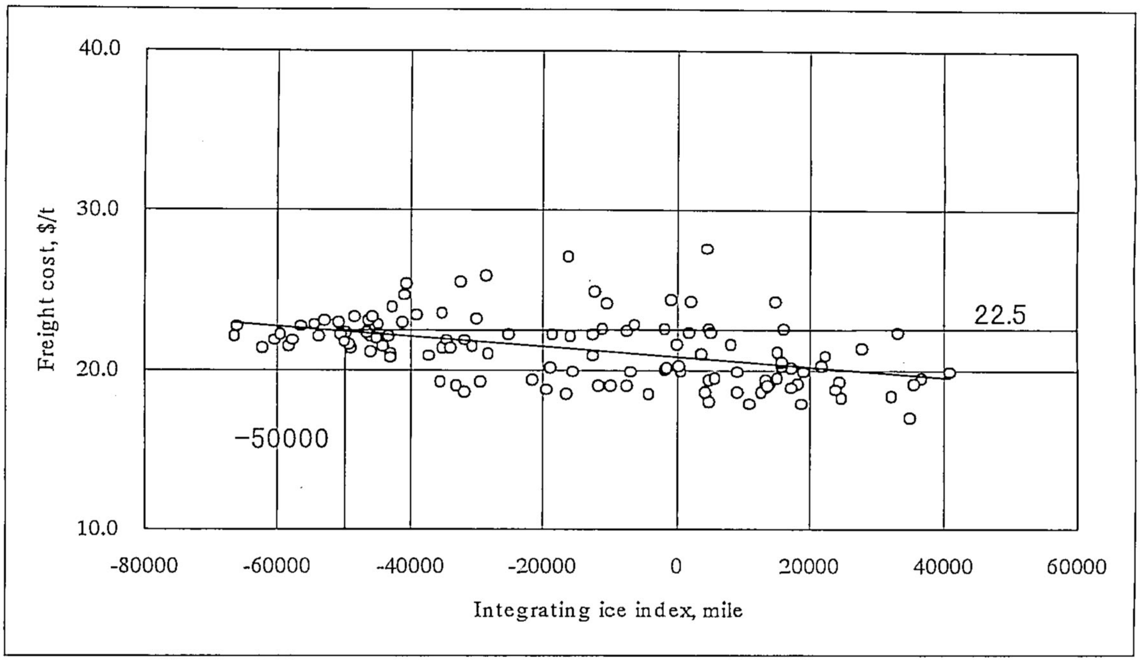


Figure 4.1.20 Integrating ice index v.s. freight cost of 50BC

As can be seen from these figures above, there is a correlation between the integrating ice index and the freight cost. As for 40BC, approximately 50% of the calculated freight costs is lower than the freight cost of through the SUEZ route, which is 39.7$/ton, as Figure 4.1.19 shows. The ideal condition of the use of NSR seems to be a year round basis. However, considering the effective use of the NSR, the SUEZ route should be used during the severe cold seasons when the freight cost is more expensive. Therefore, the route at the annual voyage simulation is assumed to switch between the NSR and the SUEZ judging the ice condition. The cumulative ice index along the route was adopted as the criterion of switching. The critical cumulative ice index for switching is decided from the value corresponding to the freight cost of the SUEZ route. From the results of Figure 4.1.19 and 4.1.20, the critical values of -26000 for 40BC and -50100 for 50BC were adopted respectively.

4.1.3 Simulation for regional route operation

The purpose of this chapter is to investigate the features of the NSR regional operation for cargo flows between Russia and Far Eastern or between Russia and Europe. Two voyage routes, which are merged to the coastal transit route (S-route), are assumed in the simulation. One is the regional east route (E-route) between Tiksi and Yokohama, and another route is the regional west route (W-route) between Dikson and Hamburg. A series of calculations by MVS was executed. 25,000 DWT type bulk/container (25BC) is employed as the cargo ship for the simulation. The icebreaker tariff rate cut by 26% was used, and the cost parameters in chapter 2.3 are adopted.

The results for 1980 are picked up as a representative example. Figures 4.1.21 to 4.1.23 show the voyage days, the escort days and the voyage cost components respectively for the regional east route. Figures 4.1.24 to 4.1.26 indicate the same for the west regional route. Table 4.1.11 and Figure 4.1.27 show the monthly tendency of the voyage-days at the entire route, the voyage-days at the NSR part and the escort-days at the NSR part for the regional east route. Table 4.1.12 and Figure 4.1.28 are the results for the regional west route. These statistical values refer to the simulation results from 1957 to 1990. The obvious difference of the escort ratio is found between E-route and W-route. The escort-days in the NSR part ranges from 1 to 11 days when E-route is used. The average ratio throughout the year is approximately 40%, but it goes up to more than 60% from February to April. On the other hand, in W-route, it needs maximum 2 days of the escort. The percentage of the independent voyage at the NSR part is more than 80%, and especially the escort is not necessary from July to January. It implies that the eastern NSR is harsher than the western NSR.

Figure 4.1.29 and 4.1.30 show the monthly tendency of the average navigation speed by sea area. In E-route, the trend in the Chukchi Sea is appeared almost same as the East Siberian Sea. The average speed in the winter season from January to April varies from 4 to 6 knots, and even in the summer season, it doesn't exceed 12 knots. On the whole, the average speed at the Laptev Sea is approximately 2 knots higher than one at the other areas. On the other hand, the speed changes smoothly in the year in W-route. This is mainly attributed to the ice condition, since the escort ratio is very low.

Table 4.1.13, 4.1.14 and Figure 4.1.31, 4.1.32 show the monthly trend of the cost components. The voyage costs at the regional east route ranges from $700,000 to $900,000. Those for the regional west route range between $460,000 and $660,000. The distance of E-route and W-route is 4,020NM and 2,397NM respectively. The reason for the cost deference is attributed to the deference of distances. However, the icebreaker fee of the both routes is almost same except for the summer season at W-route, because the flat rate is adopted. The actual escort-days is not reflected in this cost factor.

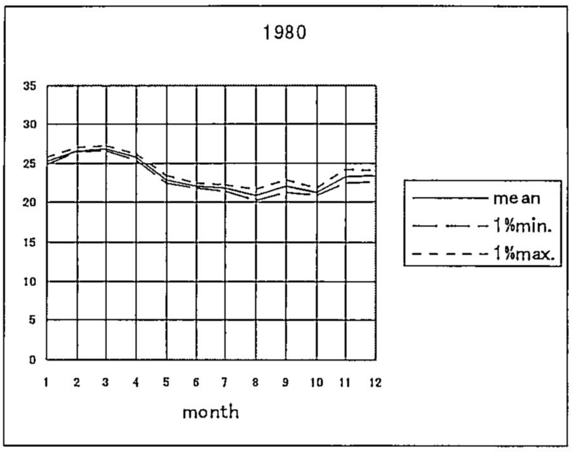


Figure 4.1.21 Voyage days from Yokohama to Tiksi (E-route)

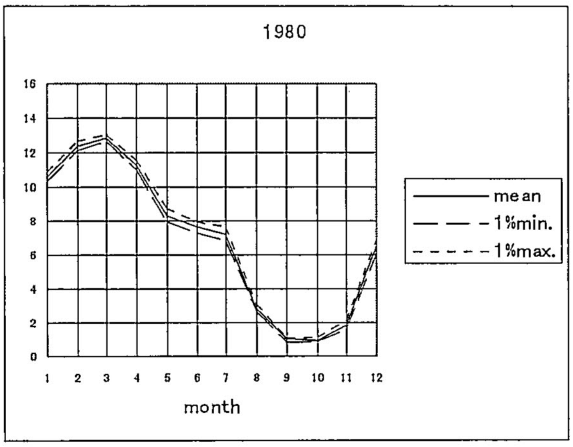


Figure 4.1.22 Escort days from Yokohama to Tiksi (E-route)

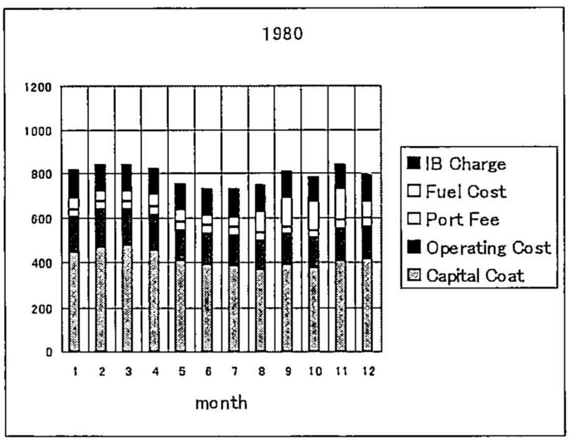


Figure 4.1.23 Voyage cost components (k$) from Yokohama to Tiksi (E-route)

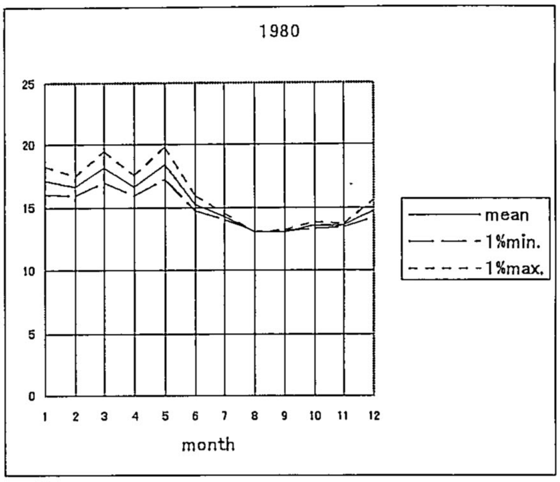


Figure 4.1.24 Voyage days of from Dikson to Hamburg (W-route)

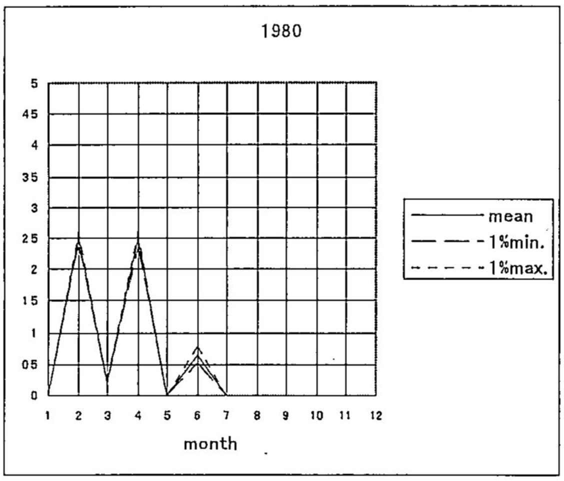


Figure 4.1.25 Escort days of from Dikson to Hamburg (W-route)

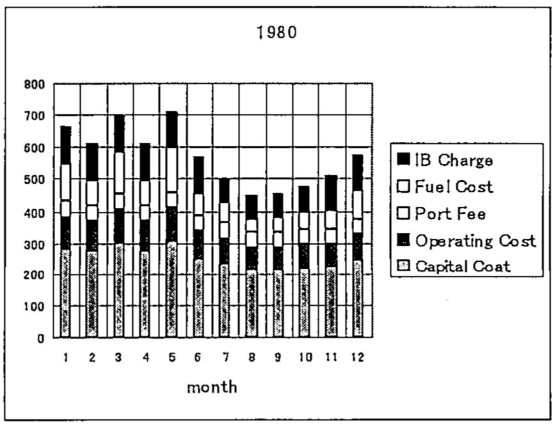


Figure 4.1.26 Voyage cost component (k$) from Dikson to Hamburg (W-route)

Table 4.1.11 Voyage days and escort days for the 25BC as statistical value for 1957-1990 at E-route; 4020NM

	Voyage days			Escort days		Escort ratio
month	Entire ave.	NSR ave.	NSR S.Dev.	Average	Standard dev.	at NSR
Jan	25.5	16.7	1.5	8.1	2.2	48.3%
Feb	26.0	17.2	0.8	10.7	1.2	62.6%
Mar	26.3	17.5	0.7	11.2	1.0	64.0%
Apr	25.4	16.6	0.7	10.5	0.9	63.1%
May	23.3	14.5	0.9	7.8	1.4	53.7%
Jun	21.8	13.7	0.9	7.1	1.2	51.7%
Jul	23.3	15.2	1.2	6.4	2.5	41.8%
Aug	20.0	11.9	1.0	1.0	1.1	8.4%
Sep	19.5	11.4	0.9	0.9	1.1	8.3%
Oct	20.9	12.8	0.9	1.4	1.5	11.3%
Nov	24.5	16.4	3.4	1.2	1.5	7.4%
Dec	24.8	16.0	1.1	3.9	1.7	24.3%
Year	23.4	15.0	2.4	5.9	4.1	39.0%

Table 4.1.12 Voyage days and escort days for the 25BC as statistical value for 1957-1990 at W-route; 2397NM

	Voyage days			Escort days		Escort ratio
month	Entire ave.	NSR ave.	NSR S.Dev.	Average	Standard dev.	at NSR
Jan	14.6	8.2	0.6	0.0	0.0	0.1%
Feb	16.2	9.8	0.7	0.8	1.1	8.4%
Mar	16.4	10.0	0.6	1.5	1.3	15.1%
Apr	16.4	10.0	0.7	1.7	1.4	17.1%
May	15.8	9.4	0.7	2.0	1.4	21.1%
Jun	13.7	8.2	0.5	0.7	0.7	8.5%
Jul	12.7	7.2	0.5	0.0	0.2	0.7%
Aug	12.1	6.6	0.2	0.0	0.0	0.1%
Sep	12.1	6.6	0.1	0.0	0.0	0.1%
Oct	12.4	6.9	0.2	0.0	0.0	0.0%
Nov	12.6	7.1	0.2	0.0	0.0	0.0%
Dec	13.8	7.4	0.1	0.0	0.0	0.0%
Year	14.1	8.1	1.4	0.6	1.1	7.0%

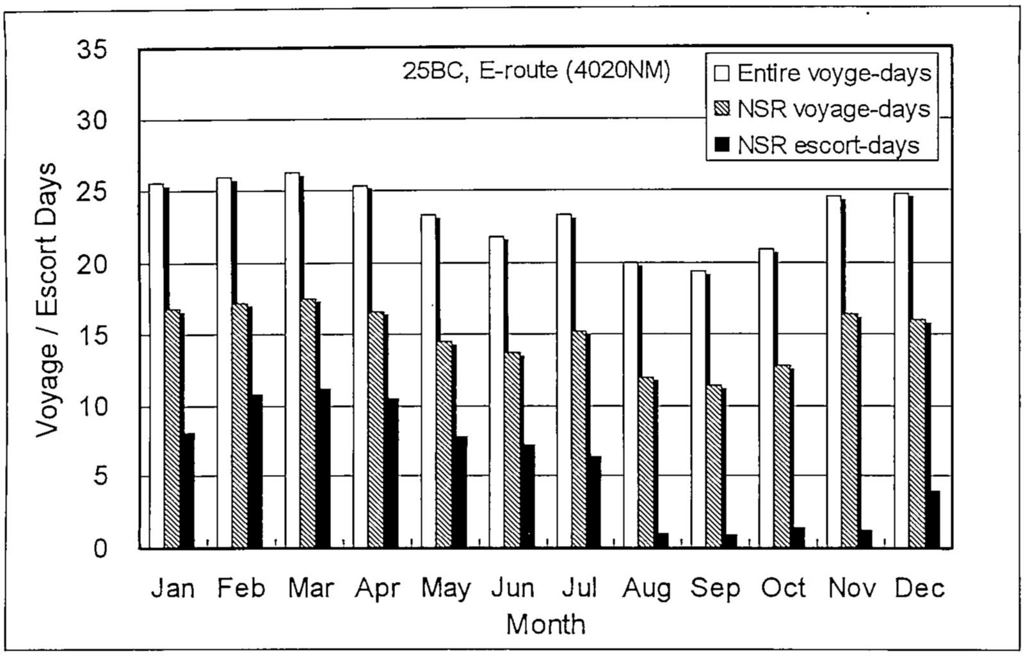


Figure 4.1.27 Voyage days and escort days for the 25BC as an average of 1957-1990 at E-route; 4020NM

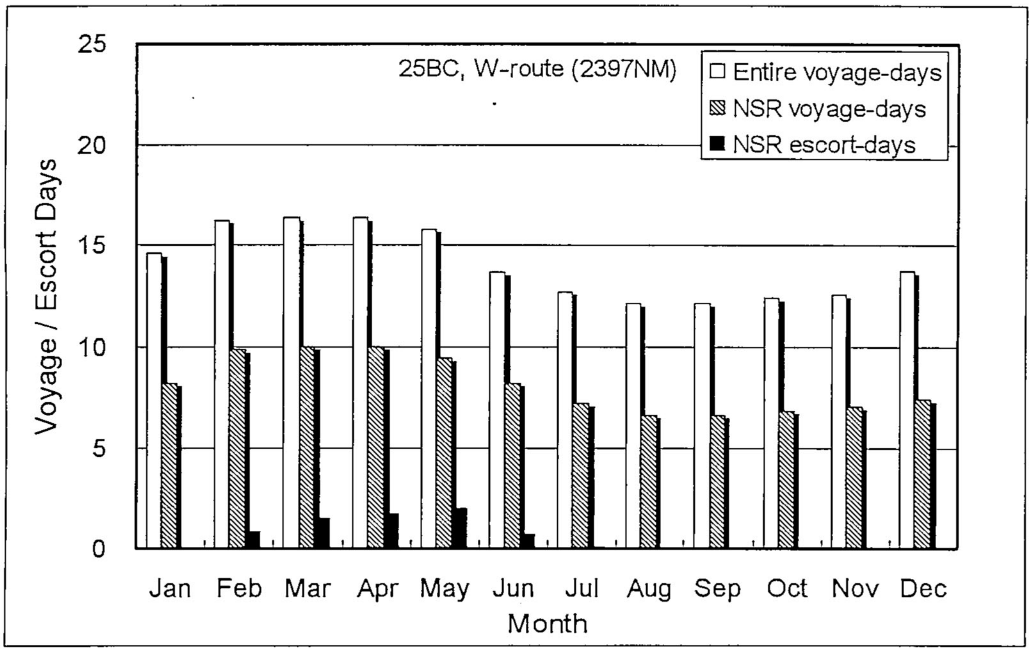


Figure 4.1.28 Voyage days and escort days for the 25BC as an average of 1957-1990 at W-route; 2397NM

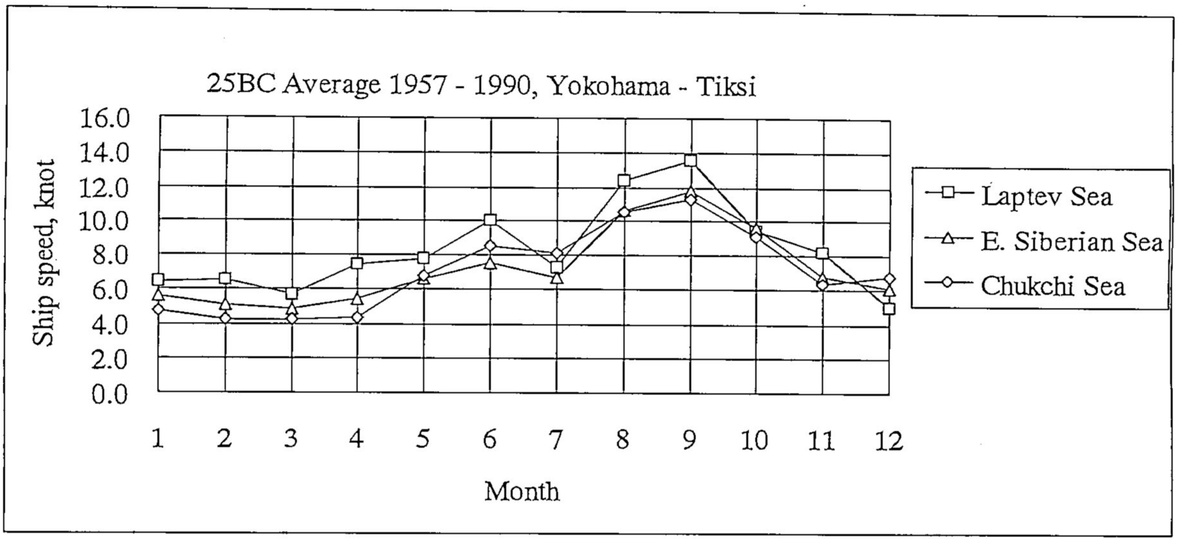


Figure 4.1.29 Navigation speed by the sea area in E-route as an average of 1957 – 1990

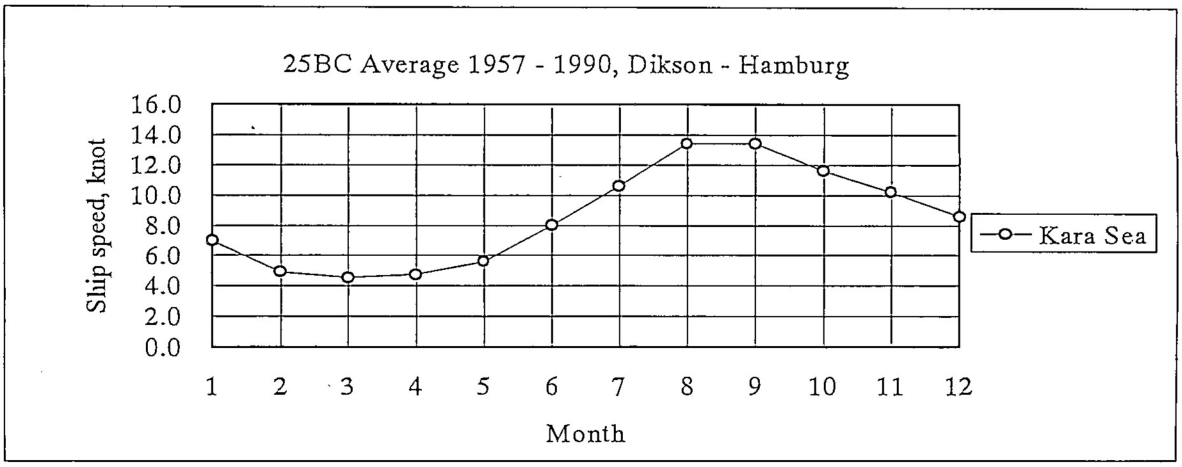


Figure 4.1.30 Navigation speed by the sea area in W-route as an average of 1957 – 1990

Table 4.1.13 Cost component in E-route as an average of 1957- 1990

Month	Capital Cost	Operating Cost	Port Fee	Fuel Cost	IB Charge	Total Cost	St. dev. of total cost
	k$	k$	k$	k$	k$	k$	k$
Jan.	451	156	37	82	118	844	72
Feb.	459	158	37	51	120	825	24
Mar.	465	160	37	50	120	832	24
Apr.	448	154	37	47	120	807	17
May	412	142	37	55	118	763	20
Jun	386	133	37	51	117	723	24
Jul.	412	142	37	79	120	790	48
Aug.	354	122	37	101	116	729	42
Sep.	344	119	37	90	116	704	34
Oct.	369	127	37	111	116	760	36
Nov.	433	149	37	166	113	898	138
Dec.	438	151	37	128	115	868	51

Table 4.1.14 Cost component in W-route as an average of 1957- 1990

Month	Capital Cost	Operating Cost	Port Fee	Fuel Cost	IB Charge	Total Cost	St. dev. of total cost
	k$	k$	k$	k$	k$	k$	k$
Jan.	258	89	49	98	114	607	23
Feb.	287	99	49	110	112	656	32
Mar.	290	100	49	103	112	653	36
Apr.	290	100	49	100	112	650	38
May	279	96	49	88	112	623	39
Jun	242	83	49	59	112	545	21
Jul.	225	78	49	53	74	479	19
Aug.	215	74	49	43	77	457	8
Sep.	214	74	49	43	77	457	6
Oct.	219	75	49	49	74	467	8
Nov.	222	76	49	54	111	512	6
Dec.	243	84	49	88	111	575	5

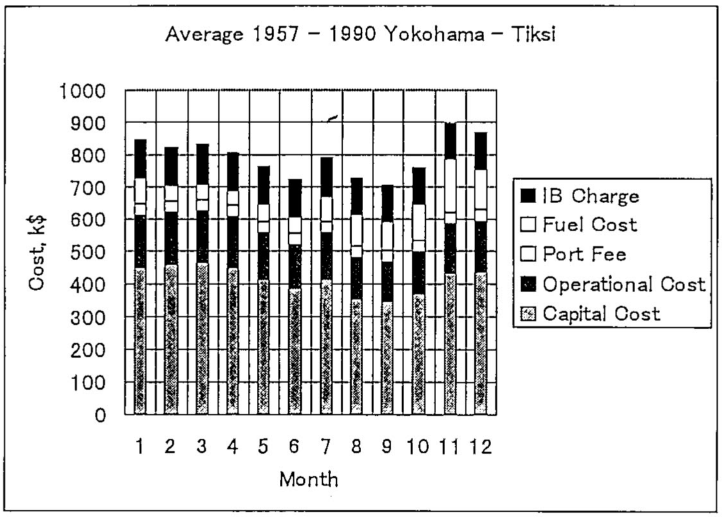


Figure 4.1.31 Voyage cost component in E-route as an average of 1957 - 1990

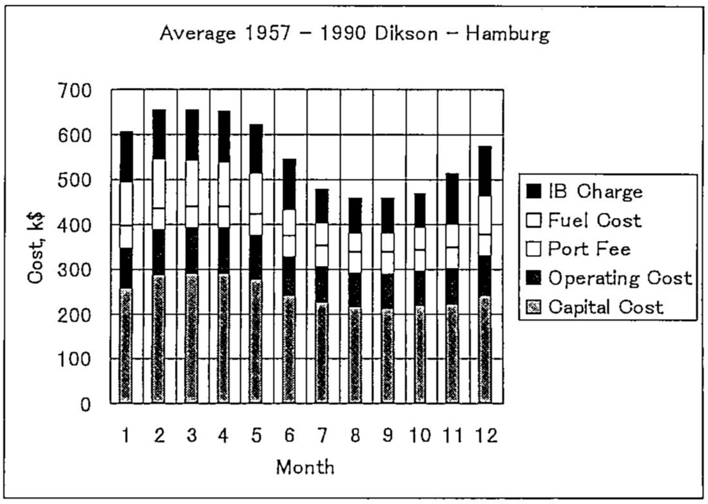


Figure 4.1.32 Voyage cost component in W-route as an average of 1957 – 1990

4.2 Seasonal simulation

The annual serial voyage simulation between Yokohama and Hamburg was performed. The high latitude transit route (N-route) , 40BC and 50BC are combined. The switching between the NSR and the SUEZ route was considered in the designated month in order to simplify the calculation. For selecting the route, the cumulative ice index in each month during the periods of ten years (from 1980 through 1989) was calculated. Then, it was compared to the critical values of the cumulative ice index (the case of 40BC is -26000, 50BC is -50000). The cumulative ice indices for 40BC and 50 BC are shown in Table 4.2.1 and 4.2.2 respectively. The values in tables are identical, however, the shaded columns in both Tables are different and indicate the portions where the ice index is lower than the critical value of each ship. That is, the NSR has disadvantage to the Suez route in terms of the freight cost in that month and year.

Table 4.2.1 Integrating ice index for 40BC

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Jan.	-40906	-30608	-12573	-10532	-39056	-18914	-32497	-16310	-30065	-12142
Feb.	-46008	-50524	-44641	-31872	-46470	-54445	-43169	-59402	-49435	-34429
Mar.	-53759	-50823	-35042	-56387	-42612	-52777	-46153	-44126	-49955	-25121
Apr.	-49678	-58413	-60327	-57841	-40478	-66545	-48491	-66268	-62363	-41260
May	-35284	-37292	-43012	-42940	-28454	-49060	-45855	-45671	-44935	-33957
Jun.	-33148	-9731	-29388	-28240	-10974	-31804	-18858	-19403	-35439	-16488
Jul.	-7320	-15633	-1753	-15956	-6732	-7501	8077	-11541	-12660	-1442
Aug.	13996	18182	27901	40902	33190	24610	21724	22378	13436	23730
Sep.	24675	365	36849	35692	32166	4908	-4198	10982	18622	35033
Oct.	684	4794	17227	13410	9137	19020	3622	15129	5797	4312
Nov.	-1630	14770	9128	4977	17314	15853	16000	15854	12837	13509
Dec.	-21730	1874	-6130	-18624	5295	15019	-45	-895	2284	4674

Table 4.2.2 Integrating ice index for 50BC

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Jan.	-40906	-30608	-12573	-10532	-39056	-18914	-32497	-16310	-30065	-12142
Feb.	-46008	-50524	-44641	-31872	-46470	-54445	-43169	-59402	-49435	-34429
Mar.	-53759	-50823	-35042	-56387	-42612	-52777	-46153	-44126	-49955	-25121
Apr.	-49678	-58413	-60327	-57841	-40478	-66545	-48491	-66268	-62363	-41260
May	-35284	-37292	-43012	-42940	-28454	-49060	-45855	-45671	-44935	-33957
Jun.	-33148	-9731	-29388	-28240	-10974	-31804	-18858	-19403	-35439	-16488
Jul.	-7320	-15633	-1753	-15956	-6732	-7501	8077	-11541	-12660	-1442
Aug.	13996	18182	27901	40902	33190	24610	21724	22378	13436	23730
Sep.	24675	365	36849	35692	32166	4908	-4198	10982	18622	35033
Oct.	684	4794	17227	13410	9137	19020	3622	15129	5797	4312
Nov.	-1630	14770	9128	4977	17314	15853	16000	15854	12837	13509
Dec.	-21730	1874	-6130	-18624	5295	15019	-45	-895	2284	4674

There is difference between 40BC and 50BC. For 40BC, when the voyage starts between February through May, the selection for the SUEZ route is relatively superior in terms of the freight cost. For 50BC, the selection for the NSR is relatively superior for all the year round. To evaluate voyage cost in the same condition, it is assumed that both ships go through the Suez route if a voyage begins between February through May. The year of 1960, 1970, and 1980 were simulated. Table 4.2.3 and 4.2.4 show the results of 40BC and 50BC in 1980 as examples.

Table 4.2.3 Seasonal simulation for 40BC in 1980

Voyage No.		1	2	3	4	5	6	7	8	9	10
Departure-Arrival		0101-0213	0214-0326	0327-0506	0507-0616	0617-0725	0726-0826	0827-0925	0926-1028	1029-1203	1204-0113
Route		NSR	via Suez	via Suez	via Suez	NSR	NSR	NSR	NSR	NSR	NSR
Direction		E->W	W->E	E->W	W->E	E->W	W->E	E->W	W->E	E->W	W->E
Voyage days	days	43.6	41.0	41.0	41.0	38.2	31.2	29.7	32.5	35.7	40.3
Escort days	days	18.7				9.9	4.0	2.7	5.7	5.5	11.0
Voyage total cost	k$	1521	1428	1428	1428	1408	1203	1155	1241	1378	1493
*capital cost	k$	893	824	824	824	780	638	608	665	730	824
*operating cost	k$	270	238	238	238	236	193	184	201	221	249
*port fee	k$	67	67	67	67	67	67	67	67	67	67
*fuel cost	k$	162	172	172	172	202	181	175	183	240	229
*icebreaker fee	k$	130				123	123	122	124	120	124
Suez canal fee	k$		127	127	127						

Table 4.2.4 Seasonal simulation for 50BC in 1980

Voyage No.		1	2	3	4	5	6	7	8	9	10	11
Departure-Arrival		0101-0212	0213-0320	0321-0425	0426-0531	0601-0704	0705-0811	0812-0909	0910-1007	1008-1108	1109-1217	1218-0125
Route		NSR	via Suez	via Suez	via Suez	NSR	NSR	NSR	NSR	NSR	NSR	NSR
Direction		E->W	W->E	E->W	W->E	E->W	W->E	E->W	W->E	E->W	W->E	E->W
Voyage days	days	42.4	36.0	36.0	36.0	33.0	37.5	28.6	27.9	31.6	38.2	38.1
Escort days	days	19.4				13.8	9.2	4.3	2.7	5.8	8.8	17.4
Voyage total cost	k$	1079	1055	1055	1055	892	1049	869	860	931	1066	987
*capital cost	k$	394	329	329	329	307	348	266	259	294	355	354
*operating cost	k$	287	224	224	224	223	253	194	189	214	258	258
*port fee	k$	92	92	92	92	92	92	92	92	92	92	92
*fuel cost	k$	140	271	271	271	108	190	156	159	168	203	118
*icebreaker fee	k$	166				162	165	162	160	163	158	164
Suez canal fee	k$		139	139	139							

50BC has the disadvantage in terms of operating cost, port cost, fuel cost and icebreaker fee. However, the capital cost is considerably less than that of 40BC, which resulted in lower total cost. A number of voyages through the NSR ranges from 6.1 to 7.4 and the difference between 40BC and 50BC is small. 50BC has more speed in open water, which reduces voyage-days in the SUEZ route. As a result, 50BC can make more voyages and transport more cargo. This condition is favorable to reduce the freight cost of 50BC. Table 4.2.4 shows the total of annual costs, annual amount of transit cargo, and annual freight costs of 40BC and 50BC calculated in 1960, 1970, and 1980.

Table 4.2.5 Total of annual costs, amount of transit cargo and freight costs

Year			1960		1970		1980	
Ship type			40BC	50BC	40BC	50BC	40BC	50BC
	Cargo tonnage	t	36000	47000	36000	47000	36000	47000
NSR	Number of voyage		6.6	6.5	6.5	6.1	6.7	7.4
	Total cargo tonnage	t	238,000	304,000	235,000	288,000	240,000	346,000
	Total cost	k$	9,147	6,304	9,025	6,189	8,926	7,100
	Freight cost	$/t	38.4	20.7	38.4	21.5	37.2	20.5
SUEZ	Number of voyage		3	4	3	4	3	3
	Total cargo tonnage	t	108,000	188,000	108,000	188,000	108,000	141,000
	Total cost	k$	4,281	4,222	4,281	4,222	4,281	3,167
	Freight cost	$/t	39.6	22.5	39.6	22.5	39.6	22.5
Total	Total cargo tonnage	t	346,000	492,000	343,000	476,000	348,000	487,000
(NSR+SUEZ)	Total cost	k$	13,428	10,526	13,306	10,411	13,207	10,267
	Freight cost	$/t	38.8	21.4	38.8	21.9	38.0	21.1

The freight cost of 50BC is superior in both the NSR and SUEZ route. The following factors can be pointed out ;

1) The low capital cost of 50BC reduces the total cost.
2) 50BC has lager amount of transit cargo than that of 40BC with the approximately same voyage-days.
3) 50BC is capable to transfer more cargoes than 40BC in the SUEZ route since 50BC is faster in open water than 40BC.
4) Icebreaker tariff being the most part of icebreaker fee adopted as a flat rate, the difference of escorted days does not significantly influence the total costs.

Therefore, in the next chapter, 50BC was selected as a representative ship type for the routing selection simulation in which the NSR and SUEZ route are switched successively judging the ice condition (integrating ice index) of each year.

4.3 Routing selection simulation

In this chapter, the routing selection between the NSR and the Suez route is studied to optimize the freight costs. The results from chapter 4.2 imply that the Suez route *should be* selected when the ice condition is harsh. The ice forecast based on advanced satellite technology will be realized in the future, we will be able to predict the ice conditions for one or two months in advance with a sufficient reliability before entering the NSR. Based on this scenario, the simulation is attempted for some periods of the historical ice data. Namely, the decision for switching the Suez route is made using the cumulative ice index. The annual serial voyage simulation (ASVS) was performed using 50BC and 10 year data from 1980 to 1989. The ice breaker tariff cut by 26%was used as depicted in Table 4.1.1 and N-route was selected. The mean ship speed in the Suez route is set to 17 knot and the voyage days are 36 days including the harbor days.

The results of the simulation are summarized in Table 4.3.1 showing for the NSR part, the Suez route part and annual total for each year. The mean value of the output distribution is shown in Table 4.3.1. The results obtained from 90%-tail value and 10%-tail value of the distribution are noted in the Appendix D.

Table 4.3.1 Summary of annual serial voyage simulation (ASVS)

Year			1980	1981	1982	1983	1984
	Cargo tonnage	t	47000	47000	47000	47000	47000
NSR	Number of voyage		8.3	8.1	9.0	8.3	10.0
	Voyage days	day	293	293	329	293	365
	Total cargo tonnage	t	390,100	382,100	421,600	391,000	468,600
	Total cost	k$	8,071	8,043	8,967	8,121	10,117
	Freight cost	$/t	20.7	21.1	21.3	20.8	21.6
SUEZ	Number of voyage		2	2	1	2	0
	Voyage days	day	72	72	36	72	0
	Total cargo tonnage	t	94,000	94,000	47,000	94,000	0
	Total cost	k$	2,111	2,111	1,056	2,111	0
	Freight cost	$/t	22.5	22.5	22.5	22.5	22.5
Total	Total cargo tonnage	t	484,100	476,100	468,600	485,000	468,600
(NSR+SUEZ)	Total cost	k$	10,182	10,154	10,023	10,232	10,117
	Freight cost	$/t	21.0	21.3	21.4	21.1	21.6

Year			1985	1986	1987	1988	1989
	Cargo tonnage	t	47000	47000	47000	47000	47000
NSR	Number of voyage		8.2	9.8	9.3	8.5	10.5
	Voyage days	day	293	365	329	293	365
	Total cargo tonnage	t	386,300	459,700	437,600	400,900	493,000
	Total cost	k$	8,132	9,925	9,045	8,122	10,028
	Freight cost	$/t	21.1	21.6	20.7	20.3	20.3
SUEZ	Number of voyage		2	0	1	2	0
	Voyage days	day	72	0	36	72	0
	Total cargo tonnage	t	94,000	0	47,000	94,000	0
	Total cost	k$	2,111	0	1,056	2,111	0
	Freight cost	$/t	22.5	22.5	22.5	22.5	22.5
Total	Total cargo tonnage	t	480,300	459,700	484,600	494,900	493,000
(NSR+SUEZ)	Total cost	k$	10,243	9,925	10,101	10,233	10,028
	Freight cost	$/t	21.3	21.6	20.8	20.7	20.3

The average annual voyage number is 10.2 times/year and the number of NSR voyages is 9 times/year. Thus, approximately 88% of the voyages are through the NSR. The freight costs vary from 20.3 to 21.6 $/ton. As shown in the Appendix D, the freight cost as the results from 90%-tail value and 10%-tail value ranges from 20.7 to 21.8 $/ton and from 20.3 to 21.5 $/ton, respectively.

Table 4.3.2 indicates the details of 1987-simulation results. The number of Suez route voyage is just one time a year. The number of voyage is 9.3 times/year for using the NSR and 10.3 times/year for a total. The voyage days in the NSR ranges from 28 to 45 days. The mean ship speed during one voyage is from 7.8 knots to 13.7 knots.

The freight cost in the summer season of 1987, which is calculated from the results for 12th June to 11th October in Table 4.3.2, is 18.8 \$/ton. On the other hand, it is 22.3 \$/ton as for the winter season from October to May. The freight costs for 1987 are estimated to be \$20.8/ton as shown in Table 4.3.1. The freight costs in other years show the similar tendency by season.

The summary of the above results is; the freight costs for the ice-strengthened 50BC range between 20.3 and 21.6 \$/ton, under the suitable route switching between the NSR and the Suez route by every voyage. As for only the summer season (about 4 months), the freight costs are 18.8 \$/ton and is nearly equal to that of the Suez route employing the conventional handy size bulker derived as follows.

50,000 DWT handy size bulk carrier (C-50BC), whose particulars are shown in Table 4.3.3, is assumed as the conventional cargo ship for the comparison.

Table 4.3.2 The results of annual serial voyage simulation (ASVS) in 1987

Voyage No.		1	2	3	4	5	6	7	8	9	10	11
Departure-Arrival		0101-0214	0215-0327	0328-0502	0503-0611	0612-0713	0714-0812	0813-0913	0914-1011	1012-1112	1113-1218	1219-0129
Route		NSR	NSR	via Suez	NSR	NSR	NSR	NSR	NSR	NSR	NSR	NSR
Direction		E->W	W->E	E->W	W->E	E->W	W->E	E->W	W->E	E->W	W->E	E->W
Voyage days	days	45	41	36	40	31	30	31	28	31	35	42
Escort days	days	18	22		16	10	9	3	4	5	6	13
Voyage total cost	k$	1151	1018	1055	1037	872	870	949	847	935	1019	1122
*capital cost	k$	414	380	329	368	289	279	292	259	291	328	390
*operating cost	k$	301	276	224	268	210	203	213	188	212	239	284
*port fee	k$	92	92	92	92	92	92	92	92	92	92	92
*fuel cost	k$	179	102	271	146	122	131	192	146	177	205	195
*icebreaker fee	k$	164	168		163	159	165	161	162	162	155	161
Suez canal fee	k$			139								
Average ship speed	knot	7.8	8.6	17.0	8.9	12.0	12.5	11.8	13.7	11.8	10.2	8.3
Freight cost	$/t	24.5	21.7	22.5	22.1	18.6	18.5	20.2	18.0	19.9	21.7	23.9

Table 4.3.3 Principal particulars of conventional bulk carrier

Conventional cargo ship (assumption) - 50,000 DWT type bulk carrier	
Type of ship	Flush decker, aft bridge and aft engine
Cargo hold	5 holds
Length overall (m)	180.0
Length between perpendiculars (m)	173.00
Breadth (m)	32.20
Depth (m)	16.50
draft (m)	11.73
Deadweight (ton)	50,900
Cargo tonnage (ton)	47,000
Gross tonnage	28,000
Service speed at NSO (knots)	15.0
Engine power MCO (ps)	12,200
NSO (ps)	11,000
Fuel consumption rate (LCV of 10,200 kcal/kg)(g/ps/hour)	128.0

It is supposed that the conventional bulker repeats a voyage throughout a year at the Suez route, from Yokohama to Hamburg. Table 4.3.4 shows the results of a freight calculation. The voyage-days are estimated to be approximately 39 days, which include an anchorage days and Suez canal transit days. The freight cost is estimated to be 18.1 $/ton and it is little less than one in the simulation for the icebreaking 50BC (I-50BC), which ranges between 20.3 and 21.6 $/ton for 10 years as Table 4.3.2. Thus, the freight profitability for the I-50BC even at selecting route is little inferior to one for the C-50BC, if a year round operation is considered. On the other hand, as for the summer operation for about 4 months, the freight cost for the I-50BC is 18.8 $/ton and there is little difference between two bulk carriers.

Table 4.3.4 Freight cost calculation for C-50BC via the SUEZ route

Ship type	50BC
DWT (ton)	50,900
Gross tonnage (GT)	28,000
Cargo tonnage (t)	47,000
Ship speed (knot)	15.0
Power NSO (PS)	11,000
M/E FOC (t/day)	35.72
D/G FOC (t/day)	1.54
D/G FOC in port (t/day)	3.08
Ship price (k$)	22,000
Voyage distance (NM)	11,588
Voyage days (including port and canal)	39.19
Voyage days	32.19
Anchorage day(day/voyage)	6
Suez canal transit days	1
Number of voyage	9.31
Annual cost (k$)	7,913
Capital cost (k$/year)	2,488
Maintenance fee (k$/year)	560
Insurance (k$/year)	134
Crewing cost (k$/year)	1,599
Fuel cost (k$/year)	1,032
Port cost (k$/year)	805
SUEZ canal transit tolls (k$)	1,295
Total cargo tonnage (ton/year)	437,752
Freight cost ($/ton)	18.1
Cost per one-voyage (k$)	850

5.0 Conclusions and Recommendation

A comprehensive simulation was performed using the multi disciplinary tasks. The authors believe that this is the first simulation incorporating the advanced ship technology and detailed historical ice data in the NSR. The following conclusions and recommendations are drawn from the study.

1) The monthly voyage simulation demonstrated the tendencies of the cost components, icebreaker tariffs, escort days for icebreaker, routes and transit days etc. The capital costs have the most significant effects among the cost parameters. Thus, 50,000DWT bulk carrier (50BC) has advantage to the other two powerful icebreaking cargo ships if the icebreaker tariff assumed here is proper. The escort days of 50BC are slightly longer than those of 40BC, although the difference is negligible under the adopted escort scenario. The transit days in the N-route is slightly longer than the Southerly route, although its difference will be also small, and the escort days in the N-route is one day longer than the S-route when comparing 25BC and 40BC. The N-route can be promising for the larger capacity ships developed in future.

2) The simulation for the regional routes shows that the western route is far easier than the eastern route. The escort days for the western routes will be less than three days and nearly independent navigation will be possible using 25BC. This fact is coincident with experience gained in the past.

3) The icebreaker tariff is the most significant parameter among the variable cost items. Currently a tariff of up to 20,000 GT is proposed. The winter tariff is slightly cheaper than the summer tariff even though winter navigation needs longer escort days as this simulation shows. In this simulation, the tariff ranging from 4.89 to 5.45 $/GT was adopted. The tariff rate of slightly less than 5.0 $/ton seems to make the NSR economically feasible under the assumptions adopted in this simulation. The tariff rate shall be further discussed based on this kind of simulation, and specified in detail by season and icebreaking capability together with the standby time and standby location of icebreakers.

4) The insurance cost in the NSR is eventually assumed as twice expensive as the Suez route. Accidental or hull damage data were gathered in the INSROP project, although none of the report presented the quantitative risks per voyage. It makes difficult to give the rational insurance cost. The total sinking rate seems to be lower, although no back up data are available. The accidental data shall be open to enable quantitative assessment.

5) The simulation shows that the proper route switching from the NSR to the Suez route considerably reduces the required cost. To realize it, the advanced satellite technology has to be developed to predict the ice conditions for one or two month in advance before a ship enters into the NSR. The procedures for the permission to the NSR and the contract between a shipping company and a cargo owner should also meet this scenario.

6) The ice data provided from the AARI will be a good bench mark to discuss the rationale for the tariff and other technical assessments. The data will be stowed in the INSROP GIS CD and will be distributed to users.

7) The concept for the ice index is modified from the ice numerals originally introduced in the CASPPR to link the data and the ship speed algorithms. The ice index enables prediction of the ice speed against the given ice conditions with reasonable accuracy. The

cumulative ice index is given as summing up the ice index multiplying the segment lengths. That will be a good index to quantitatively express the difficulty of navigation in the NSR. The difficulty of navigation is conventionally expressed in "Heavy, medium, light" in Russian literatures. It is recommended to express the navigation difficulty using the ice index.

8) The icebreaker escort for the handy size bulk ship is assumed to be feasible in this simulation, however there is no technical background for it. Further study is needed.

Acknowledgements

The authors would like to acknowledge to
Prof. H.KITAGAWA / Hokkaido University
Mr. K. Izumiyama / the Ship Research Institute
Assistant Professor Y. Yamaguchi / The University of Tokyo
Prof. S. Hayashi / Tokyo University of Mercantile Marine
They corresponded to the supervisor of other seven work packages as the coordinators of WP0 in order to proceed the inter-related this simulation works.
The authors would like to acknowledge to
Mr. R.Mori and Mr. H.Adachi/NYK(Nippon Yusen Kaisha) LINE
They investigated and provied reliable ship operating cost data.
Also, the authors wish to thank Mr. H. Tagami of the SOF for his organizations of the supervisor meetings in Tokyo and St. Petersburg.

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Appendix A : Assumed ice conditions for the segments outside the NSR

Assumption of the environmental data from Yokohama to Bering Strait

(1) The segments between Y-03 and Y-05 are assumed as ice free area throughout the year.
(2) In the segments from Y-01 to Y-03 (shadowed in Table A.1), the environmental data are assumed as shown in Table A.2. Each value is extrapolated using the segment data prior to Y-01.

Table A.1 Voyage route

Route id	Note
Y-01	Bering Strait
Y-02	
Y-03	
Y-04	
Y-05	Yokohama

Table A.2 The determination of environmental data

Parameter	Unit	Jun – Nov.	Dec. – May
Cold sum	°CDay	0	239
Mean first year ice concentration	1/10	0	5
Mean multi year ice concentration	1/10	0	0
Mean ice thickness	cm	0	45
Mean ridge size (height)	cm	0	49
Mean ridge density	1/km	0	20

Assumption of the environmental data in Barents Sea (N - route)

(1) The segments between B1-01 and B5-03 are assumed as ice free area throughout the year.
(2) In the segments from B5-03 to B1-02, the environmental data are assumed as shown in Table A.4. by the same technique using in Table A.2

Table A.3 Voyage route

Route id	Note
B1-01	North Cape
B5-03	
B1-02	Mys Zhelaniya Cape

Table A.4 The determination of environmental data

Parameter	Unit	Jun – Oct.	Nov. – May
Cold sum	°CDay	0	268
Mean first year ice concentration	1/10	0	5
Mean multi year ice concentration	1/10	0	0
Mean ice thickness	cm	0	23
Mean ridge size (height)	cm	0	32
Mean ridge density	1/km	0	15

Assumption of the environmental data in Barents Sea (S - route)

(1) The segments from B1-01 to B2-01are assumed as ice free area from January to December.

(2) In the segments from B2-01 to B2-04, the environmental data were assumed as shown in Table A.6.

Table A.5 Voyage route from North Cape to the Karskie Vorota Strait

Route id	Note
B1-01	North Cape
B2-01	
B2-02	
B2-03	
B2-04	Karskie Vorota Strait

Table A.6 The determination of environmental data

Parameter	Unit	Jun − Nov.	Dec. − May
Cold sum	°CDay	0	205
Mean first year ice concentration	1/10	0	5
Mean multi year ice concentration	1/10	0	0
Mean ice thickness	cm	0	25
Mean ridge size (height)	cm	0	32
Mean ridge density	1/km	0	14

Assumption of the environmental data on the route from Hamburg to North Cape

This voyage route are ice free area throughout the year.

Appendix B : Environmental data used for the development of ice index and the results

Table B-1 Basic environmental data

	Basic environmental data					IA			IB			IA+IB	
	DATA No.	Sub No.	Average ice thickness	Average FYI conc.	Average MYI conc.	Total ice conc.	IA for TypeA	IA for CAC1	Average ridge size(sail height)	Ridge density average	IB	IA+IB for Type A	IA+IB for CAC1
			cm	1-10	1-10	1-10			cm	1/km			
Ridge ice field	1	1	168	10	0	10	-10.0	20.0	149.0	27.7	-16.5	-26.5	3.5
		2	168	10	0	10	-10.0	20.0	149.0	13.9	-8.3	-18.3	11.7
		3	168	10	0	10	-10.0	20.0	94.0	27.7	-10.4	-20.4	9.6
		4	168	10	0	10	-10.0	20.0	94.0	13.9	-5.2	-15.2	14.8
		5	168	10	0	10	-10.0	20.0	39.0	27.7	-4.3	-14.3	15.7
		6	168	10	0	10	-10.0	20.0	39.0	13.9	-2.2	-12.2	17.8
Ridge on the pack ice field	2	1	168	6.32	1.41	7.73	-6.7	20.0	149.0	27.7	-12.8	-19.5	7.2
		2	168	6.32	1.41	7.73	-6.7	20.0	149.0	13.9	-6.4	-13.1	13.6
		3	168	6.32	1.41	7.73	-6.7	20.0	94.0	27.7	-8.1	-14.8	11.9
		4	168	6.32	1.41	7.73	-6.7	20.0	94.0	13.9	-4.0	-10.8	16.0
		5	168	6.32	1.41	7.73	-6.7	20.0	39.0	27.7	-3.3	-10.1	16.7
		6	168	6.32	1.41	7.73	-6.7	20.0	39.0	13.9	-1.7	-8.4	18.3
	3	1	168	6.32	0	6.32	1.0	20.0	149.0	27.7	-10.4	-9.4	9.6
		2	168	6.32	0	6.32	1.0	20.0	149.0	13.9	-5.2	-4.2	14.8
		3	168	6.32	0	6.32	1.0	20.0	94.0	27.7	-6.6	-5.5	13.4
		4	168	6.32	0	6.32	1.0	20.0	94.0	13.9	-3.3	-2.3	16.7
		5	168	6.32	0	6.32	1.0	20.0	39.0	27.7	-2.7	-1.7	17.3
		6	168	6.32	0	6.32	1.0	20.0	39.0	13.9	-1.4	-0.3	18.6
	4	1	168	2.33	4.04	6.37	-9.2	20.0	149.0	27.7	-10.5	-19.7	9.5
		2	168	2.33	4.04	6.37	-9.2	20.0	149.0	13.9	-5.3	-14.5	14.7
		3	168	2.33	4.04	6.37	-9.2	20.0	94.0	27.7	-6.6	-15.8	13.4
		4	168	2.33	4.04	6.37	-9.2	20.0	94.0	13.9	-3.3	-12.5	16.7
		5	168	2.33	4.04	6.37	-9.2	20.0	39.0	27.7	-2.8	-11.9	17.2
		6	168	2.33	4.04	6.37	-9.2	20.0	39.0	13.9	-1.4	-10.6	18.6
	5	1	168	2.33	1.41	3.74	5.3	20.0	149.0	27.7	-6.2	-0.9	13.8
		2	168	2.33	1.41	3.74	5.3	20.0	149.0	13.9	-3.1	2.2	16.9
		3	168	2.33	1.41	3.74	5.3	20.0	94.0	27.7	-3.9	1.4	16.1
		4	168	2.33	1.41	3.74	5.3	20.0	94.0	13.9	-2.0	3.3	18.0
		5	168	2.33	1.41	3.74	5.3	20.0	39.0	27.7	-1.6	3.6	18.4
		6	168	2.33	1.41	3.74	5.3	20.0	39.0	13.9	-0.8	4.4	19.2
	6	1	168	2.33	0	2.33	13.0	20.0	149.0	27.7	-3.8	9.2	16.2
		2	168	2.33	0	2.33	13.0	20.0	149.0	13.9	-1.9	11.1	18.1
		3	168	2.33	0	2.33	13.0	20.0	94.0	27.7	-2.4	10.6	17.6
		4	168	2.33	0	2.33	13.0	20.0	94.0	13.9	-1.2	11.8	18.8
		5	168	2.33	0	2.33	13.0	20.0	39.0	27.7	-1.0	12.0	19.0
		6	168	2.33	0	2.33	13.0	20.0	39.0	13.9	-0.5	12.5	19.5
Level ice field	1	7	168	10	0	10	-10.0	20.0	0.0	0.0	0.0	-10.0	20.0
Pack ice field	2	7	168	6.32	1.41	7.73	-6.7	20.0	0.0	0.0	0.0	-6.7	20.0
	3	7	168	6.32	0	6.32	1.0	20.0	0.0	0.0	0.0	1.0	20.0
	4	7	168	2.33	4.035	6.365	-9.2	20.0	0.0	0.0	0.0	-9.2	20.0
	5	7	168	2.33	1.41	3.74	5.3	20.0	0.0	0.0	0.0	5.3	20.0
	6	7	168	2.33	0	2.33	13.0	20.0	0.0	0.0	0.0	13.0	20.0

Table B-2 Basic environmental data

	Basic environmental data					IA			IB			IA+IB	
	DATA No.	Sub No.	Average ice thickness	Average FYI conc.	Average MYI conc.	Total ice conc.	IA for TypeA	IA for CAC1	Average ridge size(sail height)	Ridge density average	IB	IA+IB for Type A	IA+IB for CAC1
			cm	1-10	1-10	1-10			cm	1/km			
Ridge ice field	7	1	97	10	0	10	10.0	20.0	149.0	27.7	-16.5	-6.5	3.5
		2	97	10	0	10	10.0	20.0	149.0	13.9	-8.3	1.7	11.7
		3	97	10	0	10	10.0	20.0	94.0	27.7	-10.4	-0.4	9.6
		4	97	10	0	10	10.0	20.0	94.0	13.9	-5.2	4.8	14.8
		5	97	10	0	10	10.0	20.0	39.0	27.7	-4.3	5.7	15.7
		6	97	10	0	10	10.0	20.0	39.0	13.9	-2.2	7.8	17.8
Ridge on the pack ice field	8	1	97	6.32	1.41	7.73	5.9	20.0	149.0	27.7	-12.8	-6.8	7.2
		2	97	6.32	1.41	7.73	5.9	20.0	149.0	13.9	-6.4	-0.5	13.6
		3	97	6.32	1.41	7.73	5.9	20.0	94.0	27.7	-8.1	-2.1	11.9
		4	97	6.32	1.41	7.73	5.9	20.0	94.0	13.9	-4.0	1.9	16.0
		5	97	6.32	1.41	7.73	5.9	20.0	39.0	27.7	-3.3	2.6	16.7
		6	97	6.32	1.41	7.73	5.9	20.0	39.0	13.9	-1.7	4.2	18.3
	9	1	97	6.32	0	6.32	13.7	20.0	149.0	27.7	-10.4	3.2	9.6
		2	97	6.32	0	6.32	13.7	20.0	149.0	13.9	-5.2	8.4	14.8
		3	97	6.32	0	6.32	13.7	20.0	94.0	27.7	-6.6	7.1	13.4
		4	97	6.32	0	6.32	13.7	20.0	94.0	13.9	-3.3	10.4	16.7
		5	97	6.32	0	6.32	13.7	20.0	39.0	27.7	-2.7	10.9	17.3
		6	97	6.32	0	6.32	13.7	20.0	39.0	13.9	-1.4	12.3	18.6
	10	1	97	2.33	4.04	6.37	-4.5	20.0	149.0	27.7	-10.5	-15.0	9.5
		2	97	2.33	4.04	6.37	-4.5	20.0	149.0	13.9	-5.3	-9.8	14.7
		3	97	2.33	4.04	6.37	-4.5	20.0	94.0	27.7	-6.6	-11.2	13.4
		4	97	2.33	4.04	6.37	-4.5	20.0	94.0	13.9	-3.3	-7.8	16.7
		5	97	2.33	4.04	6.37	-4.5	20.0	39.0	27.7	-2.8	-7.3	17.2
		6	97	2.33	4.04	6.37	-4.5	20.0	39.0	13.9	-1.4	-5.9	18.6
	11	1	97	2.33	1.41	3.74	9.9	20.0	149.0	27.7	-6.2	3.7	13.8
		2	97	2.33	1.41	3.74	9.9	20.0	149.0	13.9	-3.1	6.8	16.9
		3	97	2.33	1.41	3.74	9.9	20.0	94.0	27.7	-3.9	6.0	16.1
		4	97	2.33	1.41	3.74	9.9	20.0	94.0	13.9	-2.0	8.0	18.0
		5	97	2.33	1.41	3.74	9.9	20.0	39.0	27.7	-1.6	8.3	18.4
		6	97	2.33	1.41	3.74	9.9	20.0	39.0	13.9	-0.8	9.1	19.2
	12	1	97	2.33	0	2.33	17.7	20.0	149.0	27.7	-3.8	13.8	16.2
		2	97	2.33	0	2.33	17.7	20.0	149.0	13.9	-1.9	15.7	18.1
		3	97	2.33	0	2.33	17.7	20.0	94.0	27.7	-2.4	15.2	17.6
		4	97	2.33	0	2.33	17.7	20.0	94.0	13.9	-1.2	16.5	18.8
		5	97	2.33	0	2.33	17.7	20.0	39.0	27.7	-1.0	16.7	19.0
		6	97	2.33	0	2.33	17.7	20.0	39.0	13.9	-0.5	17.2	19.5
Level ice field	7	7	97	10	0	10	10.0	20.0	0.0	0.0	0.0	10.0	20.0
Pack ice field	8	7	97	6.32	1.41	7.73	5.9	20.0	0.0	0.0	0.0	5.9	20.0
	9	7	97	6.32	0	6.32	13.7	20.0	0.0	0.0	0.0	13.7	20.0
	10	7	97	2.33	4.035	6.365	-4.5	20.0	0.0	0.0	0.0	-4.5	20.0
	11	7	97	2.33	1.41	3.74	9.9	20.0	0.0	0.0	0.0	9.9	20.0
	12	7	97	2.33	0	2.33	17.7	20.0	0.0	0.0	0.0	17.7	20.0

Table B-3 Basic environmental data

	Basic environmental data					IA			IB			IA+IB	
	DATA No.	Sub No.	Average ice thickness	Average FYI conc.	Average MYI conc.	Total ice conc.	IA for TypeA	IA for CAC1	Average ridge size(sail height)	Ridge density average	IB	IA+IB for Type A	IA+IB for CAC1
			cm	1-10	1-10	1-10			cm	1/km			
Ridge ice field	13	1	27	10	0	10	20.0	20.0	149.0	27.7			
		2	27	10	0	10	20.0	20.0	149.0	13.9			
		3	27	10	0	10	20.0	20.0	94.0	27.7			
		4	27	10	0	10	20.0	20.0	94.0	13.9			
		5	27	10	0	10	20.0	20.0	39.0	27.7	-4.3	15.7	15.7
		6	27	10	0	10	20.0	20.0	39.0	13.9	-2.2	17.8	17.8
Ridge on the pack ice field	14	1	27	6.32	1.41	7.73	12.2	13.7	149.0	27.7			
		2	27	6.32	1.41	7.7	12.2	13.7	149.0	13.9			
		3	27	6.32	1.41	7.7	12.2	13.7	94.0	27.7			
		4	27	6.32	1.41	7.7	12.2	13.7	94.0	13.9			
		5	27	6.32	1.41	7.7	12.2	13.7	39.0	27.7	-3.3	8.9	16.7
		6	27	6.32	1.41	7.7	12.2	13.7	39.0	13.9	-1.7	10.6	18.3
	15	1	27	6.32	0	6.32	20.0	20.0	149.0	27.7			
		2	27	6.32	0	6.3	20.0	20.0	149.0	13.9			
		3	27	6.32	0	6.3	20.0	20.0	94.0	27.7			
		4	27	6.32	0	6.3	20.0	20.0	94.0	13.9			
		5	27	6.32	0	6.3	20.0	20.0	39.0	27.7	-2.7	17.3	17.3
		6	27	6.32	0	6.3	20.0	20.0	39.0	13.9	-1.4	18.6	18.6
	16	1	27	2.33	4.04	6.37	-2.2	1.8	149.0	27.7			
		2	27	2.33	4.04	6.37	-2.2	1.8	149.0	13.9			
		3	27	2.33	4.04	6.37	-2.2	1.8	94.0	27.7			
		4	27	2.33	4.04	6.37	-2.2	1.8	94.0	13.9			
		5	27	2.33	4.04	6.37	-2.2	1.8	39.0	27.7	-2.8	-5.0	17.2
		6	27	2.33	4.04	6.37	-2.2	1.8	39.0	13.9	-1.4	-3.6	18.6
	17	1	27	2.33	1.41	3.74	12.2	13.7	149.0	27.7			
		2	27	2.33	1.41	3.7	12.2	13.7	149.0	13.9			
		3	27	2.33	1.41	3.7	12.2	13.7	94.0	27.7			
		4	27	2.33	1.41	3.7	12.2	13.7	94.0	13.9			
		5	27	2.33	1.41	3.7	12.2	13.7	39.0	27.7	-1.6	10.6	18.4
		6	27	2.33	1.41	3.7	12.2	13.7	39.0	13.9	-0.8	11.4	19.2
	18	1	27	2.33	0	2.33	20.0	20.0	149.0	27.7			
		2	27	2.33	0	2.3	20.0	20.0	149.0	13.9			
		3	27	2.33	0	2.3	20.0	20.0	94.0	27.7			
		4	27	2.33	0	2.3	20.0	20.0	94.0	13.9			
		5	27	2.33	0	2.3	20.0	20.0	39.0	27.7	-1.0	19.0	19.0
		6	27	2.33	0	2.3	20.0	20.0	39.0	13.9	-0.5	19.5	19.5
Level ice field	13	7	27	10	0	10	20.0	20.0	0.0	0.0	0.0	20.0	20.0
Pack ice field	14	7	27	6.32	1.41	7.73	12.2	13.7	0.0	0.0	0.0	12.2	20.0
	15	7	27	6.32	0	6.32	20.0	20.0	0.0	0.0	0.0	20.0	20.0
	16	7	27	2.33	4.035	6.365	-2.2	1.8	0.0	0.0	0.0	-2.2	20.0
	17	7	27	2.33	1.41	3.74	12.2	13.7	0.0	0.0	0.0	12.2	20.0
	18	7	27	2.33	0	2.33	20.0	20.0	0.0	0.0	0.0	20.0	20.0

Table B-4 Ice index v.s. ship speed for 40BC

Ice index	Ship speed				
	Min.	(Min.+Mean)/2	Mean	(Max.+Mean)/2	Max.
-26	0.21	0.21	0.22	0.23	0.24
-24	0.21	0.37	0.52	0.67	0.82
-22	0.23	0.53	0.83	1.13	1.42
-20	0.26	0.63	1.00	1.37	1.74
-18	0.28	0.87	1.46	2.05	2.64
-16	0.30	1.04	1.78	2.51	3.25
-14	0.70	1.42	2.15	2.88	3.61
-12	1.46	2.10	2.74	3.38	4.02
-10	1.48	2.15	2.83	3.50	4.17
-8	1.23	2.11	2.98	3.85	4.73
-6	1.86	2.59	3.32	4.05	4.78
-4	1.87	2.59	3.31	4.03	4.75
-2	1.75	2.49	3.23	3.96	4.70
0	1.30	2.18	3.07	3.95	4.83
2	1.30	2.44	3.58	4.72	5.86
4	1.50	2.75	4.00	5.25	6.49
6	2.00	3.19	4.38	5.58	6.77
8	3.06	3.97	4.88	5.79	6.70
10	4.38	4.92	5.46	6.00	6.53
12	5.15	5.65	6.16	6.66	7.17
14	5.34	6.03	6.71	7.39	8.07
16	5.93	6.91	7.90	8.88	9.86
18	6.64	7.81	8.98	10.15	11.32
20	8.32	9.72	11.12	12.52	13.92
22	10.00	10.98	11.96	12.94	13.92

Table B-5 Ice index v.s. ship speed for 25BC

Ice index	Ship speed				
	Min.	(Min.+Mean)/2	Mean	(Max.+Mean)/2	Max.
-26	0.21	0.21	0.22	0.22	0.23
-24	0.21	0.36	0.51	0.67	0.82
-22	0.23	0.53	0.82	1.12	1.42
-20	0.25	0.62	1.00	1.37	1.75
-18	0.27	0.87	1.47	2.07	2.67
-16	0.29	1.04	1.80	2.55	3.30
-14	0.56	1.35	2.13	2.91	3.69
-12	1.20	1.92	2.64	3.36	4.08
-10	1.34	2.06	2.77	3.49	4.20
-8	1.28	2.12	2.97	3.81	4.66
-6	1.97	2.63	3.29	3.94	4.60
-4	1.95	2.64	3.33	4.01	4.70
-2	1.85	2.58	3.30	4.03	4.75
0	1.40	2.27	3.14	4.01	4.88
2	1.40	2.55	3.70	4.84	5.99
4	1.60	2.87	4.13	5.40	6.66
6	2.10	3.35	4.60	5.85	7.10
8	3.15	4.15	5.15	6.16	7.16
10	4.46	5.03	5.60	6.17	6.74
12	5.17	5.68	6.19	6.71	7.22
14	5.42	6.12	6.83	7.54	8.24
16	6.11	7.10	8.10	9.09	10.09
18	6.84	8.01	9.18	10.35	11.52
20	8.39	9.77	11.14	12.51	13.88
22	10.00	10.97	11.94	12.91	13.88

Table B-6 Ice index v.s. ship speed for 50BC

Ice index	Min.	(Min.+Mean)/2	Mean	(Max.+Mean)/2	Max.
−26	0.11	0.12	0.12	0.13	0.13
−24	0.12	0.21	0.30	0.39	0.49
−22	0.13	0.31	0.49	0.67	0.85
−20	0.14	0.41	0.67	0.94	1.20
−18	0.15	0.59	1.03	1.47	1.91
−16	0.17	0.70	1.23	1.76	2.29
−14	0.21	0.83	1.44	2.06	2.67
−12	0.48	1.13	1.78	2.42	3.07
−10	0.69	1.31	1.92	2.54	3.16
−8	0.78	1.45	2.12	2.79	3.46
−6	1.22	1.89	2.56	3.23	3.90
−4	1.25	1.98	2.72	3.46	4.20
−2	1.10	1.95	2.80	3.65	4.50
0	1.20	2.06	2.93	3.79	4.65
2	1.30	2.18	3.05	3.93	4.80
4	1.50	2.41	3.32	4.22	5.13
6	1.70	2.60	3.50	4.40	5.31
8	2.21	2.89	3.58	4.27	4.96
10	2.95	3.36	3.78	4.19	4.60
12	3.85	4.24	4.63	5.02	5.41
14	5.16	5.51	5.87	6.22	6.57
16	6.60	7.21	7.83	8.44	9.05
18	7.49	8.39	9.29	10.19	11.09
20	9.44	10.72	11.99	13.26	14.53
22	11.50	12.26	13.02	13.77	14.53

Table B-7 Ice index v.s. ship speed for escort icebreaker

Ice index	Ship speed				
	Min.	(Min.+Mean)/2	Mean	(Max.+Mean)/2	Max.
6	0.00	0.00	0.00	0.00	0.00
8	3.62	3.92	4.21	4.51	4.80
10	4.24	4.70	5.15	5.61	6.06
12	4.30	5.13	5.96	6.80	7.63
14	4.19	5.77	7.35	8.94	10.52
16	4.29	6.68	9.06	11.45	13.84
18	5.28	8.24	11.19	14.15	17.11
20	5.99	9.09	12.19	15.29	18.39

Appendix C: Result tables (cost, voyage-days, escorted days, ship speed)

Table C.1 Freight cost by month for 25BC (using extrapolated tariff)

Tariff ($/GT)	Summer (7-10)	7.63	Winter (11-6)	7.14

Month	1 voyage cost	Icebreaker fee	1voyage days	Freight cost
	k$	k$	days	$/t
1	1485	165	45.4	69.1
2	1465	171	47.7	68.1
3	1468	171	47.8	68.3
4	1423	170	46.0	66.2
5	1373	168	43.9	63.9
6	1265	166	40.0	58.8
7	1298	168	39.9	60.4
8	1145	160	31.8	53.2
9	1209	158	33.3	56.2
10	1309	160	36.5	60.9
11	1355	154	37.3	63.0
12	1502	158	42.6	69.8
via SUEZ	1288	0	40.3	59.9

Table C.2 Freight cost by month for for 25BC (using 26% off tariff)

Tariff ($/GT)	Summer (7-10)	5.65	Winter (11-6)	5.28

Month	1 voyage cost	Icebreaker fee	1voyage days	Freight cost
	k$	k$	days	$/t
1	1447	126	45.4	67.3
2	1426	132	47.7	66.3
3	1429	132	47.8	66.5
4	1384	131	46.0	64.4
5	1335	130	43.9	62.1
6	1225	126	40.0	57.0
7	1258	128	39.9	58.5
8	1103	119	31.8	51.3
9	1169	118	33.3	54.4
10	1270	120	36.5	59.1
11	1316	114	37.3	61.2
12	1462	118	42.6	68.0
via SUEZ	1288	0	40.3	59.9

Table C.3 Freight cost by month for 50BC (using extrapolated tariff)

Tariff ($/GT)	Summer (7-10)	5.69	Winter (11-6)	5.47

Month	1 voyage cost	Icebreaker fee	1voyage days	Freight cost
	k$	k$	days	$/t
1	1080	221	41.5	23.0
2	1109	224	43.4	23.6
3	1111	224	43.5	23.6
4	1102	223	43.0	23.4
5	1074	222	41.3	22.8
6	991	218	36.5	21.1
7	1045	228	38.3	22.2
8	1012	219	32.6	21.5
9	891	220	28.1	19.0
10	974	221	31.9	20.7
11	1035	210	34.1	22.0
12	1089	214	38.6	23.2
via SUEZ	1055	0	35.4	22.5

Table C.4 Freight cost by month for 50BC (using 26% off tariff)

Tariff ($/GT)	Summer (7-10)	4.21	Winter (11-6)	4.05

Month	1 voyage cost	Icebreaker fee	1voyage days	Freight cost
	k$	k$	days	$/t
1	1027	168	41.5	21.8
2	1055	170	43.4	22.5
3	1057	170	43.5	22.5
4	1049	170	43.0	22.3
5	1020	168	41.3	21.7
6	939	166	36.5	20.0
7	989	172	38.3	21.0
8	957	164	32.6	20.4
9	836	164	28.1	17.8
10	919	166	31.9	19.6
11	981	156	34.1	20.9
12	1037	162	38.6	22.1
via SUEZ	1055	0	35.4	22.5

Table C.5 Freight cost through the SUEZ Canal

Ship type	40BC	25BC	50BC
DWT(ton)	40,000	25,000	50,900
Gross tonnage (GT)	22,600	21,000	31,000
Cargo tonnage (MT)	36,000	21,500	47,000
Voyage distance (NM)	11,588	11,588	11,588
Ship speed (knot)	14.5	14.5	17.0
Power NSO (PS)	12,508	11,421	25,000
Ship building cost (k$)	66,000	57,000	30,000
Capital cost (k$/year)	7,464	6,446	3,393
Maintenance fee (k$/year)	493	473	560
Insurance (k$/year)	124	120	149
Crewing cost (k$/year)	1,537	1,537	1,599
Voyage days	33.3	33.3	28.4
Anchorage day(day/voyage)	6	6	6
Voyage days (include anchorage days)	40.30	40.30	35.40
Number of voyage	9.06	9.06	10.31
M/E FOC (t/day)	56.17	51.28	102.72
D/G FOC (t/day)	0.00	0.00	1.54
IN PORT FOC (DG)(t/day)	3.81	3.81	3.08
Fuel cost (k$/year)	1,562	1,428	2,798
Port cost(k$/year)	611	555	950
SUEZ canal transit tolls (k$)	1,150	1,105	1,433
Total cost (k$)	12,940	11,663	10,881
total cost per 1 voyage(k$)	1,429	1,288	1,055
Total cargo tonnage (ton)	326,064	194,733	484,578
Freight cost($)	39.7	59.9	22.5

Table C.6 Voyage-days and Escorted days for 40BC

Voyage days
Escorted days

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1957	38.6	42.9	43.2	44.3	39.2	32.7	35.2	31.4	30.1	31.2	37.9	39.2
	16.2	20.6	22.2	23.3	17.7	10.6	12.3	4.3	3.7	5.9	3.5	7.0
1958	38.6	42.6	43.4	43.4	39.4	34.0	34.3	32.7	31.2	32.4	38.0	40.5
	16.2	20.4	23.0	22.0	19.2	13.7	11.9	3.1	2.3	7.0	3.5	7.1
1959	41.1	43.3	42.6	43.0	39.5	36.7	36.8	31.0	30.2	31.8	37.8	39.5
	15.4	11.4	21.7	19.2	16.7	11.3	8.5	3.0	0.8	1.8	3.5	6.7
1960	42.0	42.0	44.9	41.0	39.0	35.3	37.7	34.8	31.4	31.6	37.9	39.5
	11.7	14.9	22.5	20.2	16.8	13.5	11.8	0.5	0.9	3.4	3.5	6.7
1964	43.8	44.1	44.7	42.6	38.0	36.1	34.8	31.5	30.9	35.0	37.9	39.5
	12.0	20.9	21.7	16.6	17.6	13.9	12.2	2.4	1.6	3.6	3.5	7.4
1965	43.8	43.6	41.7	43.3	43.2	37.0	35.1	29.1	32.2	33.7	37.9	41.1
	12.0	16.2	18.6	22.2	17.0	12.9	11.3	3.1	0.0	2.1	3.5	8.2
1966	43.4	44.1	44.2	43.3	40.8	36.3	36.9	32.5	31.1	32.2	37.8	39.1
	15.3	23.9	23.6	23.1	19.1	14.5	15.5	3.0	1.1	2.5	3.5	9.3
1967	40.7	45.5	42.4	40.7	37.3	34.5	35.9	33.7	32.1	30.3	37.9	40.3
	17.3	17.2	18.0	20.6	15.9	13.2	6.0	1.1	1.7	5.1	3.5	7.9
1968	41.5	43.8	44.4	41.3	38.9	33.9	34.7	29.9	29.6	32.0	37.9	41.0
	17.9	21.6	22.5	19.4	17.3	9.6	8.6	1.5	1.9	2.5	3.5	7.9
1969	45.6	43.4	44.0	43.1	40.6	36.5	36.0	31.4	32.6	31.8	37.9	40.5
	14.6	21.9	23.3	22.0	18.9	15.0	15.0	4.1	3.4	6.1	3.5	6.8
1970	43.9	42.6	44.2	43.8	40.8	36.4	36.0	34.9	35.7	31.9	36.2	40.2
	13.1	17.9	24.1	18.4	18.7	15.6	13.9	2.4	2.4	6.0	4.1	7.3
1971	43.3	42.6	47.0	42.8	39.9	36.2	34.5	32.6	32.8	30.7	32.4	40.4
	13.3	18.3	17.5	21.9	19.5	13.2	9.4	0.5	0.7	2.0	2.4	4.5
1973	43.9	44.8	42.4	43.7	39.7	35.6	35.2	31.5	30.4	33.3	36.0	39.0
	14.9	13.1	16.1	19.1	17.0	12.3	6.0	2.2	2.3	4.7	4.7	9.4
1974	43.5	44.1	44.0	43.2	42.0	33.9	37.3	31.9	29.1	30.4	34.6	43.1
	15.0	23.3	18.3	14.5	12.8	13.3	7.9	2.5	1.7	4.1	2.5	5.1
1975	43.5	44.2	46.7	41.6	40.3	34.0	34.8	30.8	30.3	31.2	33.6	38.0
	15.3	20.1	13.1	18.0	19.1	12.7	12.6	3.0	3.4	3.2	2.9	5.4
1976	43.3	45.5	46.8	42.5	39.3	34.9	35.2	30.6	29.0	32.9	37.9	40.2
	10.4	11.7	12.9	17.9	17.1	13.0	9.7	1.4	1.3	3.9	3.5	8.6
1977	43.6	44.1	44.0	42.8	39.2	34.8	36.3	31.9	30.9	32.7	36.9	39.1
	17.1	22.3	20.4	22.2	18.3	13.3	8.1	2.4	0.0	4.3	2.4	6.4
1978	45.1	47.1	43.0	42.9	41.8	34.6	34.7	29.7	31.3	32.3	36.6	40.0
	10.5	12.0	21.3	21.6	17.2	11.6	8.2	4.1	3.7	2.2	3.1	6.9
1979	44.8	44.8	43.7	44.9	40.6	35.0	37.4	31.3	29.6	31.4	33.6	37.6
	13.9	19.1	23.4	18.1	17.5	12.8	13.7	3.1	3.0	7.8	7.1	10.0
1980	44.6	45.8	43.9	43.2	39.0	35.0	37.9	31.2	29.7	32.5	35.7	40.0
	16.5	16.8	22.4	19.0	14.7	13.8	9.1	4.0	2.7	5.7	5.5	10.8
1981	44.4	44.6	44.6	42.2	39.7	34.5	37.1	30.6	32.3	36.1	37.8	40.3
	16.0	22.3	21.9	21.7	17.9	12.1	15.0	3.4	4.5	3.6	3.1	7.0
1982	42.8	43.3	43.7	43.9	39.9	36.6	36.2	33.6	31.2	35.4	32.7	38.3
	11.7	18.1	18.8	22.9	18.6	15.9	13.0	2.2	2.1	3.0	4.8	7.9
1983	45.1	45.7	44.6	43.4	39.9	37.2	39.2	31.4	30.6	31.5	33.1	42.9
	9.2	17.8	23.2	23.2	19.2	13.2	12.5	0.8	1.8	5.1	4.8	9.9
1984	47.2	44.3	44.0	45.4	45.4	38.6	35.4	34.5	29.9	31.1	31.5	37.0
	14.4	19.5	15.3	14.4	13.1	10.7	10.7	1.2	2.2	3.6	3.3	5.6
1985	50.4	45.3	44.9	43.8	41.2	33.7	33.3	31.2	29.7	32.1	33.5	35.6
	8.0	20.4	21.8	23.2	19.8	12.6	10.5	2.4	4.5	3.8	4.2	6.2
1986	45.5	45.7	43.7	43.8	42.2	35.7	36.5	32.6	31.2	34.7	35.8	39.5
	11.9	19.0	18.7	19.5	17.6	12.4	7.4	2.9	5.9	4.9	4.0	7.8
1987	48.1	44.0	42.7	43.7	41.9	34.1	34.0	33.0	29.6	32.0	33.7	39.1
	10.2	23.4	22.3	21.2	16.0	12.4	10.3	2.8	4.4	4.9	4.5	6.5
1988	43.3	43.9	43.8	42.3	40.8	35.4	36.3	31.2	30.3	31.9	32.3	39.8
	13.9	20.3	19.6	22.1	17.3	14.4	11.0	3.5	4.1	5.3	4.3	6.1
1989	45.1	43.7	43.5	43.9	39.7	34.4	34.7	30.8	28.4	31.6	31.7	43.3
	10.7	21.4	17.5	20.7	17.2	14.0	8.8	2.9	1.8	5.6	5.0	4.6
1990	47.7	48.1	45.1	43.4	37.6	32.7	36.3	29.4	28.8	32.0	32.5	38.9
	8.6	11.6	20.2	22.2	11.9	9.2	3.0	1.1	0.3	1.5	2.1	8.1

Table C.7 Voyage-days and Escorted days for 25BC

Voyage days
Escorted days

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1957	42.3	45.8	45.5	45.7	41.0	35.0	37.0	31.5	29.9	33.2	42.1	40.5
	10.4	17.5	25.0	19.0	17.4	13.2	9.4	1.1	0.8	1.9	0.2	5.7
1958	42.3	45.4	44.2	44.1	40.2	33.3	37.4	33.7	29.2	34.3	42.1	40.3
	10.4	18.8	21.1	20.5	19.6	13.3	7.9	2.5	1.9	2.2	0.2	5.7
1959	41.4	44.5	43.6	44.0	39.1	34.0	39.1	31.2	28.7	31.5	42.2	40.1
	12.1	15.9	22.6	23.4	15.9	9.8	8.2	0.7	0.1	0.0	0.1	5.2
1960	40.4	43.7	46.4	43.6	39.0	35.0	36.4	30.8	29.8	31.9	42.3	40.2
	11.1	14.1	20.5	18.6	16.3	11.2	9.6	0.6	0.0	1.1	0.1	4.8
1961	40.7	42.0	46.1	42.7	39.5	34.9	35.4	32.1	31.0	32.8	42.0	40.2
	9.1	14.1	20.1	17.1	16.2	9.7	10.6	0.1	0.4	0.1	0.2	4.8
1965	43.2	44.0	44.2	42.7	44.4	36.8	36.7	29.5	29.5	32.2	42.3	41.4
	12.2	15.9	16.9	22.1	17.0	13.7	12.7	2.2	0.0	4.2	0.1	6.0
1966	43.2	46.2	48.0	45.0	41.0	35.9	37.1	31.8	30.2	32.9	42.3	40.0
	12.2	21.7	20.0	24.4	19.6	13.7	13.6	2.3	1.4	1.2	0.1	7.2
1967	43.5	46.3	44.3	44.9	39.8	35.2	33.5	30.5	30.6	32.4	41.9	39.8
	13.5	21.4	22.1	20.8	17.6	11.7	7.7	1.4	0.7	3.1	0.2	6.3
1968	42.3	45.5	46.8	45.0	40.7	34.6	36.0	32.0	30.3	31.3	42.3	40.1
	11.9	17.7	18.8	15.5	12.0	9.0	2.8	0.7	1.0	1.9	0.1	7.7
1969	44.5	45.5	45.6	44.0	40.9	36.9	36.4	30.2	29.9	32.9	41.9	40.4
	14.4	23.5	22.4	20.3	18.7	16.2	12.0	2.2	1.3	0.3	0.2	6.0
1970	41.5	43.1	45.9	44.4	43.4	38.4	36.6	33.9	29.6	33.1	37.4	40.4
	12.3	14.7	18.7	17.0	16.6	14.1	12.7	1.6	2.4	1.6	0.8	4.8
1971	42.0	43.4	43.6	44.0	40.6	36.2	35.5	33.0	30.7	31.8	34.8	37.2
	11.3	18.4	18.2	17.2	17.9	13.5	11.9	0.5	0.0	0.0	0.4	4.4
1973	42.8	46.1	44.4	42.6	40.7	33.3	35.0	31.7	30.9	36.6	41.9	40.4
	12.8	19.5	23.6	22.1	17.1	10.5	7.0	1.2	0.0	1.7	1.4	7.9
1974	42.0	47.4	47.0	42.9	40.2	34.6	38.0	31.0	29.8	31.2	35.2	41.6
	14.8	21.0	20.2	18.9	15.0	12.5	8.4	0.9	0.2	1.0	1.7	2.2
1975	40.1	43.1	47.6	42.6	40.1	36.1	35.1	31.0	29.8	30.7	39.4	39.8
	12.3	17.8	15.2	13.6	18.5	12.6	12.3	2.0	3.7	4.2	0.2	5.5
1976	42.0	45.3	46.3	42.3	38.3	35.9	34.4	31.1	29.9	33.4	41.9	39.9
	10.1	15.4	15.9	16.3	13.8	11.5	9.1	1.0	1.4	2.0	0.2	7.1
1977	43.2	46.1	44.3	44.0	39.4	35.0	34.2	30.3	29.6	33.1	37.5	39.7
	14.0	21.6	20.7	17.8	16.8	13.2	8.4	0.0	0.0	1.6	0.1	4.0
1978	40.9	45.1	43.1	44.9	40.5	36.2	35.6	30.2	31.5	33.2	37.1	40.0
	11.2	15.1	19.2	19.5	18.2	11.6	5.1	2.0	2.4	2.7	2.1	5.1
1979	46.1	44.1	46.7	43.4	40.5	35.0	37.9	31.5	29.5	33.4	33.7	40.4
	10.6	22.7	22.0	22.9	18.9	13.6	11.8	2.8	3.7	5.8	6.1	8.4
1980	45.1	45.1	46.9	43.9	41.3	36.3	34.5	31.7	32.6	33.9	36.1	38.4
	13.3	23.8	20.1	20.1	14.2	13.6	10.9	4.4	1.0	3.7	2.7	7.7
1981	44.5	46.4	45.1	44.0	41.1	35.7	39.0	31.3	32.7	33.7	33.5	41.1
	13.4	18.6	19.5	23.5	19.7	14.6	12.8	2.1	1.8	2.9	3.6	4.9
1982	43.4	46.2	45.0	45.5	42.0	35.8	35.4	30.8	30.9	31.7	34.1	37.6
	8.0	19.9	24.5	20.2	19.4	14.8	10.6	1.2	1.6	2.2	4.1	5.9
1983	41.3	45.3	45.7	46.1	41.4	37.6	38.1	30.6	31.0	32.1	34.9	41.3
	10.6	20.3	21.4	19.2	13.1	10.1	11.7	1.1	0.7	4.1	3.5	8.9
1984	43.3	44.7	44.4	44.6	41.6	35.3	34.5	31.8	29.8	32.4	32.2	40.5
	14.4	18.6	20.7	22.1	17.1	11.9	12.2	2.0	0.7	3.0	2.3	3.6
1985	47.7	45.3	46.9	47.0	39.6	35.7	34.3	30.6	32.4	32.9	33.6	39.0
	5.7	18.2	22.6	22.5	18.2	11.0	7.0	0.7	3.8	4.2	3.1	6.0
1986	44.6	47.3	47.2	45.8	42.0	35.2	33.1	30.2	29.9	34.6	33.9	42.0
	11.6	20.6	19.6	19.9	18.5	12.9	9.9	3.7	2.8	3.1	3.4	2.2
1987	42.8	45.7	46.3	43.9	40.3	36.5	34.4	30.6	31.4	32.0	34.0	40.8
	14.7	18.3	22.2	23.4	19.5	15.4	11.2	2.2	2.7	2.5	2.7	3.9
1988	41.0	46.6	45.9	43.6	41.4	36.6	36.7	30.7	30.7	31.5	32.7	39.6
	14.0	15.7	18.7	23.1	18.3	15.0	12.4	3.5	3.7	2.6	4.6	5.4
1989	45.2	46.2	46.1	44.8	40.4	35.2	35.7	30.6	29.6	32.3	31.8	42.3
	9.4	16.8	18.5	21.4	16.9	13.4	10.3	1.2	0.3	2.8	2.7	2.7
1990	46.8	44.7	46.5	43.2	35.9	33.8	33.4	29.3	29.3	31.1	33.4	41.6
	4.1	19.1	19.1	16.5	6.2	5.7	3.0	0.6	0.1	0.8	0.0	5.9

Table C.8 Voyage-days and Escorted days for 50BC

Voyage days
Escorted days

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1957	36.9	40.6	41.3	42.6	37.4	30.8	33.2	29.6	28.3	29.3	39.2	37.7
	16.5	21.7	22.4	23.3	17.9	10.6	12.3	4.5	3.7	5.9	3.9	8.6
1958	36.9	41.3	41.5	42.0	37.5	31.8	32.5	32.2	28.8	29.2	39.3	34.5
	16.5	20.4	23.0	22.0	19.2	13.7	11.9	3.1	2.6	8.1	3.9	10.5
1959	39.3	43.2	40.8	39.8	38.4	35.9	35.5	29.7	27.8	30.3	39.0	33.6
	16.3	12.8	21.7	21.6	16.7	11.5	9.1	3.0	0.8	1.8	3.9	9.6
1960	36.1	39.6	42.3	39.2	37.6	33.6	36.5	30.7	28.6	29.7	39.2	33.6
	14.9	17.4	23.9	20.2	16.8	13.5	12.0	1.4	1.3	3.5	3.9	9.6
1964	41.0	41.2	43.4	42.1	36.1	34.3	32.2	29.1	29.4	34.7	39.2	38.3
	14.2	23.0	22.0	16.9	17.6	13.9	12.3	2.7	1.6	3.9	3.9	8.6
1965	41.0	44.4	40.6	41.1	43.4	32.1	33.1	26.4	27.8	33.6	39.2	36.0
	14.2	16.2	18.6	22.9	17.0	14.1	11.3	3.1	0.8	2.1	3.9	11.1
1966	38.7	42.1	42.3	41.3	39.3	34.8	34.7	30.5	30.4	29.7	39.1	35.1
	18.0	23.9	23.6	23.1	19.1	14.5	15.7	3.3	1.1	2.8	3.9	11.1
1967	39.2	42.7	41.8	38.8	35.0	32.3	35.4	33.8	29.6	27.4	39.2	35.3
	17.8	20.2	18.0	20.6	16.0	13.2	6.4	1.1	2.0	5.3	3.9	11.1
1968	39.2	42.3	42.3	39.4	37.1	31.9	32.5	28.1	27.2	30.8	39.2	36.2
	18.8	21.9	23.1	19.8	17.5	10.0	8.8	1.5	1.9	2.6	3.9	10.9
1969	40.7	41.3	42.1	41.6	39.1	35.0	33.7	30.8	32.4	29.6	39.2	37.9
	18.4	22.5	23.5	22.0	18.9	15.0	15.2	4.1	3.5	7.0	3.9	8.7
1970	37.4	41.6	42.3	43.3	38.8	34.5	33.8	33.1	35.8	30.4	37.7	38.8
	16.7	18.1	24.1	18.8	19.3	15.6	13.9	2.9	2.6	6.0	4.1	8.5
1971	37.7	41.2	47.6	41.1	38.0	34.9	32.7	29.6	32.4	28.6	31.1	40.1
	18.1	18.9	19.6	21.9	19.5	13.3	9.4	1.7	0.7	2.0	2.4	5.8
1973	39.0	44.7	39.9	42.0	37.9	33.2	33.0	30.3	28.6	32.9	34.2	34.0
	18.2	15.4	19.3	20.1	17.2	12.6	6.9	2.2	2.4	4.8	5.7	12.1
1974	38.0	42.4	43.8	43.0	42.0	32.1	37.1	29.8	26.1	27.9	34.9	46.2
	19.3	23.3	18.5	14.7	13.1	13.3	7.9	3.3	1.7	4.1	2.5	5.3
1975	44.1	42.2	48.3	41.0	38.6	31.6	32.4	29.3	27.9	29.0	32.1	38.3
	15.5	22.2	14.9	18.0	19.1	12.7	12.6	3.0	3.5	3.2	3.1	5.6
1976	43.0	41.2	47.4	41.7	38.0	33.0	34.1	29.0	26.1	30.3	39.2	35.5
	11.6	19.2	14.6	18.1	17.1	13.0	9.7	1.4	1.4	5.1	3.9	11.5
1977	39.8	42.2	43.0	40.9	37.3	32.5	35.4	31.0	30.2	31.8	38.2	38.4
	19.6	23.1	20.4	22.2	18.3	13.3	8.3	2.5	0.0	4.3	2.5	7.6
1978	40.4	49.3	41.6	40.6	41.3	33.2	33.6	27.3	30.0	30.8	37.4	35.4
	13.9	14.1	21.5	22.4	17.2	11.6	9.0	4.2	3.8	2.3	3.4	9.6
1979	38.8	41.9	41.9	45.1	39.4	33.0	35.8	29.9	27.8	28.9	30.5	35.4
	18.3	22.1	23.4	18.1	17.5	13.0	13.9	3.1	3.0	7.9	7.7	10.6
1980	44.6	41.8	42.0	41.4	37.8	33.0	37.6	29.6	27.9	31.6	36.7	34.0
	16.8	22.3	22.8	19.8	15.0	13.8	9.2	4.3	2.7	5.8	5.5	14.3
1981	39.5	42.3	43.2	40.3	38.0	32.4	35.0	29.4	31.9	36.3	39.4	37.7
	19.3	23.5	22.5	21.7	18.1	12.1	15.0	3.4	4.6	4.2	3.2	9.0
1982	39.3	42.0	43.2	41.7	38.3	34.2	34.3	33.3	29.6	31.8	31.6	38.3
	14.5	19.2	18.8	23.5	18.6	16.0	13.0	2.4	2.1	4.6	4.8	8.1
1983	42.3	41.4	43.1	41.5	38.1	36.5	38.1	30.2	29.1	29.6	30.7	38.6
	12.5	22.8	23.2	23.2	19.2	13.2	12.7	0.8	1.8	5.1	5.2	12.9
1984	42.9	41.8	43.2	45.4	46.1	38.8	33.4	34.7	27.7	28.8	29.2	36.4
	18.2	21.6	16.5	15.4	14.1	10.7	10.8	1.3	2.2	3.8	3.3	5.6
1985	54.7	43.2	43.6	42.0	39.6	32.0	31.8	29.5	27.7	31.0	32.0	34.3
	8.7	22.8	22.4	23.2	19.8	12.6	10.7	2.7	4.5	3.8	4.5	6.2
1986	45.1	41.9	42.6	43.2	39.1	34.7	35.4	31.4	29.0	33.5	36.4	36.5
	13.7	23.1	19.5	19.9	20.2	12.4	7.8	3.4	6.1	5.3	4.1	9.4
1987	47.8	42.2	40.7	42.4	41.9	32.2	31.7	32.3	27.4	30.7	32.6	40.7
	12.9	23.4	22.5	21.2	16.0	12.4	10.5	2.8	4.4	4.9	4.7	6.6
1988	41.5	40.8	41.0	40.4	39.8	33.7	35.3	30.1	27.5	30.8	29.3	40.5
	15.8	22.2	22.3	22.1	17.3	14.4	11.5	3.6	4.4	5.3	5.1	6.5
1989	43.9	41.3	41.4	42.9	38.6	32.3	33.3	28.7	25.1	29.5	29.9	46.1
	13.4	22.6	20.5	21.1	17.2	14.0	9.0	3.1	1.8	5.7	5.0	5.3
1990	48.1	42.6	42.6	41.0	36.4	30.7	37.2	26.7	25.7	30.6	30.6	33.7
	10.7	20.3	22.7	22.8	11.9	9.2	3.0	1.1	0.3	1.5	2.2	10.7

Table C.9 Average ship speed for 40BC between 1957 and 1990 in the sea area

	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot
1	4.8	5.0	4.8	5.2
2	4.2	5.2	4.5	4.3
3	4.4	4.9	4.5	4.3
4	4.3	5.5	4.7	4.4
5	5.3	6.4	5.8	5.7
6	6.9	9.1	7.4	8.6
7	8.2	6.7	8.6	8.4
8	10.4	10.6	9.9	11.5
9	11.6	11.2	10.6	12.4
10	9.6	9.0	9.4	10.6
11	8.2	6.7	8.6	8.4
12	6.8	5.6	6.3	6.6

Table C.10 Average ship speed for 25BC between 1957 and 1990 in the sea area

	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot
1	6.1	6.1	5.6	4.7
2	4.7	5.9	5.0	4.2
3	4.6	5.5	4.8	4.2
4	4.7	6.5	5.4	4.3
5	5.7	7.2	6.6	6.7
6	7.8	9.6	7.5	8.5
7	8.9	8.0	6.7	6.3
8	12.0	11.8	10.6	10.5
9	12.5	12.4	11.8	11.3
10	10.7	9.4	9.6	9.1
11	8.9	8.0	6.7	6.3
12	7.4	6.2	6.1	6.8

Table C.11 Average ship speed for 25BC between 1957 and 1990 in the sea area

	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot
1	4.5	6.1	4.8	5.0
2	4.3	5.2	4.5	4.3
3	4.3	4.8	4.5	4.2
4	4.3	5.5	4.6	4.4
5	5.2	6.4	5.8	5.5
6	7.0	9.3	7.5	8.9
7	8.2	6.0	8.7	8.2
8	10.8	11.2	10.2	12.6
9	12.5	12.0	11.2	13.9
10	9.8	9.2	9.6	11.3
11	8.2	6.0	8.7	8.2
12	6.6	7.1	6.2	6.1

Table C.12 Average ship speed for three types of ships in the sea area

January														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	5.3	6.3	6.3	5.9	1957	6.3	5.4	6.1	5.1	1957	5.2	6.3	6.3	5.9
1958	5.3	6.3	6.3	5.9	1958	6.3	5.4	6.1	5.1	1958	5.2	6.3	6.3	5.9
1959	5.7	6.8	5.2	4.2	1959	6.5	6.1	6.4	4.9	1959	5.5	6.8	5.2	4.6
1960	5.7	4.4	6.0	7.1	1960	7.5	5.8	6.5	5.5	1960	5.5	7.4	6.0	7.1
1964	5.0	5.4	5.5	4.6	1961	7.0	5.8	7.4	5.5	1964	4.9	6.9	5.5	4.2
1965	5.0	5.4	5.5	4.6	1965	6.2	5.5	5.6	4.6	1965	4.9	6.9	5.5	4.2
1966	5.2	4.7	4.6	5.6	1966	6.2	5.5	5.6	4.6	1966	4.9	6.6	4.6	5.6
1967	4.7	5.8	5.2	5.6	1967	5.7	6.4	5.0	4.5	1967	4.6	5.8	5.2	5.6
1968	4.8	5.6	4.8	5.5	1968	6.0	6.0	6.2	4.7	1968	5.1	5.6	4.8	5.6
1969	4.6	4.2	5.1	4.3	1969	5.4	6.0	5.0	4.3	1969	4.5	6.3	5.1	4.3
1970	5.5	4.5	5.3	5.1	1970	6.5	6.2	6.2	5.2	1970	5.3	7.6	5.8	5.1
1971	5.4	4.2	4.9	5.9	1971	6.5	5.5	5.6	4.5	1971	5.1	6.8	4.9	5.9
1973	5.0	4.5	4.6	5.3	1973	5.9	6.1	5.4	4.6	1973	4.9	6.1	4.6	5.3
1974	5.0	4.5	4.6	5.3	1974	6.1	6.0	5.4	4.6	1974	5.0	6.4	4.6	5.3
1975	4.5	5.5	4.0	5.5	1975	6.9	6.3	7.1	5.9	1975	4.2	5.5	3.4	5.5
1976	4.1	6.2	4.8	5.3	1976	6.4	6.5	5.8	4.3	1976	3.2	6.4	4.8	5.3
1977	4.7	4.7	4.2	5.8	1977	5.7	6.2	5.6	4.2	1977	4.6	5.8	4.2	5.8
1978	4.9	4.3	4.9	5.1	1978	6.1	7.4	6.7	4.5	1978	4.7	7.1	5.0	4.7
1979	5.1	4.8	4.6	4.5	1979	5.6	5.5	4.1	4.4	1979	5.1	6.2	5.3	4.9
1980	3.8	5.4	4.1	5.2	1980	4.9	6.2	5.0	4.5	1980	2.8	5.5	4.1	5.2
1981	5.1	4.5	4.4	4.8	1981	5.5	6.0	5.2	4.1	1981	4.9	6.1	4.4	4.9
1982	5.0	4.9	5.7	5.0	1982	6.2	5.7	5.1	5.1	1982	4.9	6.1	5.8	4.8
1983	4.0	4.6	4.7	6.9	1983	5.8	6.9	5.6	6.2	1983	3.3	6.2	4.7	6.1
1984	4.5	4.1	4.1	4.6	1984	6.8	5.8	4.8	4.3	1984	4.0	6.0	4.1	4.6
1985	4.3	4.1	3.9	3.4	1985	5.1	6.6	4.2	3.4	1985	3.5	3.4	3.9	2.6
1986	5.5	4.0	4.3	4.3	1986	6.3	5.5	4.7	4.3	1986	4.6	4.0	4.3	4.3
1987	4.0	4.4	3.9	4.7	1987	5.5	7.6	5.3	4.3	1987	3.1	5.0	3.8	4.5
1988	4.1	5.1	5.3	5.4	1988	6.2	6.9	5.7	4.8	1988	3.8	5.6	5.1	5.4
1989	4.1	5.8	4.0	5.7	1989	5.6	6.3	5.0	4.4	1989	3.6	5.6	4.4	5.7
1990	4.5	5.6	3.6	3.8	1990	6.2	5.7	4.4	4.0	1990	4.3	5.9	3.3	2.7
Ave.	4.8	5.0	4.8	5.2	Ave.	6.1	6.1	5.6	4.7	Ave.	4.5	6.1	4.8	5.0

Table C.13 Average ship speed for three types of ships in the sea area

February														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	4.1	5.0	5.1	4.5	1957	4.1	5.3	6.0	4.6	1957	4.1	5.0	5.1	4.5
1958	4.2	5.0	5.6	4.6	1958	5.2	5.3	4.7	4.2	1958	3.9	5.0	5.6	4.6
1959	4.5	6.4	5.0	4.5	1959	4.6	6.4	5.8	4.3	1959	4.2	6.3	4.4	4.7
1960	3.8	5.8	5.7	5.9	1960	5.8	5.4	5.5	4.7	1960	4.5	5.8	5.7	5.9
1964	4.7	5.4	4.1	4.1	1961	5.0	7.0	7.0	4.8	1964	4.7	6.0	4.1	4.1
1965	4.6	6.1	5.2	3.6	1965	5.1	7.5	5.7	4.1	1965	4.2	6.1	5.2	2.9
1966	4.2	4.6	4.1	4.4	1966	4.4	5.3	5.0	4.1	1966	4.2	4.6	4.1	4.4
1967	4.2	4.9	4.5	3.6	1967	4.6	6.3	4.2	3.6	1967	4.2	4.6	4.5	4.5
1968	4.9	4.7	4.5	4.3	1968	4.5	5.6	5.5	4.0	1968	5.0	4.7	4.5	4.4
1969	4.2	5.4	4.8	4.1	1969	4.5	5.4	4.7	4.0	1969	4.3	5.4	4.8	4.1
1970	5.1	5.6	5.1	4.3	1970	5.6	6.9	5.7	4.1	1970	5.1	5.3	5.1	4.3
1971	4.5	6.4	4.1	5.0	1971	5.3	6.3	5.5	4.1	1971	4.4	6.2	4.1	5.0
1973	3.5	7.0	4.6	4.6	1973	4.5	5.8	4.6	4.1	1973	3.4	6.9	4.6	4.6
1974	4.1	5.0	4.1	4.1	1974	3.8	5.6	4.5	4.1	1974	4.0	5.0	4.1	4.1
1975	4.2	4.4	4.7	4.4	1975	5.8	5.4	5.9	5.1	1975	3.9	4.6	4.7	4.4
1976	3.7	5.8	4.3	4.7	1976	4.7	6.4	4.9	4.1	1976	4.2	6.0	4.5	4.7
1977	4.1	5.0	4.1	4.3	1977	4.2	5.6	4.7	4.1	1977	4.1	5.0	4.1	4.3
1978	3.9	5.0	4.9	3.1	1978	4.1	6.3	6.3	4.9	1978	3.9	4.6	4.8	2.3
1979	4.3	5.3	4.6	3.3	1979	4.7	6.4	5.1	4.8	1979	4.2	5.3	4.6	4.0
1980	4.3	4.8	4.3	3.6	1980	4.7	5.7	4.3	4.2	1980	4.4	5.1	4.3	4.0
1981	4.0	4.9	4.1	4.1	1981	4.5	5.4	4.5	4.1	1981	4.1	4.9	4.1	4.1
1982	4.1	5.1	4.4	5.7	1982	4.1	5.8	4.6	4.3	1982	4.1	4.9	4.1	5.4
1983	4.2	5.1	4.1	3.3	1983	5.0	5.6	4.5	4.1	1983	4.4	5.1	4.3	4.2
1984	4.4	4.9	4.1	4.6	1984	6.0	5.2	4.4	4.1	1984	4.5	4.9	4.1	4.6
1985	4.2	4.6	4.1	4.1	1985	4.9	5.5	4.6	4.2	1985	4.4	4.6	4.1	4.0
1986	3.5	4.8	4.2	4.1	1986	4.1	5.8	4.4	4.1	1986	4.2	4.8	4.2	4.1
1987	4.3	4.9	4.1	4.2	1987	4.4	6.5	4.7	4.1	1987	4.1	4.9	4.1	4.2
1988	3.8	5.4	4.5	4.6	1988	4.2	5.6	4.6	4.4	1988	4.3	5.4	4.5	4.6
1989	4.1	5.2	4.1	4.8	1989	4.6	5.4	4.5	4.2	1989	4.2	5.2	4.1	4.8
1990	4.5	4.7	3.6	3.5	1990	4.9	5.8	4.4	4.1	1990	4.3	4.8	4.4	4.1
Ave.	4.2	5.2	4.5	4.3	Ave.	4.7	5.9	5.0	4.2	Ave.	4.3	5.2	4.5	4.3

Table C.14 Average ship speed for three types of ships in the sea area

March														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	4.9	5.1	4.2	4.6	1957	4.6	5.0	4.8	4.1	1957	4.9	5.1	4.2	4.6
1958	4.4	5.0	4.6	4.2	1958	5.1	4.9	5.5	4.1	1958	4.3	5.0	4.6	4.2
1959	4.3	6.0	4.9	4.1	1959	4.5	7.0	5.4	4.1	1959	4.3	6.0	4.9	3.9
1960	4.0	4.3	4.5	4.2	1960	4.5	5.2	4.3	4.1	1960	4.2	4.3	4.5	4.2
1964	4.1	4.8	4.2	4.1	1961	4.7	5.2	4.4	4.1	1964	4.1	4.6	4.2	4.1
1965	4.8	5.6	5.3	4.8	1965	5.1	6.8	5.5	4.8	1965	4.6	5.4	5.3	4.8
1966	4.9	4.3	4.1	4.1	1966	4.2	4.7	4.4	4.1	1966	4.8	4.3	4.1	4.1
1967	4.1	5.1	5.2	5.4	1967	4.4	5.7	4.6	7.0	1967	4.1	4.6	5.2	5.2
1968	4.3	4.7	4.1	4.2	1968	4.2	5.2	4.6	4.3	1968	4.4	4.7	4.1	4.0
1969	4.2	4.7	4.2	4.1	1969	4.6	5.1	4.7	4.1	1969	4.2	4.7	4.2	4.1
1970	4.2	4.9	4.2	4.1	1970	4.4	5.5	5.1	4.1	1970	4.2	4.9	4.2	4.1
1971	4.2	4.4	3.9	4.1	1971	5.3	5.7	6.2	4.1	1971	4.1	4.2	3.7	4.1
1973	4.3	6.1	5.2	4.1	1973	4.8	6.1	5.0	4.1	1973	4.5	6.2	5.1	4.1
1974	4.2	5.0	4.7	4.1	1974	3.9	5.4	5.0	4.1	1974	4.1	4.5	4.2	4.1
1975	4.4	5.3	3.6	4.2	1975	4.6	5.5	4.5	3.7	1975	4.2	4.8	3.1	4.6
1976	3.9	5.6	3.7	4.1	1976	4.2	6.3	4.3	4.1	1976	3.7	4.6	3.9	4.1
1977	5.2	4.9	4.4	4.2	1977	5.7	5.7	4.6	4.1	1977	4.8	4.9	4.4	4.2
1978	4.0	5.4	4.7	4.2	1978	5.4	5.6	5.8	4.3	1978	3.9	5.4	4.7	4.2
1979	5.3	4.4	4.1	4.1	1979	4.5	5.3	4.2	4.1	1979	5.2	4.4	4.1	4.1
1980	4.8	4.5	4.3	4.1	1980	4.4	5.3	4.3	4.1	1980	4.7	4.5	4.3	4.1
1981	4.0	4.9	4.2	4.1	1981	4.9	5.4	4.4	4.1	1981	3.8	4.9	4.2	4.1
1982	4.3	5.1	4.6	4.2	1982	4.4	5.8	4.6	4.1	1982	4.3	4.9	4.1	4.2
1983	4.5	4.6	4.1	4.1	1983	4.9	5.3	4.6	4.1	1983	4.4	4.6	4.1	4.1
1984	4.1	5.0	4.8	5.1	1984	5.1	5.9	4.7	4.1	1984	4.3	4.5	4.7	5.1
1985	4.0	4.6	4.6	4.1	1985	4.4	4.9	4.2	4.1	1985	3.8	4.6	4.6	4.1
1986	4.2	4.2	6.0	4.4	1986	4.3	5.3	4.3	4.1	1986	4.2	3.9	6.0	4.4
1987	4.2	5.2	5.7	4.1	1987	4.1	5.2	4.9	4.3	1987	4.2	5.2	5.7	4.1
1988	4.4	4.7	4.9	4.2	1988	4.2	5.3	5.8	4.1	1988	4.3	5.0	4.9	4.2
1989	4.4	4.9	4.8	4.7	1989	4.2	5.5	4.7	4.6	1989	4.4	4.9	4.8	4.2
1990	4.1	4.4	4.4	4.1	1990	4.1	5.3	4.9	4.6	1990	3.9	4.8	4.4	4.1
Ave.	4.4	4.9	4.5	4.3	Ave.	4.6	5.5	4.8	4.2	Ave.	4.3	4.8	4.5	4.2

Table C.15 Average ship speed for three types of ships in the sea area

April														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	4.1	4.5	4.3	4.3	1957	4.6	5.6	5.0	4.2	1957	4.0	4.5	4.3	4.4
1958	4.4	5.2	4.3	4.2	1958	4.8	6.2	4.9	4.2	1958	4.3	5.2	4.3	4.2
1959	4.4	5.4	5.0	4.3	1959	4.9	6.2	5.0	4.3	1959	4.5	5.7	5.3	4.3
1960	4.5	5.9	5.4	5.5	1960	5.1	6.9	4.9	4.9	1960	4.5	5.9	5.5	5.5
1964	4.9	5.6	4.4	5.2	1961	7.1	6.5	4.9	4.1	1964	4.9	5.2	4.1	5.2
1965	4.1	5.6	4.4	4.1	1965	4.9	7.2	5.4	4.2	1965	4.2	5.6	4.4	4.1
1966	4.9	5.2	4.2	4.1	1966	4.5	5.6	4.8	4.1	1966	4.9	5.2	4.2	4.1
1967	4.5	6.0	5.7	4.9	1967	4.6	6.5	4.8	4.3	1967	4.5	6.0	5.7	4.9
1968	4.6	6.5	5.2	4.7	1968	4.0	6.1	6.9	5.2	1968	4.6	6.5	5.2	4.7
1969	4.1	5.7	4.4	4.2	1969	4.3	6.5	6.4	4.2	1969	4.0	5.7	4.4	4.2
1970	5.1	5.4	4.4	4.3	1970	4.2	6.7	6.6	4.2	1970	5.0	5.2	4.3	4.3
1971	4.2	5.8	4.6	4.4	1971	5.3	6.3	5.9	4.1	1971	4.1	5.8	4.6	4.4
1973	4.3	6.1	4.1	4.1	1973	6.0	6.9	5.0	4.1	1973	4.0	6.2	4.1	4.1
1974	4.0	6.1	5.7	4.3	1974	4.9	7.1	5.7	4.0	1974	3.9	5.6	5.7	4.3
1975	4.7	5.7	5.7	4.3	1975	5.0	6.8	8.4	4.2	1975	4.6	5.5	5.5	4.2
1976	4.9	6.6	4.4	4.1	1976	4.8	7.4	7.0	4.1	1976	4.5	6.5	4.4	4.1
1977	4.8	5.7	4.3	4.1	1977	4.9	7.4	4.9	4.1	1977	4.8	5.7	4.3	4.1
1978	4.3	5.4	4.7	4.2	1978	4.7	6.1	5.0	4.1	1978	4.4	5.4	4.7	4.2
1979	4.1	5.2	4.2	4.2	1979	5.1	6.7	4.9	4.3	1979	3.9	5.1	4.2	3.6
1980	4.1	5.2	4.2	7.2	1980	4.8	6.7	4.6	4.8	1980	4.1	5.1	4.2	7.1
1981	4.4	6.1	4.5	4.5	1981	4.3	6.3	5.7	4.1	1981	4.4	6.1	4.5	4.5
1982	4.0	5.3	4.2	4.1	1982	4.1	6.5	5.0	4.1	1982	4.1	5.3	4.2	4.1
1983	4.3	5.3	4.2	4.1	1983	4.0	6.5	4.9	4.1	1983	4.3	5.3	4.2	4.1
1984	3.9	5.3	4.1	4.2	1984	4.2	6.7	5.1	4.1	1984	4.0	4.5	3.8	4.2
1985	4.1	5.5	4.2	4.1	1985	4.0	5.9	4.3	4.1	1985	4.0	5.5	4.2	4.1
1986	4.0	4.9	5.3	4.2	1986	4.1	6.6	4.8	4.3	1986	4.1	4.6	5.1	4.1
1987	4.2	5.4	4.3	4.1	1987	4.6	6.4	5.1	4.1	1987	4.2	5.1	4.2	4.1
1988	4.1	5.6	5.4	4.1	1988	4.3	6.9	5.5	4.1	1988	4.1	5.6	5.4	4.1
1989	3.8	4.8	5.1	4.2	1989	4.4	6.4	5.0	4.1	1989	3.6	4.8	5.1	4.2
1990	4.0	5.4	4.7	4.2	1990	4.9	6.4	6.3	5.3	1990	4.2	5.4	4.7	4.2
Ave.	4.3	5.5	4.7	4.4	Ave.	4.7	6.5	5.4	4.3	Ave.	4.3	5.5	4.6	4.4

Table C.16 Average ship speed for three types of ships in the sea area

May														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	6.3	6.0	6.0	5.7	1957	5.4	6.6	6.4	6.5	1957	6.3	6.0	6.0	5.5
1958	6.1	5.4	6.3	6.5	1958	5.3	5.8	6.8	8.7	1958	6.1	5.4	6.3	6.5
1959	4.7	7.0	6.8	4.9	1959	7.0	7.7	6.8	6.2	1959	4.7	7.0	7.0	4.3
1960	5.6	7.6	6.0	5.5	1960	7.7	7.8	6.1	5.5	1960	5.5	7.8	6.0	5.3
1964	5.4	6.1	7.1	7.7	1961	6.6	6.9	6.4	6.3	1964	5.4	6.1	7.1	7.9
1965	5.2	4.9	4.7	4.8	1965	4.3	6.5	5.5	4.6	1965	5.2	4.4	4.6	4.5
1966	4.6	5.8	5.6	5.3	1966	5.0	6.8	6.0	6.3	1966	4.6	5.8	5.6	5.0
1967	4.6	6.6	8.7	9.4	1967	6.4	7.5	6.2	8.7	1967	4.6	6.6	9.1	10.3
1968	4.9	7.1	6.7	6.7	1968	5.0	7.4	8.1	7.8	1968	4.9	7.1	6.7	7.0
1969	5.0	5.9	5.8	4.8	1969	5.0	7.0	6.5	7.5	1969	4.9	5.9	5.8	4.5
1970	4.7	6.2	5.7	5.3	1970	4.2	7.1	6.0	6.1	1970	4.8	6.2	5.7	5.3
1971	5.9	6.5	5.2	5.5	1971	6.0	7.3	5.9	6.5	1971	5.9	6.5	5.2	5.5
1973	5.3	7.7	5.7	4.9	1973	6.0	7.0	6.0	6.3	1973	5.2	8.0	5.7	4.7
1974	5.2	6.0	4.9	4.9	1974	5.8	7.8	6.4	6.5	1974	5.1	5.7	4.8	4.6
1975	4.8	6.4	5.5	5.5	1975	6.3	7.6	6.3	6.5	1975	4.7	6.4	5.5	5.5
1976	5.6	7.7	5.7	5.7	1976	6.7	8.2	7.6	6.2	1976	5.4	7.7	5.7	5.7
1977	5.9	7.4	6.0	5.0	1977	6.2	9.0	6.0	6.2	1977	6.0	7.7	6.1	4.8
1978	5.4	5.1	5.2	6.0	1978	5.5	6.4	6.2	7.2	1978	5.4	4.7	5.2	6.0
1979	5.4	5.9	5.4	5.9	1979	5.7	7.1	6.3	6.7	1979	5.4	5.9	5.4	5.5
1980	5.7	7.1	6.1	5.5	1980	5.0	7.6	6.5	6.7	1980	5.8	7.1	6.1	4.7
1981	4.5	6.8	6.6	5.3	1981	4.9	6.4	7.1	7.0	1981	4.5	6.8	6.6	5.1
1982	4.9	6.7	5.4	5.4	1982	5.4	6.3	5.4	6.3	1982	4.9	6.7	5.4	4.9
1983	5.1	6.5	5.8	6.0	1983	5.1	6.7	7.4	6.7	1983	5.0	6.5	5.9	6.0
1984	4.3	4.3	4.6	5.2	1984	5.3	6.1	7.5	7.0	1984	3.9	4.6	4.3	5.1
1985	6.0	5.8	4.8	5.4	1985	7.7	7.4	5.3	6.5	1985	6.0	5.8	4.8	5.4
1986	5.4	5.6	4.7	4.7	1986	5.4	6.9	5.6	6.6	1986	5.4	5.8	5.1	4.7
1987	5.3	6.0	4.4	5.4	1987	5.5	6.5	6.6	6.5	1987	5.3	5.7	4.4	4.3
1988	5.9	6.5	4.6	5.6	1988	5.8	7.0	6.2	7.0	1988	5.9	6.5	4.3	5.6
1989	5.8	6.8	5.5	5.1	1989	5.9	7.3	6.3	6.5	1989	5.8	6.8	5.5	4.6
1990	4.9	8.8	8.7	6.3	1990	6.0	9.9	12.7	8.7	1990	4.7	9.3	9.3	6.3
Ave.	5.3	6.4	5.8	5.7	Ave.	5.7	7.2	6.6	6.7	Ave.	5.2	6.4	5.8	5.5

Table C.17 Average ship speed for three types of ships in the sea area

Jun														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	10.9	9.0	9.0	7.4	1957	8.3	9.2	10.0	6.2	1957	11.9	9.0	9.0	7.5
1958	7.4	9.5	7.3	9.3	1958	7.8	10.0	8.5	11.4	1958	7.4	9.5	7.3	9.9
1959	5.7	8.4	7.5	8.2	1959	9.4	10.4	8.2	9.0	1959	5.5	8.1	7.5	8.7
1960	7.0	9.4	7.1	7.5	1960	7.6	9.3	8.7	7.6	1960	6.9	9.7	7.1	7.4
1964	5.5	8.2	7.2	7.8	1961	9.2	9.2	8.2	8.9	1964	5.5	8.3	7.1	7.9
1965	6.5	7.9	7.0	8.6	1965	6.4	10.0	7.0	7.2	1965	10.1	8.0	7.0	8.8
1966	5.6	9.4	6.8	7.3	1966	7.5	10.3	7.1	7.8	1966	5.5	9.4	7.0	7.3
1967	6.2	9.7	7.8	10.9	1967	7.4	10.2	7.3	11.7	1967	6.2	9.7	8.0	12.1
1968	6.5	9.7	9.9	9.2	1968	7.4	10.5	9.9	8.6	1968	6.4	10.1	10.3	10.1
1969	6.5	8.4	6.9	6.8	1969	7.4	9.1	6.4	7.5	1969	6.5	8.4	7.1	6.4
1970	5.5	9.7	6.6	8.6	1970	5.5	10.0	6.1	7.4	1970	5.3	9.8	6.7	9.0
1971	7.3	8.2	6.1	8.3	1971	7.6	9.3	6.6	7.9	1971	7.4	8.2	5.9	8.5
1973	5.7	8.3	8.4	9.7	1973	8.7	9.6	9.7	9.9	1973	5.6	9.3	8.7	9.8
1974	6.2	9.1	9.3	8.4	1974	7.4	9.5	8.5	11.0	1974	6.2	9.1	9.3	8.1
1975	10.7	9.9	6.3	8.4	1975	8.1	10.0	6.5	8.0	1975	12.0	10.1	6.3	8.6
1976	6.6	10.6	7.2	8.4	1976	7.8	9.8	6.1	9.2	1976	6.4	11.1	7.5	8.5
1977	6.5	9.8	7.5	8.4	1977	8.3	9.9	6.6	7.8	1977	6.5	10.2	8.0	8.5
1978	7.8	10.2	6.9	8.3	1978	8.3	9.5	5.7	8.3	1978	7.7	10.6	6.9	8.7
1979	7.3	9.9	6.9	8.4	1979	8.0	9.5	7.0	8.3	1979	7.5	10.3	7.0	8.8
1980	7.6	9.5	7.3	7.3	1980	7.1	9.3	6.7	9.4	1980	7.7	9.8	7.5	7.0
1981	5.6	9.4	8.5	9.9	1981	7.7	9.5	8.0	8.6	1981	5.6	9.6	8.9	10.3
1982	6.1	8.8	6.2	9.7	1982	8.5	8.9	6.0	8.7	1982	6.1	9.1	6.3	11.1
1983	6.5	8.1	5.9	8.1	1983	7.0	9.1	6.2	6.8	1983	6.5	7.9	5.7	7.9
1984	5.5	6.8	5.9	10.0	1984	7.3	9.1	8.1	10.2	1984	5.1	6.4	5.6	10.5
1985	9.2	9.6	7.7	7.2	1985	9.0	10.2	7.6	7.0	1985	9.4	9.6	7.7	7.0
1986	6.2	7.7	7.3	9.4	1986	7.9	8.9	7.7	7.5	1986	6.1	7.5	7.1	10.3
1987	6.7	9.6	7.3	9.9	1987	8.1	9.2	6.8	7.0	1987	6.7	9.6	7.3	10.4
1988	7.2	9.3	6.6	6.8	1988	7.9	8.5	6.4	7.9	1988	7.2	9.4	6.6	6.5
1989	7.1	8.9	7.1	9.7	1989	8.1	8.9	6.6	9.1	1989	7.2	8.9	7.1	10.5
1990	6.5	11.4	10.2	9.5	1990	8.2	10.4	10.8	9.3	1990	6.2	11.8	11.2	10.4
Ave.	6.9	9.1	7.4	8.6	Ave.	7.8	9.6	7.5	8.5	Ave.	7.0	9.3	7.5	8.9

Table C.18 Average ship speed for three types of ships in the sea area

July														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	10.7	6.3	6.1	10.0	1957	10.1	7.4	6.2	7.3	1957	11.8	6.3	6.1	10.7
1958	6.9	10.4	7.3	9.4	1958	8.2	10.0	5.5	6.8	1958	6.8	10.7	7.3	10.3
1959	5.8	10.7	5.3	10.0	1959	9.8	8.9	4.8	7.4	1959	5.8	11.5	5.0	11.0
1960	6.8	8.3	5.0	9.0	1960	9.0	8.0	5.6	10.1	1960	6.5	8.5	5.0	9.8
1964	6.5	9.9	7.5	10.1	1961	12.4	9.4	5.9	6.7	1964	6.5	10.6	8.0	11.4
1965	10.1	10.2	5.6	8.3	1965	9.1	8.1	5.8	7.2	1965	10.9	10.9	5.7	8.8
1966	5.9	8.9	5.1	9.8	1966	7.0	9.4	5.6	7.8	1966	5.9	9.1	5.1	10.9
1967	6.1	9.1	7.4	10.9	1967	9.8	9.2	7.5	14.5	1967	6.0	9.3	7.5	12.3
1968	5.6	11.5	8.3	11.3	1968	8.9	10.4	7.5	9.1	1968	5.4	12.6	9.1	12.9
1969	6.1	8.1	6.3	10.4	1969	7.7	9.2	6.4	9.0	1969	6.1	8.1	6.3	11.9
1970	6.0	10.5	6.0	8.2	1970	8.3	10.5	5.5	6.2	1970	5.9	11.0	6.0	9.1
1971	8.2	11.2	6.2	9.9	1971	10.5	8.9	6.1	7.3	1971	8.0	12.1	6.5	10.9
1973	4.4	12.0	10.9	8.8	1973	8.6	10.7	7.1	7.5	1973	3.8	13.5	11.5	10.5
1974	5.1	7.3	9.5	10.1	1974	8.2	8.3	7.6	7.0	1974	4.7	7.6	9.8	10.7
1975	10.8	9.6	5.9	8.6	1975	10.5	9.7	6.4	7.7	1975	12.1	10.0	5.9	9.1
1976	6.1	10.2	7.7	9.4	1976	12.3	7.8	8.3	7.9	1976	5.5	10.6	8.1	10.2
1977	6.0	8.8	8.5	8.0	1977	11.5	8.0	8.6	8.6	1977	5.7	9.2	8.8	8.2
1978	9.0	10.2	5.8	11.0	1978	8.4	9.5	6.2	10.4	1978	9.0	10.2	5.7	11.9
1979	7.2	7.3	5.2	9.3	1979	8.8	9.1	6.4	5.9	1979	7.2	7.3	5.2	9.9
1980	7.8	8.6	5.0	7.8	1980	8.5	10.1	7.0	8.3	1980	7.8	9.1	4.6	7.8
1981	4.7	8.2	7.0	9.5	1981	7.4	8.1	6.4	5.9	1981	4.7	8.3	7.0	10.5
1982	5.4	9.7	5.6	11.5	1982	10.1	8.8	5.3	10.6	1982	5.1	10.3	5.6	12.7
1983	5.0	9.5	5.1	8.7	1983	8.6	9.0	4.8	6.7	1983	4.8	10.0	5.1	9.4
1984	7.1	9.2	6.8	9.9	1984	10.2	9.4	7.3	6.6	1984	7.2	9.8	6.8	11.0
1985	8.3	9.8	7.9	9.7	1985	10.4	9.7	7.2	8.6	1985	8.0	9.8	7.9	10.3
1986	5.8	8.7	6.8	10.8	1986	9.5	9.9	7.9	10.8	1986	5.1	8.6	7.3	12.3
1987	10.2	8.1	7.5	11.0	1987	9.7	9.2	6.9	9.0	1987	10.6	8.3	7.5	12.1
1988	6.4	10.2	6.0	6.5	1988	9.2	8.9	5.9	7.2	1988	6.0	10.4	6.0	7.0
1989	6.2	10.5	7.7	9.2	1989	9.2	8.2	6.9	8.9	1989	5.9	11.0	8.0	9.7
1990	6.8	9.9	8.6	9.5	1990	10.6	11.2	10.8	6.7	1990	6.4	10.3	8.9	10.1
Ave.	6.9	9.4	6.8	9.6	Ave.	9.4	9.2	6.6	8.1	Ave.	6.8	9.8	6.9	10.5

Table C.19 Average ship speed for three types of ships in the sea area

August														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	12.5	11.5	10.4	7.7	1957	12.3	9.6	13.7	8.7	1957	13.7	11.5	11.5	7.2
1958	10.0	10.7	8.9	11.4	1958	10.7	12.1	6.0	10.1	1958	10.8	10.7	8.6	12.5
1959	10.4	11.4	10.7	12.4	1959	11.9	13.6	9.7	12.4	1959	10.9	12.5	10.6	14.3
1960	12.2	10.1	6.6	12.6	1960	13.5	12.1	9.2	13.7	1960	13.5	10.9	9.3	14.0
1964	10.5	8.9	11.2	13.4	1961	14.4	11.5	5.9	10.7	1964	10.4	9.2	12.7	15.3
1965	13.6	11.0	11.3	12.8	1965	13.8	13.0	10.9	11.3	1965	15.5	12.0	11.3	14.0
1966	10.1	12.3	7.9	11.8	1966	10.5	11.4	9.2	11.3	1966	10.2	13.7	8.1	13.0
1967	10.5	9.8	6.7	12.1	1967	12.6	10.5	9.7	13.7	1967	10.7	10.0	5.9	13.5
1968	10.6	11.3	12.8	12.0	1968	9.6	13.1	13.6	10.8	1968	10.4	12.3	14.4	13.2
1969	11.5	11.1	6.9	12.6	1969	11.5	12.9	10.9	10.7	1969	11.5	11.3	5.9	14.0
1970	6.7	9.4	10.6	12.2	1970	11.2	13.0	8.0	9.1	1970	7.9	9.7	10.9	13.8
1971	10.2	10.5	9.8	10.5	1971	11.1	12.8	9.5	8.4	1971	11.9	12.4	10.2	11.0
1973	8.3	13.4	10.4	10.3	1973	10.2	11.7	11.0	9.5	1973	7.8	15.4	10.4	11.2
1974	10.7	9.6	10.8	9.9	1974	10.7	11.8	13.1	10.7	1974	10.6	11.3	11.5	10.3
1975	13.1	10.2	10.1	8.9	1975	13.4	9.3	9.7	10.6	1975	15.0	10.4	9.9	8.6
1976	10.5	11.3	10.6	11.7	1976	12.1	11.1	10.8	9.3	1976	11.0	12.1	10.9	12.5
1977	9.8	12.5	9.2	9.6	1977	11.2	12.9	13.1	10.2	1977	10.0	13.7	9.1	9.9
1978	10.8	12.4	10.9	11.3	1978	12.8	11.9	11.0	10.2	1978	11.4	13.4	11.1	12.0
1979	10.5	10.2	9.4	12.1	1979	12.9	10.9	9.4	8.3	1979	11.0	10.4	9.0	13.5
1980	9.4	11.7	10.7	9.9	1980	12.1	11.4	11.6	6.8	1980	8.9	13.3	10.5	10.3
1981	9.1	9.7	11.6	12.9	1981	11.0	11.7	10.9	11.8	1981	8.6	9.8	11.9	14.4
1982	9.1	11.2	6.7	12.4	1982	12.3	11.5	9.1	12.5	1982	9.0	11.5	6.3	13.8
1983	9.0	11.6	8.2	12.1	1983	12.4	12.9	8.8	11.8	1983	9.0	12.6	7.5	13.6
1984	9.7	8.7	6.8	12.9	1984	11.7	11.7	9.6	7.7	1984	9.9	8.3	6.2	14.5
1985	11.4	9.7	10.1	11.3	1985	14.1	11.2	9.0	11.7	1985	12.5	10.6	9.9	12.4
1986	8.9	9.4	9.2	11.6	1986	13.0	10.3	11.5	11.0	1986	8.5	9.2	10.2	12.9
1987	10.5	6.3	10.7	13.0	1987	11.8	12.0	12.2	8.9	1987	11.1	5.6	10.6	14.5
1988	8.9	10.1	11.1	11.8	1988	10.2	11.5	11.7	11.7	1988	8.6	10.4	11.3	12.9
1989	11.5	10.3	12.1	10.6	1989	11.8	11.0	14.5	11.0	1989	11.6	10.3	13.7	12.0
1990	10.7	10.5	13.8	11.9	1990	12.7	13.1	14.5	10.7	1990	10.9	11.1	15.9	13.1
Ave.	10.4	10.6	9.9	11.5	Ave.	12.0	11.8	10.6	10.5	Ave.	10.8	11.2	10.2	12.6

Table C. 20 Average ship speed for three types of ships in the sea area

September														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	12.9	11.5	10.9	12.3	1957	13.0	10.7	13.6	10.7	1957	14.3	11.5	11.8	13.9
1958	10.5	11.9	9.2	12.4	1958	12.2	12.9	12.5	13.0	1958	10.9	12.5	10.3	13.9
1959	12.0	12.4	10.8	14.0	1959	14.4	14.3	12.0	13.9	1959	13.0	14.2	11.6	16.2
1960	13.6	11.2	10.3	13.8	1960	13.2	12.9	12.1	13.5	1960	15.7	12.8	11.1	15.9
1964	10.5	12.2	9.8	14.5	1961	14.3	13.5	10.0	10.1	1964	10.6	13.3	10.5	17.0
1965	14.0	12.5	7.3	13.6	1965	12.6	14.1	10.1	13.0	1965	16.3	14.7	9.2	15.6
1966	7.1	11.0	11.1	12.6	1966	11.6	12.4	12.0	10.8	1966	5.9	11.8	11.6	14.1
1967	10.4	10.5	10.7	13.9	1967	12.3	12.1	10.5	14.0	1967	11.8	11.2	11.8	16.0
1968	11.6	11.8	13.0	12.6	1968	12.2	11.8	14.5	11.0	1968	12.2	12.9	14.9	14.1
1969	9.9	11.3	8.0	11.8	1969	12.4	11.7	12.6	14.5	1969	9.7	11.7	7.8	13.4
1970	10.5	7.9	7.8	12.3	1970	12.0	12.9	12.5	11.3	1970	10.7	8.3	7.3	13.7
1971	11.3	10.3	10.4	9.9	1971	12.4	12.7	11.4	10.1	1971	12.2	10.9	11.2	10.2
1973	11.8	12.7	8.5	12.6	1973	11.4	14.5	10.4	12.6	1973	12.4	14.2	8.1	14.2
1974	11.5	12.0	11.9	12.7	1974	11.7	13.5	14.3	10.3	1974	12.3	13.2	13.1	14.3
1975	13.2	11.2	10.8	11.6	1975	13.4	13.4	11.5	9.8	1975	14.9	12.1	11.3	12.3
1976	13.2	11.0	12.5	12.2	1976	13.0	12.6	12.8	9.3	1976	15.0	11.9	13.7	13.3
1977	10.2	10.4	10.4	12.6	1977	11.3	13.3	14.1	10.4	1977	10.5	10.8	11.1	14.1
1978	11.6	8.8	10.7	12.4	1978	12.1	10.1	10.8	10.4	1978	12.3	8.8	10.8	13.8
1979	13.2	9.6	11.1	12.9	1979	13.8	10.5	11.5	11.8	1979	15.0	9.6	10.9	14.6
1980	10.3	12.4	11.3	9.6	1980	12.2	13.0	8.4	6.6	1980	10.7	13.8	11.3	10.0
1981	11.8	10.4	9.4	9.5	1981	12.0	9.5	10.3	9.2	1981	12.3	10.6	9.2	9.9
1982	11.7	11.8	9.6	13.2	1982	12.8	11.6	9.9	13.1	1982	13.0	12.9	9.3	14.9
1983	12.6	12.2	9.2	11.7	1983	12.7	13.5	11.1	8.1	1983	13.8	13.5	9.0	12.8
1984	12.6	12.2	10.3	13.7	1984	12.3	13.3	11.3	14.5	1984	14.0	13.6	10.3	15.9
1985	13.6	11.4	11.0	10.0	1985	12.9	8.5	11.5	9.4	1985	15.4	12.1	10.9	10.1
1986	10.4	9.4	11.5	13.6	1986	14.1	12.6	11.0	12.1	1986	11.8	9.0	11.5	15.7
1987	12.6	10.0	11.5	12.2	1987	12.7	12.4	10.7	8.8	1987	14.1	9.9	11.5	14.0
1988	10.6	10.8	11.4	11.9	1988	11.1	12.2	11.9	10.1	1988	10.7	11.4	12.7	12.9
1989	12.0	11.7	13.9	13.1	1989	11.2	12.5	14.5	14.0	1989	12.5	12.6	16.1	14.8
1990	10.0	13.1	14.5	13.3	1990	12.4	14.0	14.5	11.5	1990	10.2	14.8	17.0	15.1
Ave.	11.6	11.2	10.6	12.4	Ave.	12.5	12.4	11.8	11.3	Ave.	12.5	12.0	11.2	13.9

Table C. 21 Average ship speed for three types of ships in the sea area

October														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	9.9	10.0	9.3	11.3	1957	11.3	9.0	9.3	5.9	1957	10.3	10.1	9.3	12.0
1958	9.3	9.0	9.3	10.0	1958	9.9	9.4	6.9	9.6	1958	9.5	9.5	10.4	10.8
1959	9.6	10.5	10.2	12.0	1959	12.0	11.1	9.6	10.0	1959	9.8	11.1	10.8	13.4
1960	9.0	9.6	10.3	12.0	1960	10.8	9.6	11.3	10.0	1960	8.9	9.7	11.0	13.4
1964	9.1	7.0	7.7	10.8	1961	11.4	10.2	7.9	8.4	1964	8.9	6.7	7.5	11.5
1965	10.1	8.8	7.7	8.2	1965	10.8	10.4	8.8	6.9	1965	10.5	8.7	7.2	7.8
1966	9.5	9.1	8.4	10.1	1966	10.3	9.7	8.4	8.1	1966	9.7	9.7	8.3	10.5
1967	9.3	10.6	10.8	12.3	1967	11.5	9.8	9.7	9.8	1967	9.9	10.9	11.0	14.2
1968	8.8	10.0	9.0	10.6	1968	10.7	10.7	11.7	9.9	1968	8.7	10.4	8.9	11.2
1969	8.7	9.5	10.0	10.5	1969	10.0	8.5	10.1	10.0	1969	8.7	9.5	10.1	11.9
1970	9.3	8.8	9.5	10.5	1970	10.3	9.8	8.8	9.8	1970	9.6	8.7	9.5	11.3
1971	10.4	9.7	11.2	10.5	1971	10.6	10.4	10.5	8.0	1971	11.0	10.0	12.0	11.0
1973	9.2	8.9	8.2	8.0	1973	8.2	8.8	8.1	5.7	1973	9.3	9.1	7.6	7.5
1974	8.6	9.7	12.9	11.5	1974	10.0	9.9	13.2	9.2	1974	8.5	9.9	14.6	12.6
1975	11.1	9.2	9.0	10.4	1975	13.7	10.1	9.4	10.1	1975	11.9	9.5	9.0	11.0
1976	10.2	7.6	9.5	9.2	1976	11.6	8.7	8.8	6.6	1976	11.0	8.5	9.8	9.3
1977	8.2	9.3	9.0	12.0	1977	10.2	9.5	8.9	9.2	1977	8.0	9.4	9.1	13.4
1978	9.2	8.8	10.1	11.7	1978	10.5	8.9	9.6	9.2	1978	9.1	8.7	10.6	12.9
1979	10.2	9.2	8.4	11.1	1979	10.6	7.5	8.8	11.7	1979	11.0	9.2	8.4	11.8
1980	9.1	9.2	9.2	9.1	1980	10.2	9.0	8.5	8.0	1980	9.0	9.1	9.3	9.1
1981	9.2	8.5	5.8	9.0	1981	9.3	10.1	9.5	7.3	1981	9.4	9.6	4.9	8.9
1982	8.9	7.7	7.7	9.3	1982	11.0	10.2	9.4	9.1	1982	9.1	10.1	8.0	9.5
1983	10.3	9.4	8.9	10.7	1983	10.9	10.0	8.5	9.5	1983	10.7	9.4	9.0	11.6
1984	11.6	8.7	9.6	12.9	1984	11.1	7.9	9.8	11.5	1984	12.6	9.1	9.6	14.6
1985	12.4	8.9	8.2	9.1	1985	12.8	8.3	9.3	7.9	1985	13.8	8.8	7.9	8.9
1986	9.9	6.2	9.2	10.9	1986	10.3	7.9	8.9	7.7	1986	10.1	6.4	9.1	11.9
1987	10.2	8.6	9.6	9.1	1987	10.5	9.2	9.7	9.5	1987	10.5	8.4	9.6	9.1
1988	8.4	9.4	10.0	9.7	1988	10.0	9.4	10.7	10.8	1988	8.3	9.4	10.2	9.7
1989	8.5	9.1	10.2	12.4	1989	10.5	8.4	10.3	12.8	1989	8.9	9.1	10.6	13.9
1990	8.7	8.3	12.0	12.5	1990	10.7	9.9	12.6	10.0	1990	8.4	8.2	13.4	14.1
Ave.	9.6	9.0	9.4	10.6	Ave.	10.7	9.4	9.6	9.1	Ave.	9.8	9.2	9.6	11.3

Table C. 22 Average ship speed for three types of ships in the sea area

November														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	7.3	5.2	8.4	7.6	1957	7.9	7.2	4.4	4.4	1957	7.1	4.0	8.7	7.0
1958	7.3	5.2	8.4	7.3	1958	8.1	7.2	4.4	4.3	1958	7.1	4.0	8.7	6.7
1959	7.5	5.2	8.4	7.7	1959	8.2	7.2	4.4	4.2	1959	7.3	4.0	8.7	7.2
1960	7.3	5.2	8.4	7.6	1960	8.0	7.2	4.4	4.1	1960	7.1	4.0	8.7	7.1
1964	7.3	5.2	8.4	7.6	1961	8.0	7.2	4.4	4.4	1964	7.1	4.0	8.7	7.0
1965	7.3	5.2	8.4	7.7	1965	7.9	7.2	4.4	4.1	1965	7.1	4.0	8.7	7.1
1966	7.3	5.2	8.4	7.7	1966	8.0	7.2	4.4	4.1	1966	7.1	4.0	8.7	7.2
1967	7.5	5.2	8.4	7.4	1967	8.5	7.2	4.4	4.4	1967	7.3	4.0	8.7	6.7
1968	7.3	5.2	8.4	7.6	1968	7.9	7.2	4.4	4.1	1968	7.1	4.0	8.7	7.0
1969	7.5	5.2	8.4	7.3	1969	8.5	7.2	4.4	4.3	1969	7.3	4.0	8.7	6.7
1970	8.4	6.2	7.6	8.1	1970	8.7	7.5	7.5	5.5	1970	8.2	5.1	7.1	7.7
1971	9.6	8.6	8.7	9.3	1971	9.9	9.7	7.8	5.4	1971	9.7	8.5	8.5	9.5
1973	9.5	6.0	8.4	7.5	1973	8.9	7.1	4.4	4.4	1973	9.6	6.4	8.7	6.8
1974	8.1	7.2	9.9	7.6	1974	8.8	9.5	10.1	4.4	1974	7.9	6.8	10.3	7.1
1975	9.8	8.6	8.4	7.3	1975	10.4	8.8	4.4	4.3	1975	10.1	8.5	8.7	6.7
1976	7.5	5.2	8.4	7.3	1976	8.8	7.2	4.4	4.3	1976	7.3	4.0	8.7	6.7
1977	7.3	5.2	8.4	9.1	1977	8.2	8.0	7.2	6.8	1977	7.0	4.0	8.4	9.1
1978	7.3	5.2	8.9	9.3	1978	8.3	7.0	8.6	6.6	1978	7.1	4.0	9.2	9.4
1979	7.5	9.5	8.1	8.9	1979	9.2	7.2	8.8	9.1	1979	9.7	9.5	8.0	8.9
1980	8.8	5.1	9.3	8.1	1980	9.1	8.3	7.9	5.1	1980	8.7	3.9	9.3	7.9
1981	8.7	5.8	7.3	8.4	1981	8.8	8.4	9.8	8.6	1981	8.7	4.7	6.9	8.6
1982	9.2	8.4	8.1	10.5	1982	9.7	8.4	8.0	9.1	1982	9.2	8.0	7.8	11.0
1983	9.0	9.2	8.6	7.6	1983	10.0	8.9	6.4	8.0	1983	9.7	9.3	8.9	7.2
1984	9.6	9.3	8.5	10.5	1984	9.7	8.6	9.5	11.9	1984	9.8	9.5	8.5	11.0
1985	9.3	8.4	8.7	8.6	1985	10.6	9.3	7.7	7.3	1985	9.5	8.5	9.0	8.3
1986	8.4	5.8	9.3	9.5	1986	10.2	7.6	8.8	9.5	1986	8.3	4.9	9.4	9.9
1987	9.2	7.6	9.4	8.5	1987	9.7	8.4	7.9	8.4	1987	9.4	7.6	9.4	8.3
1988	9.1	9.1	9.2	9.0	1988	9.5	8.7	9.7	9.0	1988	9.2	9.2	10.0	10.0
1989	8.8	9.5	8.8	9.8	1989	10.6	9.1	9.0	9.8	1989	8.9	9.4	8.8	10.0
1990	8.1	9.0	9.0	11.1	1990	8.3	8.9	9.7	9.6	1990	7.8	9.3	9.1	11.9
Ave.	8.2	6.7	8.6	8.4	Ave.	8.9	8.0	6.7	6.3	Ave.	8.2	6.0	8.7	8.2

Table C. 23 Average ship speed for three types of ships in the sea area

December														
40BC					25BC					50BC				
	Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea		Kara Sea	Laptev Sea	East Siberian Sea	Chukchi Sea
Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed	Year	Ship speed	Ship speed	Ship speed	Ship speed
	knot	knot	knot	knot		knot	knot	knot	knot		knot	knot	knot	knot
1957	6.8	5.3	7.7	6.6	1957	7.2	5.9	6.4	7.0	1957	6.8	6.1	7.9	5.8
1958	7.1	5.0	6.7	6.4	1958	7.7	5.7	6.4	7.2	1958	7.3	8.3	7.0	5.5
1959	7.1	5.0	7.6	6.7	1959	7.5	5.9	6.7	7.4	1959	7.0	8.9	7.7	6.2
1960	7.1	5.0	7.6	6.7	1960	7.5	6.1	6.6	7.7	1960	7.0	8.9	7.7	6.2
1964	6.8	5.5	7.1	6.5	1961	7.5	6.1	6.6	7.7	1964	6.7	6.1	7.2	6.0
1965	6.3	5.3	5.8	6.6	1965	7.1	5.9	5.4	6.7	1965	6.3	8.3	6.1	5.7
1966	6.7	5.4	6.8	6.5	1966	7.3	5.9	6.4	6.6	1966	6.8	7.3	7.1	5.6
1967	6.6	5.1	6.5	6.3	1967	7.1	5.8	7.3	7.0	1967	6.4	7.5	6.8	5.7
1968	6.5	4.8	6.7	6.0	1968	7.0	5.8	6.5	6.3	1968	6.3	8.0	6.7	4.8
1969	6.8	5.1	6.9	6.1	1969	7.5	6.1	5.8	7.3	1969	6.8	6.7	7.3	5.3
1970	7.0	5.5	5.9	7.1	1970	7.9	6.5	5.4	6.7	1970	6.9	6.5	5.6	6.4
1971	7.0	5.9	5.3	7.5	1971	8.2	8.0	6.2	6.5	1971	6.7	6.6	4.9	7.0
1973	7.0	5.8	6.5	6.4	1973	7.2	6.1	5.8	6.8	1973	7.1	8.5	6.6	5.5
1974	6.0	5.5	4.6	6.5	1974	7.6	5.5	5.2	7.2	1974	5.7	5.3	3.5	5.6
1975	6.5	6.7	6.6	6.4	1975	7.6	6.1	7.0	6.5	1975	6.0	6.5	6.7	5.4
1976	6.4	5.2	6.1	6.6	1976	7.1	5.7	6.9	6.3	1976	6.4	7.7	6.2	5.8
1977	7.1	5.2	6.8	7.3	1977	7.5	5.9	6.3	7.3	1977	7.0	5.9	6.4	6.8
1978	6.8	5.3	6.7	6.9	1978	6.8	6.3	6.6	7.2	1978	6.5	7.9	6.8	6.1
1979	8.2	6.0	5.5	6.7	1979	6.8	5.9	6.9	6.4	1979	8.2	6.7	5.5	6.3
1980	7.1	5.7	6.0	5.0	1980	7.6	6.8	6.5	6.7	1980	7.1	7.9	6.0	7.2
1981	7.1	5.3	5.7	7.1	1981	6.8	6.3	5.7	6.8	1981	7.1	7.2	5.3	6.8
1982	6.1	5.8	6.5	8.0	1982	8.2	6.7	6.0	8.4	1982	5.8	5.2	6.5	8.2
1983	6.0	4.8	5.1	5.3	1983	7.5	5.7	5.8	5.4	1983	5.4	8.0	5.2	4.9
1984	7.1	6.8	5.7	8.3	1984	6.5	6.1	6.7	8.8	1984	6.9	6.3	5.5	8.3
1985	7.9	7.3	5.9	7.5	1985	8.2	7.2	4.9	7.0	1985	7.7	7.0	5.9	7.3
1986	6.5	5.6	6.1	7.0	1986	8.0	6.0	5.2	4.6	1986	6.2	7.4	6.0	6.3
1987	7.0	5.4	6.5	6.2	1987	7.7	6.3	4.9	6.1	1987	6.5	4.4	6.5	5.4
1988	5.4	6.7	5.6	7.3	1988	7.3	6.8	6.2	5.7	1988	4.9	6.4	5.4	7.1
1989	5.4	6.6	4.5	4.7	1989	7.9	6.2	4.7	5.2	1989	5.4	6.5	3.7	3.7
1990	7.7	5.2	6.5	6.4	1990	6.8	5.8	5.8	6.8	1990	7.6	8.1	6.6	5.5
Ave.	6.8	5.6	6.3	6.6	Ave.	7.4	6.2	6.1	6.8	Ave.	6.6	7.1	6.2	6.1

Table C.24 Total cost (k$) for 40BC

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1957	1345	1461	1449	1481	1348	1166	1241	1203	1147	1174	1501	1509
1958	1345	1450	1446	1463	1336	1184	1219	1274	1215	1218	1503	1558
1959	1463	1614	1431	1484	1375	1326	1367	1196	1179	1248	1497	1523
1960	1553	1505	1518	1385	1354	1234	1359	1388	1225	1228	1500	1523
1964	1625	1509	1523	1510	1301	1265	1230	1230	1205	1373	1501	1513
1965	1625	1554	1442	1452	1527	1316	1251	1114	1276	1340	1500	1571
1966	1561	1461	1469	1440	1397	1265	1275	1263	1228	1274	1499	1469
1967	1419	1620	1479	1371	1290	1201	1366	1345	1258	1150	1502	1538
1968	1443	1484	1497	1410	1340	1228	1266	1164	1141	1263	1501	1569
1969	1664	1464	1469	1450	1391	1264	1247	1212	1268	1201	1502	1567
1970	1615	1490	1465	1529	1402	1250	1262	1377	1414	1209	1418	1543
1971	1589	1483	1681	1437	1353	1278	1255	1301	1296	1208	1282	1597
1973	1585	1652	1511	1518	1377	1264	1328	1228	1183	1290	1404	1463
1974	1570	1471	1542	1563	1536	1184	1397	1252	1130	1160	1374	1700
1975	1564	1521	1732	1446	1373	1186	1224	1198	1157	1216	1327	1479
1976	1630	1702	1737	1485	1361	1225	1282	1199	1131	1279	1500	1524
1977	1543	1489	1509	1433	1337	1215	1355	1247	1232	1258	1475	1511
1978	1702	1763	1454	1446	1465	1232	1286	1133	1206	1273	1453	1544
1979	1638	1566	1456	1582	1410	1231	1325	1216	1137	1158	1267	1395
1980	1591	1640	1475	1497	1387	1218	1414	1202	1155	1241	1378	1486
1981	1592	1509	1513	1417	1366	1220	1291	1184	1243	1421	1498	1555
1982	1591	1515	1520	1470	1366	1255	1278	1328	1213	1403	1261	1457
1983	1722	1622	1494	1445	1356	1324	1413	1249	1193	1200	1280	1623
1984	1733	1536	1589	1657	1680	1413	1275	1379	1155	1201	1231	1433
1985	1820	1567	1525	1462	1402	1187	1202	1217	1124	1243	1305	1365
1986	1700	1602	1521	1515	1475	1270	1374	1278	1175	1336	1404	1510
1987	1835	1466	1430	1484	1487	1204	1229	1294	1126	1229	1308	1511
1988	1578	1510	1512	1414	1422	1231	1322	1211	1159	1218	1252	1544
1989	1701	1485	1531	1502	1376	1192	1277	1193	1095	1195	1219	1717
1990	1839	1816	1561	1458	1357	1179	1425	1150	1122	1265	1290	1479
Ave.	1606	1551	1516	1473	1398	1240	1301	1241	1193	1249	1398	1526
St.dev.	124	93	79	59	79	54	65	71	67	69	104	74

Table C.25 Total cost (k$) for 25BC

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1957	1437	1482	1373	1457	1301	1110	1227	1116	1059	1183	1538	1432
1958	1437	1447	1374	1375	1245	1050	1272	1192	1018	1223	1537	1425
1959	1381	1452	1331	1335	1249	1113	1316	1099	1003	1132	1544	1424
1960	1357	1444	1463	1382	1243	1137	1207	1086	1050	1138	1546	1432
1961	1396	1380	1457	1368	1261	1147	1150	1147	1091	1192	1536	1432
1965	1449	1430	1424	1303	1432	1169	1177	1026	1052	1120	1546	1462
1966	1449	1438	1529	1359	1273	1137	1187	1123	1064	1184	1546	1391
1967	1444	1446	1363	1405	1251	1132	1112	1079	1082	1137	1530	1397
1968	1418	1464	1501	1475	1359	1143	1268	1132	1060	1102	1547	1390
1969	1469	1391	1406	1377	1284	1144	1178	1057	1048	1194	1531	1423
1970	1384	1414	1466	1434	1399	1227	1177	1206	1032	1182	1356	1437
1971	1414	1378	1389	1414	1281	1151	1139	1181	1089	1156	1263	1324
1973	1425	1464	1348	1302	1293	1081	1186	1129	1104	1318	1517	1398
1974	1369	1494	1490	1353	1304	1108	1279	1096	1051	1112	1263	1514
1975	1331	1376	1573	1411	1250	1155	1120	1091	1022	1052	1434	1408
1976	1431	1486	1519	1364	1247	1165	1133	1106	1051	1188	1530	1391
1977	1425	1435	1381	1407	1248	1112	1135	1078	1048	1183	1369	1421
1978	1374	1484	1357	1420	1272	1177	1237	1060	1103	1173	1327	1418
1979	1576	1348	1453	1322	1261	1104	1238	1104	1015	1144	1152	1394
1980	1504	1370	1487	1374	1352	1157	1125	1095	1161	1194	1285	1328
1981	1483	1486	1427	1337	1277	1115	1265	1100	1157	1193	1175	1464
1982	1510	1465	1361	1435	1314	1123	1151	1092	1084	1129	1188	1322
1983	1398	1425	1424	1466	1370	1247	1242	1085	1093	1118	1228	1417
1984	1423	1424	1385	1377	1331	1139	1102	1126	1049	1137	1139	1456
1985	1547	1449	1454	1460	1240	1164	1159	1084	1125	1140	1183	1371
1986	1510	1492	1503	1448	1326	1126	1078	1042	1030	1222	1192	1528
1987	1403	1466	1436	1334	1250	1141	1115	1071	1097	1134	1204	1466
1988	1344	1531	1466	1327	1307	1148	1182	1068	1063	1114	1133	1402
1989	1560	1499	1476	1390	1287	1113	1171	1074	1043	1131	1121	1534
1990	1525	1419	1486	1393	1243	1150	1163	1029	1029	1111	1217	1469
Ave.	1439	1443	1437	1387	1292	1139	1183	1099	1066	1158	1356	1422
St.dev.	64	44	61	49	50	38	60	43	39	49	166	52

Table C.26 Total cost (k$) for 50BC

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1957	965	1012	1025	1050	966	861	914	892	869	871	1135	1051
1958	965	1043	1025	1047	957	861	901	968	888	851	1137	958
1959	1028	1155	1019	994	1003	983	1001	910	879	930	1130	942
1960	959	1024	1038	990	981	909	1001	947	897	903	1135	942
1964	1089	1018	1081	1093	935	920	889	893	912	1027	1135	1070
1965	1089	1156	1041	1016	1124	866	921	824	877	1008	1134	988
1966	999	1033	1040	1020	1004	928	923	925	941	912	1133	965
1967	1012	1079	1075	978	923	878	1021	1025	911	827	1135	972
1968	1005	1054	1045	999	962	894	927	877	856	931	1135	995
1969	1045	1026	1037	1037	1001	929	905	927	969	873	1135	1057
1970	977	1072	1035	1107	989	912	917	991	1065	902	1094	1083
1971	973	1053	1208	1024	969	942	928	912	995	884	942	1140
1973	1002	1173	1016	1064	985	905	959	933	885	973	993	929
1974	968	1046	1123	1135	1123	872	1054	905	823	851	1035	1299
1975	1157	1050	1266	1056	987	865	892	894	861	889	962	1095
1976	1162	1050	1247	1074	988	898	959	902	827	902	1135	971
1977	1012	1041	1085	1018	960	881	1004	943	942	948	1120	1081
1978	1075	1301	1040	1008	1069	914	955	839	909	938	1093	986
1979	997	1044	1031	1160	1019	897	965	912	859	841	881	979
1980	1157	1038	1039	1050	1001	892	1054	895	860	931	1058	912
1981	1006	1043	1074	1007	980	890	935	896	952	1059	1141	1050
1982	1043	1071	1104	1027	982	901	939	1002	912	944	933	1073
1983	1136	1024	1063	1023	972	984	1035	933	899	886	909	1040
1984	1101	1046	1124	1191	1218	1061	935	1050	864	877	885	1045
1985	1484	1070	1084	1038	1004	875	893	903	847	931	949	988
1986	1198	1036	1083	1096	989	946	1011	947	868	983	1062	1016
1987	1272	1040	1010	1063	1096	881	894	976	837	913	962	1145
1988	1088	1014	1019	1004	1031	903	976	912	842	915	874	1141
1989	1167	1025	1043	1077	1003	872	946	880	799	876	889	1294
1990	1299	1076	1055	1015	993	872	1097	845	828	939	933	934
Ave.	1097	1064	1080	1053	1012	907	959	921	890	921	1025	1048
St.dev.	120	61	67	52	65	42	57	54	61	56	100	98

Appendix D: Results for routing selection simulation

Table D.1 The summary of annual serial voyage simulation (ASVS) for 90% tail

Year			1980	1981	1982	1983	1984
NSR	Number of voyage		8.2	8.0	9.0	8.3	9.8
	Voyage days	day	293	293	329	293	365
	Total cargo tonnage	t	387,000	374,000	421,000	389,000	461,000
	Total cost	k$	8,023	7,966	8,963	8,142	10,045
	Freight cost	$/t	20.7	21.3	21.3	20.9	21.8
SUEZ	Number of voyage		2	2	1	2	0
	Voyage days	day	72	72	36	72	0
	Total cargo tonnage	t	94,000	94,000	47,000	94,000	0
	Total cost	k$	2,111	2,111	1,056	2,111	0
	Freight cost	$/t	22.5	22.5	22.5	22.5	22.5
Total (NSR+SUEZ)	Total cargo tonnage	t	481,000	468,000	468,000	483,000	461,000
	Total cost	k$	10,134	10,077	10,019	10,253	10,045
	Freight cost	$/t	21.1	21.5	21.4	21.2	21.8

Year			1985	1986	1987	1988	1989
NSR	Number of voyage		8.2	9.7	9.2	8.5	10.3
	Voyage days	day	293	365	329	293	365
	Total cargo tonnage	t	384,000	455,000	431,000	399,000	484,000
	Total cost	k$	8,122	9,874	9,008	8,108	9,999
	Freight cost	$/t	21.2	21.7	20.9	20.3	20.7
SUEZ	Number of voyage		2	0	1	2	0
	Voyage days	day	72	0	36	72	0
	Total cargo tonnage	t	94,000	0	47,000	94,000	0
	Total cost	k$	2,111	0	1,056	2,111	0
	Freight cost	$/t	22.5	22.5	22.5	22.5	22.5
Total (NSR+SUEZ)	Total cargo tonnage	t	478,000	455,000	478,000	493,000	484,000
	Total cost	k$	10,233	9,874	10,064	10,219	9,999
	Freight cost	$/t	21.4	21.7	21.1	20.7	20.7

Table D.2 The summary of annual serial voyage simulation (ASVS) for 10% tail

Year			1980	1981	1982	1983	1984
NSR	Number of voyage		8.4	8.2	9.1	8.5	10.1
	Voyage days	day	293	293	329	293	365
	Total cargo tonnage	t	396,000	383,000	429,000	401,000	473,000
	Total cost	k$	8,102	8,035	9,000	8,180	10,151
	Freight cost	$/t	20.5	21.0	21.0	20.4	21.5
SUEZ	Number of voyage		2	2	1	2	0
	Voyage days	day	72	72	36	72	0
	Total cargo tonnage	t	94,000	94,000	47,000	94,000	0
	Total cost	k$	2,111	2,111	1,056	2,111	0
	Freight cost	$/t	22.5	22.5	22.5	22.5	22.5
Total (NSR+SUEZ)	Total cargo tonnage	t	490,000	477,000	476,000	495,000	473,000
	Total cost	k$	10,213	10,146	10,056	10,291	10,151
	Freight cost	$/t	20.8	21.3	21.1	20.8	21.5

Year			1985	1986	1987	1988	1989
NSR	Number of voyage		8.3	9.9	9.4	8.6	10.5
	Voyage days	day	293	365	329	293	365
	Total cargo tonnage	t	392,000	465,000	442,000	403,000	495,000
	Total cost	k$	8,169	9,956	9,101	8,145	10,024
	Freight cost	$/t	20.8	21.4	20.6	20.2	20.3
SUEZ	Number of voyage		2	0	1	2	0
	Voyage days	day	72	0	36	72	0
	Total cargo tonnage	t	94,000	0	47,000	94,000	0
	Total cost	k$	2,111	0	1,056	2,111	0
	Freight cost	$/t	22.5	22.5	22.5	22.5	22.5
Total (NSR+SUEZ)	Total cargo tonnage	t	486,000	465,000	489,000	497,000	495,000
	Total cost	k$	10,280	9,956	10,157	10,256	10,024
	Freight cost	$/t	21.2	21.4	20.8	20.6	20.3

Review

of INSROP discussion paper WP8

"Simulation Based on Year Round and Seasonal Operation Scenarios"
by K. Kamesaki, S. Kishi, Y. Yamauchi, NKK

by Alfred Tunik
ABS, 2 WTC, 106th Floor, New York, NY 10048, USA

February 1999

The discussion paper is the summary report of simulating ship navigation along NSR. It incorporates partial reports of a coordinated 5-year work of seven WPs focused on specific aspects of dada processing, NSR ship design, transit simulations and cost analysis. This fundamental multi-discipline study is to justify the feasibility of NSR cargo transit and to demonstrate the conditions under which the NSR operation can be economically beneficial. The broad multi-discipline character of this report calls for a multi-discipline review of the summary – a task which may exceed the scope of expertise of this reviewr. As a results, some aspects of the report are not reviewed to a level they deserve.

The study is marked by high value and quality which are due to a broad range of factors analyzed, comprehensive data acquisition and processing, and the depth of analytical studies performed on each topic with random simulations, where applicable, of the processes modelled. The authors (both of the WP8 summary and relevant componet WP's) should also be credited for recognizing and attempting to account the fact that ships in reality tend to follow a seemingly easier path when navigating in relatively severe ice conditions.And this study is one of the few recent studies where an attemt is made to quantify this tendency. The authors should also be complemented for attempting to quantify incertain but practically important operational mode - ship transit motion under compression by ice fields.

There are some weaknesses in the report which do not necessarily diminish its value but rather point out to the areas for further improvement. Namely:

1. Fig.2.3.1. presents the specter of exported cargo but does not even mention timber - one of the main export commodity transported almost entirely through northern ports. The reviewer does not have timber export data in tons or currency. However, by the number of ships and by tonnage, timber carriers constitue one of the largest group in the Russian commercial fleet, and market demand for new building of this ship type is not declining and they are being built in Russian shipyards inspite of their current economic hardships.

2. Table 2.4. Open water speed of the ARKTIKA is about 21 knots, not 10.7 – a misprint.

3. Section 2.5, Table 2.5.5 is poorly presented and is hardly understandable without explanations. Relationship between ice regime's numeras on the bottom paragraph on page 2-24and this table is unclear.

4. Section 2.6. The five different types of ice conditions are considered in 2.6.1 in simulating the transit ship speed. Of these, level ice is unlikely to occur in a considerable amount and channel ice (understood here as re-frozen channel) is quite rightly excluded from this simulation. Of the two remaining ice types, pack ice is treated simply as the level ice but with a lower probability of occurance and ridged ice is treated as a number of individual ridges situated perpendicular to the heading. As a result, the simulation is too simplified being reduced to open water, level ice, and perpendicular ridges These ice types should be added by at least two more very important types (1) broken ice floes and (2) narrow leads or fractures, and a distinction should also be made for simulating ship transit behind icebreaker. The simulation should also take a due account for the time wasted when the ship is stuck in ice under compression.

Pack ice as defined in the report indeed constitutes a certain percentage of ice types, but this definition implies relatively large ice floes but does not include so-called broken ice - smaller floes which broken and pushed away by ship, which are frequent over NSR in all seasons especially in summer-fall and which is more appropriate for simulating motion behind an icebreaker.

Narrow leads and fractures always exist in virtually any ice conditions. Although their areal concentration can be negligibly small, their importance may not be ignored since experienced navigators never miss a chance to take advantage of the leads/fractures by-passing severe ice and formidable features. As a result, the route-specific (i.e along the pach of ship) ice conditions are considerably easier than region-specific (average over a rigion) ice condition. Leads, fractures, polynyas and other openings contribute most into this difference. Although this difference was aknowledged in 2.6.4 this was done based on a wrong assumption that ice thickness and concenteration are the main factors in selecting an easier path. The main obstacles to by-pass are usually breccia fields, hammocked ice, embedded multi-year features and so on. And the main features to by-pass throughout are leads, fractures or cracks of any widths, and other openings. When the ship is wider than the fracture or crack, she is moving by further widening the fracture like in a too-narrow channel. Formulations for level ice resistance are not applicable for this mode. Resistanse in broken ice and in widening a channel has been well described by Ryvlin and Kashtelyan (see e.g. Ryvlin & Kheisin. *Tests of Ships in Ice*).

5. Section 2.7. It is unclear why legal assessments are based on an L2 ice class vessels and what correction should be made to ajust it to L1 or higher ice classes.

6. Tables 4.1.2 and 4.1.3. It looks amazing that the freight cost in October is less than that in September.

Box B: Simulation of Ship Navigation along the NSR
WP8: Simulation based on Year round and Seasonal Operation Scenarios

Reply to the reviewer

We appreciate very much Dr.Alfred Tunik's careful review and commentary. Some of the comments indicate a gap between the level of model simulation and limitation of the historical environmental data. In reality, a ship moves on a plane, although a ship moves on a line in our model. In the beginning of the study, we tried to implement a more sophisticated model that enables a course decision looking at spatial distribution of the environmental data. However we realized that we are not at a stage to implement such a detailed analysis. We made an effort to match the level of historical environmental data over an extended period, the ship speed algorithms by means of introducing a concept of ice index and finally, to grasp a trend of cost. Thus, several assumptions were adopted without sufficient verification, but we trust we are able to maintain an acceptable degree of accuracy. We recognize that these comments are well worthy of further study.

The followings are replies for each item.

#Comment 1.

The total export of forest products on the NSR reached 1.3 million tons in 1987 and it comprised 20% of the total cargo flow of 6.6 million tons in the NSR. However the export of timber rapidly decreased in 1993 due to the confusion of the Russian economy, especially high costs for fuel and transportation tariffs imposed on river transport goods. Timber exports to South Korea and Japan in 1997 were less than 100 thousand tons and have not recovered yet. Actual statistics for the timber in 1996 is not listed in the report, although it is estimated in the order of 1 % of the total cargo flow. Detail are referred to in WP 3 report. (Ivanov et al., 1998)

#Comment 2.

We corrected as you pointed out and found it was a misprint. The open water speed of the Arktika class is 21 knots and that figure was used in the simulation.

#Comment 3

Figure 2.5.5 expresses the relation between the navigation speed for SA-15 and the severity of the ice condition. The severity is expressed as a function of multiples of ice concentration and its particular category such as ice free water, gray-white ice, first-year ice, second-year ice and multi-year ice conditions. CASPPR adopted ice numerals that are calculated from ice class and ice conditions. In order to develop the ice numeral, we need the data as depicted in Figure 2.5.5 that shows the ice conditions including ice categories, their ice concentrations and average navigation velocity. Data such as Figure 2.5.5 are useful to verify the relation between ice index and velocities. We attempt to show that these kinds of data shall be collected for verification purposes and try to develop the ice numeral from the actual results. We add an explanation for the relation between ice numeral and data as in Figure 2.5.5.

#Comment 4.

We well recognize the difference between ice conditions along a route and a certain wide area. Our model does not take into account for stuck in ice under compression and we roughly estimated ship speed behind icebreakers. We should have categorized more detailed navigation modes as you pointed out. In this study, we focused on link ice conditions given by the AARI/WP2 and the algorithms developed by WP6. The historical data from the AARI are mainly based on satellite data and their resolution is not sufficient to recognize narrow leads or other small ice features. Even ridge distributions are lacking as we indicated in chapter 2.2. We have to develop probabilistic models to estimate the existence of narrow lead or other ice features that are easy to by-pass in order to fulfill a gap between limited data and the implementation of more detailed simulation. We recognize that the issues you raised are important points to enhance accuracy of the simulation in the future.

#Comment 5
The analysis done by WP7 and the developed ships by WP4 was disjointed as you pointed out. WP7 had conducted their assessment in a much earlier stage than WP4. We pointed out the same issue you raised in the coordination meeting in Feb.1998. WP7 answered that if a ship is designed to meet the regulations applicable to year round to navigation and the navigation is as frequent as assumed in the analysis, the analysis may lead to the same results as implemented by WP7. We are not certain of this assumption, although the risk level from the environmental assessment is not directly reflected in the insurance cost in chapter 2.3.

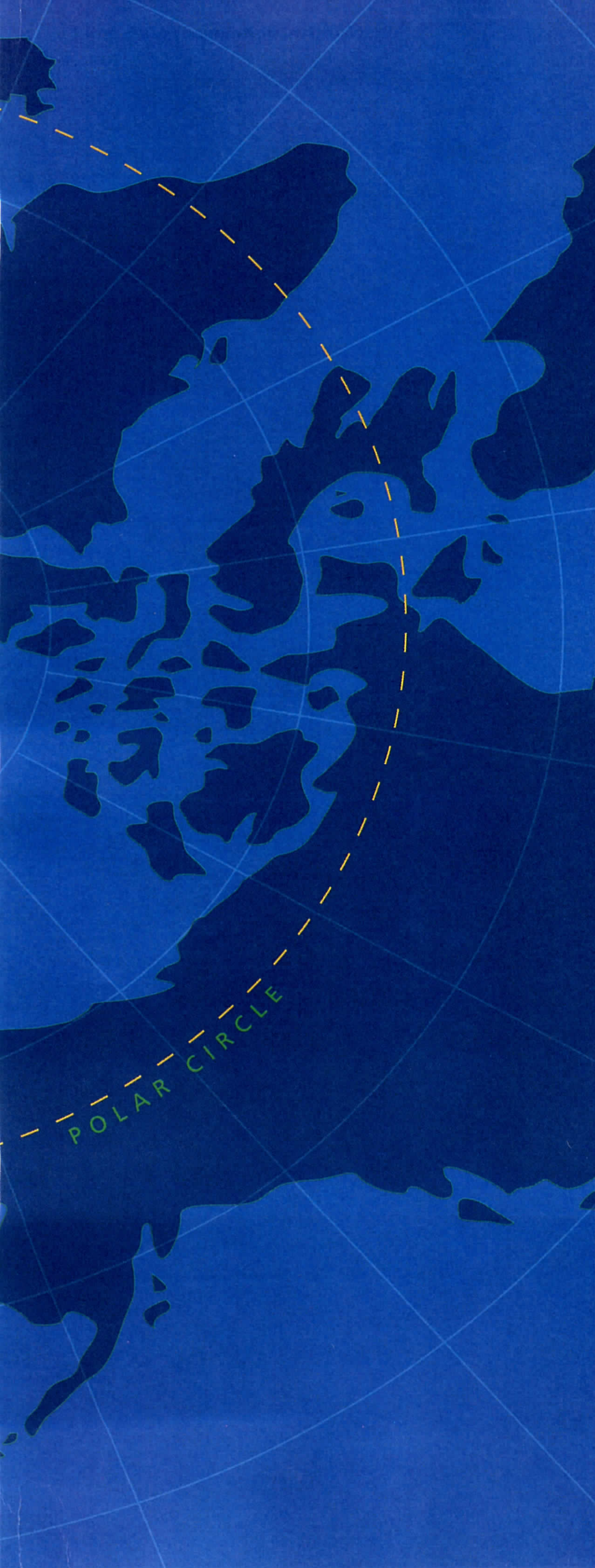
#Comment 6
The cost component and escorted days corresponding to Figure 4.1.2 and Figure 4.1.3 are shown in Table A and Table B respectively. From these figures, it is clear that the difference in fuel cost is the main reason for the fact that freight costs in October are slightly lower than those in September. In September, the ice condition was locally very severe in the vicinity of Mys Archicheskiy Cape, so that the escort icebreaker appeared for about 3 days in that area. Navigation conditions were not so different in other areas of N route. The fuel consumption of the simulated vessel in escorted mode is smaller than the independent voyage mode and is assumed to have a 10% increase in fuel consumption in open water. As a result, the freight cost in October was slightly lower than that in September.

Table A Cost component and escorted days corresponding to Table 4.1.2

	Capital Cost	Operating Cost	Port Fee	Fuel Cost	IB Charge	Total	Escorted Days
	k$	k$	k$	k$	k$	k$	day
Sep.	672	203	67	191	166	1300	5.8
Oct.	670	203	67	144	168	1252	8.7

Table B Cost component and escorted days corresponding to Table 4.1.3

	Capital Cost	Operating Cost	Port Fee	Fuel Cost	IB Charge	Total	Escorted Days
	k$	k$	k$	k$	k$	k$	day
Sep.	672	203	67	191	124	1258	5.8
Oct.	670	203	67	144	127	1211	8.7



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 Sasakawa 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.