Project no. 265863

# ACCESS

## Arctic Climate Change, Economy and Society

Instrument: Collaborative Project
Thematic Priority: Ocean.2010-1 “Quantification of climate change impacts on economic sectors in the Arctic”

# D2.16 – Report presenting results of ICEROUTE calculations of traveling time for different scenarios and routes on NSR and NWSR in past, present, and future

Due date of deliverable: **28/02/2014**

Actual submission date: **28/02/2014**

Used Person/months: 5

Start date of project: **March 1st, 2011** Duration: **48 months**

Organisation name of lead contractor for this deliverable: **HSVA**

| Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013) | | |
|---|---|---|
| **Dissemination Level** | | |
| **PU** | Public | X |
| **PP** | Restricted to other programme participants (including the Commission Services) | |
| **RE** | Restricted to a group specified by the consortium (including the Commission Services) | |
| **CO** | Confidential, only for members of the consortium (including the Commission Services) | |

# Contents

## List of Figures

## List of Tables



**Abrreviations:**

| **Abbreviation** | **Longname** |
|---|---|
| HSVA | The Hamburg ship Model Basin |
| ARCDEV | Arctic Demonstration and Exploratory Voyage |
| NSR | Northern Sea Route |
| NWP | North West Passage |
| RoRo | Roll on Roll off |
| GT | Gross Tonnage |
| Lpp | Length between Perpendiculars |
| LoA | Length over All |
| Low | Length of Waterline |
| AP | Aft Perpendiculum |
| FP | Fore Perpendiculum |
| CV | Container Vessel |

# 1. Introduction

## 7.1 Work Task Description

Task 2.1.6 Calculation of the travelling time needed on the North-East and North-West Passage in the past (1960-2000), present (2000-2010) and in the years to come (HSVA) While traveling in ice infested waters the required actual power is very much depending on the actual ice condition. The conditions can vary from open water to severe ice features resulting in huge difference of time needed per traveled mile. The aim of this task is to (1) analyse the variability of various sea-ice parameters provided by AARI (Task 2.1.1)(terms of ice formations and melting, ice thickness, ice extent, presence and positions of ice massifs, fast ice etc.) for the 20th and the beginning of the 21st century and (2) to develop scenarios of the most probable changes of the ice conditions for the future. The Routing Software, ICEROUTE, developed by the Hamburg Ship Model Basin (HSVA) and verified in different EU funded projects (ARCDEV and ARCOP) will be used to calculate the traveling time needed for a passage in arctic waters from location A to destination B. The model uses data on seaway, ice features (level ice, pressure ridges, rubble fields and pack ice), ice & snow thickness, ice strength and lateral ice pressure. Simulations will be carried out for different ship types optimized for different environmental conditions including, for example, open water, level ice, deformed ice as well as different operation areas and different time horizons. The time horizon covers the past (1960 to 2000), the present (2000 to 2010) as well as future ice data predictions (scenarios). Ship routes to be investigated are the North-East-Passage as well as the North-West-Passage, if information on ice conditions can be provided. Results from this work will be fed into Task 2.4.1 determining atmospheric pollutant emissions [1].

## 7.1 Introduction to Arcitc Transit

Within WP2 Task 2.16 of EU Project ACCESS HSVA has carried out traveling time simulations for different ice scenarios based on ice data for the period 2000 to 2007 using the program ICEROUTE which had been developed throughout earlier research projects. Originally it was planned to simulate the travelling time for different merchant ships on the Northern Sea Route (NSR) and North West Passage but during the project the ice data for the north west passage turned out to be unavailable regarding their availability and uncertainties and therefore the investigations on the transit simulation on the Northern Sea Route were extended.

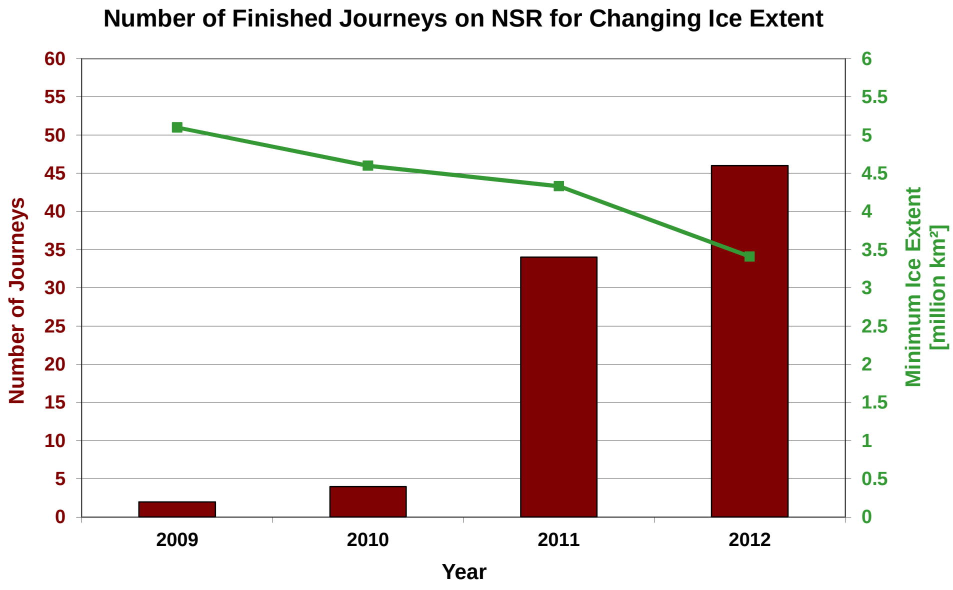


*Figure 1 Transit statistic on Northern Sea Route for the recent years*

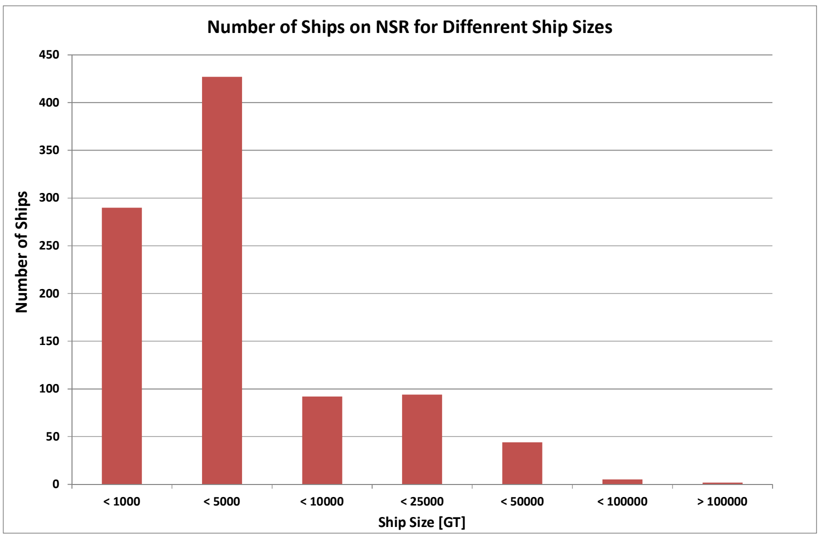


*Figure 2 Transit statistic on Northern Sea Route for 2010*

| Ship Type and Size (GT) | < 1000 | 1000-4999 | 5000-9999 | 10000-24999 | 25000-49999 | 50000-99999 | >100000 | All Sizes |
|---|---|---|---|---|---|---|---|---|
| Oil Tankers | 0 | 19 | 9 | 8 | 7 | 1 | 0 | 44 |
| Chemical / Product Tankers | 1 | 11 | 5 | 9 | 1 | 0 | 0 | 27 |
| Gas Tankers | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Bulk Carrier | 0 | 2 | 1 | 23 | 26 | 0 | 0 | 52 |
| Container Vessel | 0 | 0 | 5 | 7 | 0 | 0 | 0 | 12 |
| General Cargo | 6 | 69 | 19 | 11 | 1 | 0 | 0 | 106 |
| Reefers | 1 | 24 | 13 | 5 | 0 | 0 | 0 | 43 |
| RoRo Vessels | 1 | 1 | 2 | 1 | 0 | 0 | 0 | 5 |
| Passenger | 3 | 13 | 6 | 9 | 8 | 4 | 1 | 44 |
| Offshore Supply | 6 | 18 | 6 | 0 | 0 | 0 | 0 | 30 |
| Other Offshore Vessels | 3 | 1 | 1 | 1 | 0 | 0 | 0 | 6 |
| Other Activities | 110 | 58 | 12 | 19 | 1 | 0 | 0 | 200 |
| Fishing Vessels | 159 | 211 | 13 | 1 | 0 | 0 | 0 | 384 |
| **Sum** | 290 | 427 | 92 | 94 | 44 | 5 | 2 | 954 |

*Table 1 Statistic on different ship types and sizes in arctic waters August to November 2010*

# 1. Description of HSVA Program Ice Route

## 2.1 General description

The program ETA (Estimated Time of Arrival) has been developed at HSVA within the research project ARCDEV in 1998 [2] and is based on semi empirical - analytical formulations for predicting ship resistance in different environmental conditions including ice coverage. Additionally the data of the specific propulsion arrangement are used to calculated the required power and thereby obtain the maximum attainable speed. The routes are subdivided into legs while the number of legs is chosen according to the required spatial resolution with regard to variations in environmental conditions. In a second step the traveling time for the entire route can be determined by summation of travel time for each leg.

## 2.2 Ice Resistance

The focus of the module route is put on the additional resistance in different ice conditions namely concentrations and ice thicknesses. Further single features like ridges are taken into account. The resistance calculation is based on the well established method of Lindqvist [3] subdividing the total resistance in level ice into components with regard to their origin.

$$\mathrm{Rt} = \mathrm{Rc} + \mathrm{Rb} + \mathrm{Rs} + \mathrm{Row} \qquad (1)$$

with:

Rt: Total Resistance

Rb Breaking Resistance (including initial crushing)

Rs Submersion Resistance (including ice hull friction)

Row Open Water Resistance

The ice resistance components are calculated using input data for the ice thickness, strength and density as well as friction coefficient. Additionally the ships ice breaking ability is taken into account by the main dimensions of the ship and characteristic hull shape factors. The final formulation for ice resistance then yields:

$$\mathrm{Rice} = (\mathrm{Rc} + \mathrm{Rb}) \cdot \left(1 + 1.4 \frac{\mathrm{v}}{\sqrt{\mathrm{g} \cdot \mathrm{hice}}}\right) + \mathrm{Rs} \cdot \left(1 + 9.4 \cdot \frac{\mathrm{v}}{\sqrt{\mathrm{g} \cdot \mathrm{L}}}\right) \qquad (2)$$

with:

Rc: Crushing Resistance

Rb: Bending Resistance

Hice: Ice thickness

## 2.3 Calm Water Resistance

For the calm water resistance the program is either able to use either the method of Holtrop-Mennen [4] or Hollenbach [5]. Both methods are generally speaking based on the subdivision of ship resistance into components like wave resistance, viscous resistance and residual resistance.

## 2.4 Additional Resistance in Waves

The additional resistance in waves is calculated empirically using a method of Blume [6] who has carried out parametric model testing campaigns with varying hull shapes.

## 2.5 Wind Resistance

The wind resistance is included using a method according to Blendermann [7] using force coefficients cx calculated from the lateral and frontal wind area above waterline.

$$Rwind = cx \cdot \frac{\rho_A}{2} \cdot va^2 \cdot A_L \qquad (3)$$

with:

cx: Wind force coefficient

$\rho_A$ Density of air

va Wind speed

$A_L$ Lateral wind area above water surface

## 2.6 Shallow Water Effects

The effect of shallow water that might occur in coastal zones or close to islands is taken into account using the well established method of Lackenby [8]. Thereby mainly two effects lead to an increase of resistance resulting in a reduction of attainable speed in shallow waters.

1. different propagation of waves will increase the wave resistance of the ship
2. obstruction of the ship section will increase the local flow velocity below the ship and therefore increase the frictional resistance

The resulting speed reduction may be expressed by:

$$\frac{\delta v}{v} = 0.1242 \cdot \left( \frac{Am}{h^2} - 0.05 \right) + 1 - \left( \tanh \frac{g \cdot h}{v^2} \right)^{1/2}, \frac{Am}{h^2} > 0.05 \qquad (4)$$

with:

| | |
|---|---|
| $\delta v$ | Speed reduction |
| v | Ship speed |
| Am | area of main section |
| H | Water dept |

## 2.7 Calculation of Ship Propulsion Data

For the current simulation the thrust and power were calculated using propeller open water data from model tests at HSVA. Throughout an open water thrust and torque coefficients of a propeller may be determined for different advance coefficients J (ratio of inflow and turning speed).

Advance Coefficient $$J = \frac{va}{n \cdot D} \quad (5)$$

Propeller Thrust: $$T = kT \cdot \rho \cdot n^2 \cdot D^4 \quad (6)$$

Propeller Torque: $$Q = kQ \cdot \rho \cdot n^2 \cdot D^5 \quad (7)$$

Shaft Power: $$Pd = 2 \cdot \pi \cdot Q \cdot n \quad (8)$$

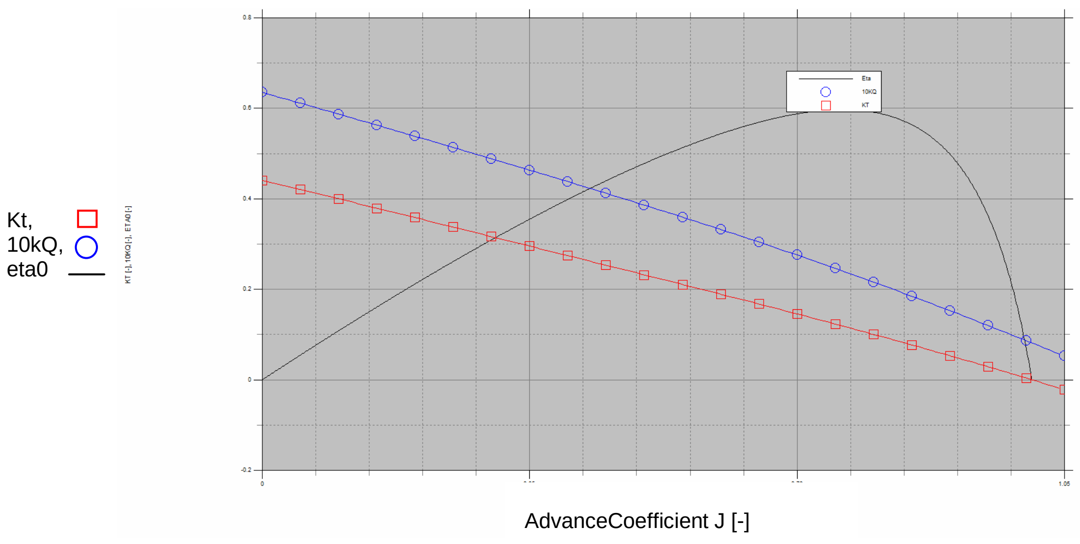


*Figure 3 Open water diagram of typical ice propeller*

# 2. Investigated Scenarios

## 2.1 Route Options

For the transit scenario it was assumed that most of the ships would travel from Europe to East Asia via Northern Sea Route. Therefore the transit route was started from Rotterdam and registration at Murmansk port was taken into account before the ship may enter the NSR. Afterwards four different route options along the NSR are considered (Figure 5 to 8) before the ship has reached Bering Strait and will continue its journey in ice free water to Yokohama.

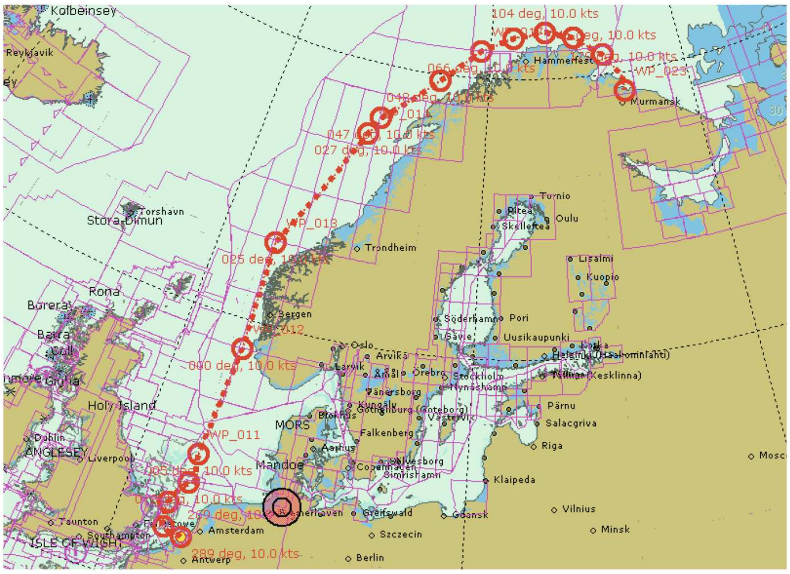


*Figure 4 Route from Rotterdam to Murmansk*


*Figure 5 Route from Bering Strait to Yokohama*

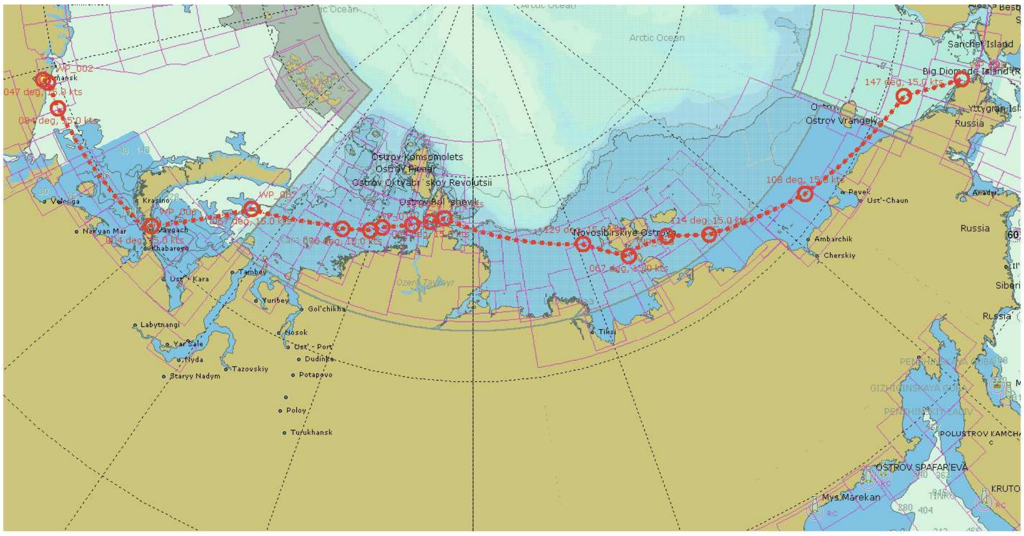


*Figure 6 Route Option 1 along NSR, south of Novaya Zemlya and south of Novo Siberian Islands*

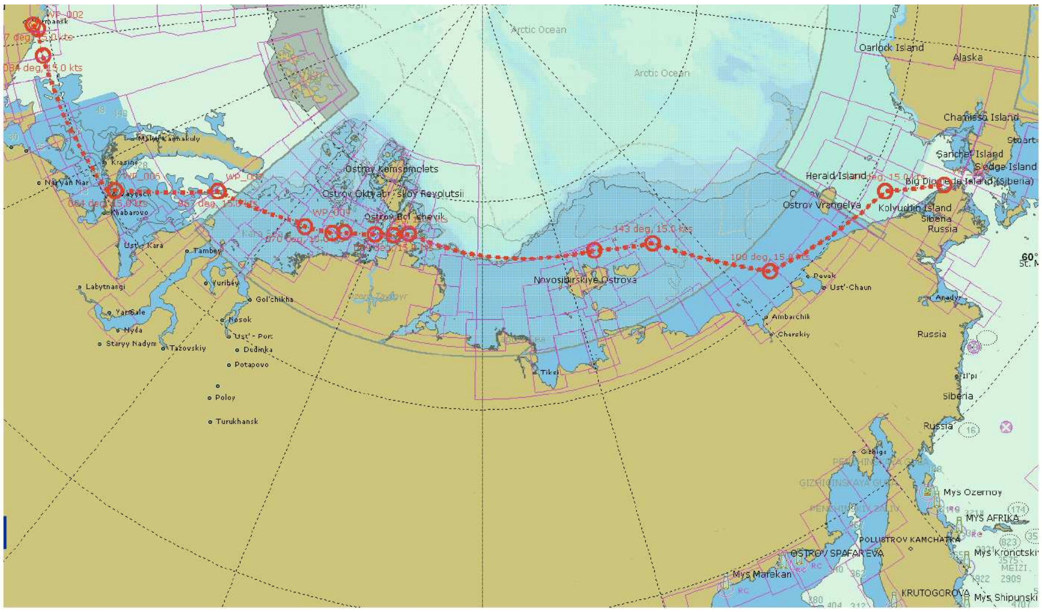


*Figure 7  Route Option 2 along NSR, south of Novaya Zemlya and north of Novo Siberian Islands*

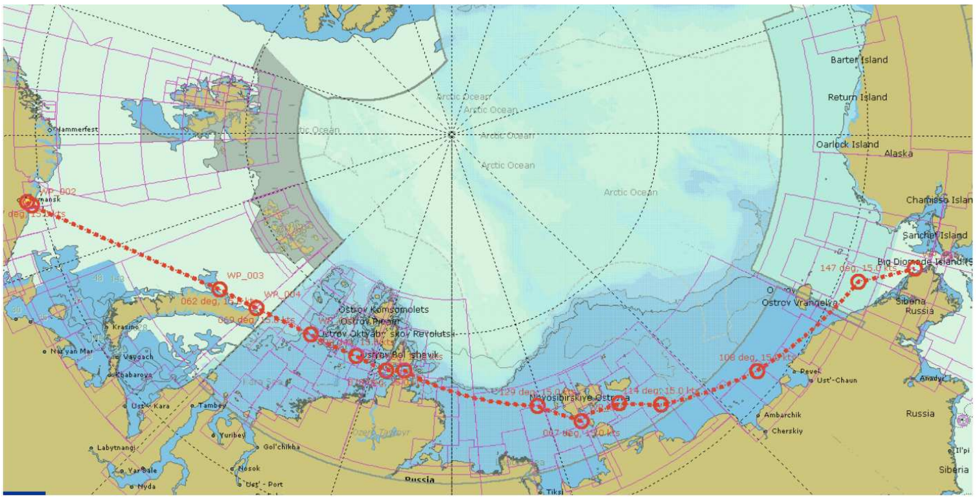

*Figure 8  Route Option 2 along NSR, north of Novaya Zemlya and south of Novo Siberian Island*

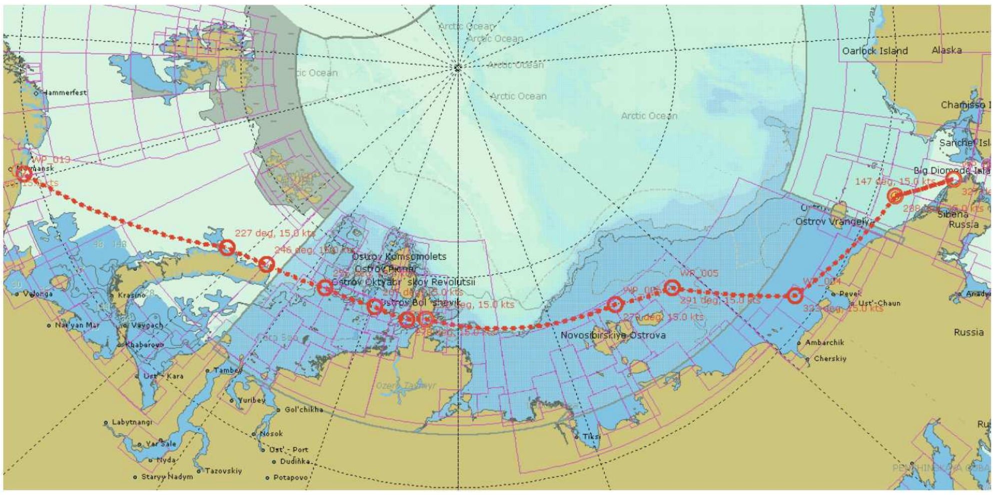

*Figure 9  Route Option 2 along NSR, north of Novaya Zemlya and north of Novo Siberian Islands*

| Route Section | Short label | Distance [nm] |
|---|---|---|
| Rotterdam to Murmansk | romu | 1672.1 |
| NSR Route Option I | 121 | 3017.8 |
| NSR Route Option II | 122 | 2976.9 |
| NSR Route Option III | 123 | 2842.6 |
| NSR Route Option IV | 124 | 2801.8 |
| Bering Strait to Yokohama | by | 2747.1 |
| Average Total Route | | 7329.0 |
| Alternative Suez Route | | 11500 |

**Table 2 Distance of each route section and total distance**

## 2.2 Environmental Input Data

In order to perform transit scenario investigations along the northern sea route, ice data are required at a reasonable spatial and temporal resolution with regard to typical transit speed of cargo ships in these regions. Usually most of the available ice data are collected for purpose of climate investigation and are therefore rather coarse. Local observation data are often restricted to special areas in coastal zones where they are used to assist frequent ship traffic.

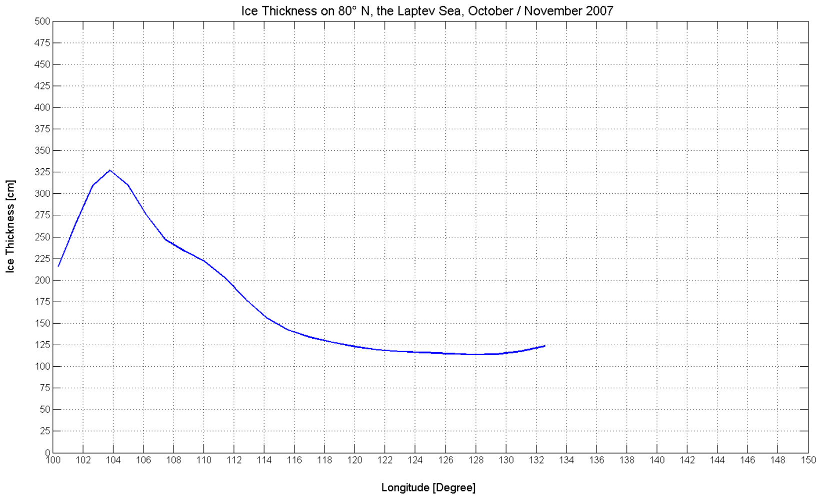


*Figure 10 Example of ice thickness (IceSat) on 80° N, Laptev Sea, October / November 2007 [9]*

For the current investigation the ice data namely ice concentration and thickness should be available at an acceptable resolution in relation to the whole passage along the northern sea route with a travel distance of about 7300 nautical miles. As no sufficient data could be acquired from one source, the ice data for the whole northern Sea Route were manually processed from different grabbing data from different publications of institutions.

Most data were thereby obtained from radarsat charts of US National/Naval Ice Center (Figure 12). The charts include both color code presentation of ice concentration for different areas and Egg Code information on the stage of development of the ice.

Form the ice charts local data were written to route files in which all legs of a route are stored with their main data like starting point and endpoint as well as meta data like ice and environmental parameters (Figure 11).

```
----------Leg005----------------------------------------

Y               / Ice
 500.0           / Bending strength [kN/m**2]
   .00           / Ridge occurance [%]
  .7000          / Ice concentration (0.0 ... 1.0) [-]
     .00         / Floe size [m]
  .0000          / Max. allowed velocity in leg [m/s]
    .0           / Ice pressure [-]
  1.49           / Velocity to emlpoy icebreaker [m/s]
      0.         / Max. delivered power [kW]
N               / Broken channel [-]

  .600    .120    / H_ice H_snow [m]

   .00           / Wind direction [deg]
   .00           / Wind speed [m/s]

   .00           / Current direction [deg]
   .000          / Current velocity [m/s]
 100.00          / Water depth [m]

  69.  55.27     / Start: Latitude [deg,min]
  48.  55.13     / Start: Longitude [deg,min]
  70.    .00     / End: Latitude [deg,min]
  50.    .00     / End: Longitude [deg,min]
```

*Figure 11 Input of leg data within a route file*

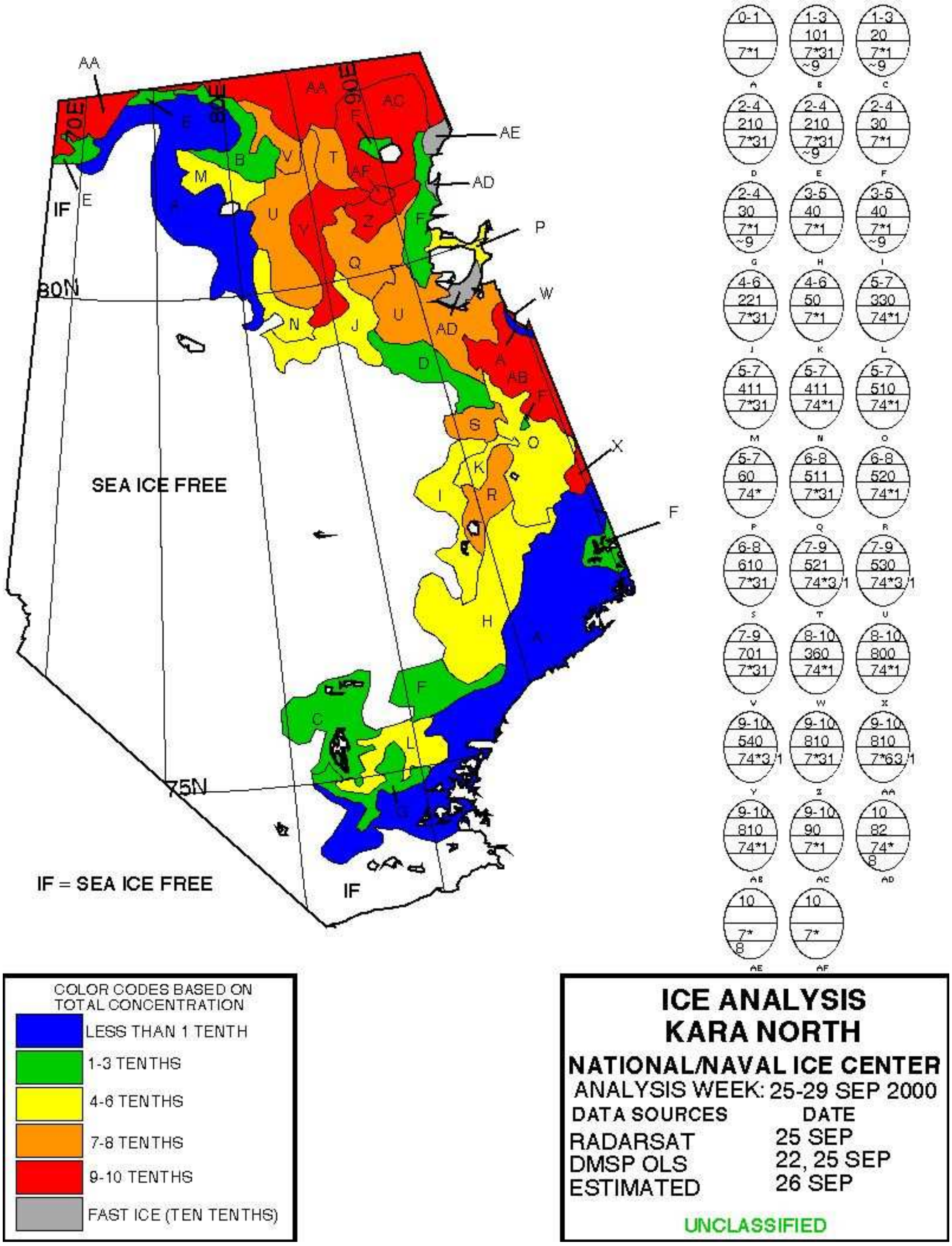


*Figure 12 Ice chart of North Kara Sea, National / Naval Ice Centre 2000 [10]*

## 2.3 Ship Types and Data

In order provide realistic predictions for typical ship types for arctic operation three different ship data models were generated from data that could be obtained from HSVA's data basis. The models differ in their type of ship, main dimensions hull shape and propulsion systems. Therefore the data were chosen such that different results for traveling time could be expected and the extent of required icebreaker assistance should also vary. The data are presented in Table 3, 4 and 5. In order to perform simulations the maximum speed of each ship in light ice conditions is limited to eight knots which represents a safe speed in case of ice floe collision events. Additionally it is assumed that the ships would call for icebreaker assistance if the speed would drop down to a value below 3knots. In this case the program will switch to speed calculation mode in a broken channel behind an icebreaker.

| Input Data | Value | unit |
|---|---|---|
| Lpp[2] | 183.40 | [m] |
| Low[2] | 187.80 | [m] |
| Los[1] | 187.80 | [m] |
| Loa[2] | 189.00 | [m] |
| Beam[2] | 30.00 | [m] |
| Draft AP[2] | 11.50 | [m] |
| Draft FP[2] | 11.50 | [m] |
| Displacement[2] | 43732.00 | [t] |
| Bottom coverage w. ice[1] | 30 | % |
| N° of shafts[2] | 1 | |
| Propeller diameter[1] | 6.00 | [m] |
| Midship section coefficient[1] | 0.990 | |
| Waterline coefficient[1] | 0.900 | |
| LCO, forward 0.5 L[1] | -1.50 | [%Lpp] |
| Lateral area above WL[1] | 660.00 | [m²] |
| Frontal area above WL[1] | 180.00 | [m²] |
| Max. delivered power (open water)[2] | 11931.20 | [kW] |
| Max. delivered power (ice)[1] | 11931.20 | [kW] |
| Max. ships speed (open water)[2] | 13.40 | [kts] |
| Max. ship speed (ice)[1] | 5.00 | [kts] |

*Table 3 Main input data for ice going bulk carrier [11]*

| Input Data | Value | unit |
|---|---|---|
| Lpp[3] | 160.00 | [m] |
| Low[3] | 162.40 | [m] |
| Los[3] | 162.40 | [m] |
| Loa[4] | 177.75 | [m] |
| Beam[4] | 28.00 | [m] |
| Draft AP[4] | 11.00 | [m] |
| Draft FP[4] | 11.00 | [m] |
| Displacement[4] | 32200.00 | [t] |
| Bottom coverage w. ice[3] | 30 | % |
| N° of shafts[3] | 1 | |
| Propeller diameter[3] | 7.00 | [m] |
| Midship section coefficient[3] | 0.990 | |
| Waterline coefficient[3] | 0.900 | |
| LCO, forward 0.5 L[3] | -1.50 | [%Lpp] |
| Lateral area above WL[3] | 660.00 | [m²] |
| Frontal area above WL[3] | 180.00 | [m²] |
| Max. delivered power (open water)[3] | 12000.00 | [kW] |
| Max. delivered power (ice)[3] | 12000.00 | [kW] |
| Max. ships speed (open water)[4] | 15.10 | [kts] |
| Max. ship speed (ice)[3] | 5.00 | [kts] |

*Table 4  Main input data for ice going tanker [11]*

It should be mentioned that then northern sea route is currently mainly frequented by bulk carries and tankers as the container vessels are approaching several different ports on the way from east Asia to Europe. In the simulation the containership has been modelled to include a scenario of a further developed area along the NSR which would be a motivation for container shipping companies to use this route. The container vessel was therefore be assumed to have higher icebreaking capability than the tanker and bulk carrier as travel time is of major concern.

| Input Data | Value | unit |
|---|---|---|
| Lpp[6] | 134.96 | [m] |
| Low[5] | 136.98 | [m] |
| Los[5] | 136.98 | [m] |
| Loa[5] | 142.95 | [m] |
| Beam[6] | 18.90 | [m] |
| Draft AP[6] | 7.90 | [m] |
| Draft FP[6] | 7.90 | [m] |
| Displacement[6] | 12000.00 | [t] |
| Bottom coverage w. ice[5] | 30 | % |
| N° of shafts[6] | 1 | |
| Propeller diameter[5] | 5.00 | [m] |
| Midship section coefficient[5] | 0.990 | |
| Waterline coefficient[5] | 0.900 | |
| LCO, forward 0.5 L[5] | -1.50 | [%Lpp] |
| Lateral area above WL[5] | 660.00 | [m²] |
| Frontal area above WL[5] | 180.00 | [m²] |
| Max. delivered power (open water)[6] | 6000.00 | [kW] |
| Max. delivered power (ice)[5] | 6000.00 | [kW] |
| Max. ships speed (open water)[6] | 15.50 | [kts] |
| Max. ship speed (ice)[5] | 7.00 | [kts] |

*Table 5 Main input data of icegoing container vessel [11]*

# 3. Presentation of Results

| Route | traveling-time [days:hours:minutes] | | distance [nm] | expected ice conditions | | | |
|---|---|---|---|---|---|---|---|
| | | | | winter | | summer | |
| | winter | summer | | yes | no | yes | no |
| Rotterdam to Murmansk (A1.1) | 04:23:27 | 04:23:27 | 1672.08 | | • | | • |
| Murmansk to Bering Strait via Kara Gate and sailing south of Novosiberian Island (A1.2.1) | 42:18:23 | 08:23:37 | 3017.76 | • | | • | |
| Murmansk to Bering Strait via Kara Gate and sailing north of Novosiberian Island (A1.2.2) | 40:21:43 | 08:20:42 | 2976.94 | • | | • | |
| Murmansk to Bering Strait sailing west of Novaya Zemlya and south of Novosiberian Island (A1.2.3) | 32:09:10 | 08:11:06 | 2842.60 | • | | • | |
| Murmansk to Bering Strait sailing west of Novaya Zemlya and north of Novosiberian Island (A1.2.4) | 28:20:06 | 08:08:11 | 2801.78 | • | | • | |
| Murmansk to Bering Strait via North-Pole (A1.2.5) | 648:03:21* | 219:13:02 | 2639.47 | • | | • | |
| Bering Strait to Yokohama (A1.3) | 12:09:19 | 08:04:17 | 2747.14 | • | | | • |
| Suez route via English Channel, Biscay, Mediterranean, Red Sea. Indian Ocean, Malacca Strait, South- and East-China Sea | ≈ 32 days | ≈ 32 days | ≈ 11500 | | • | | • |

*Table 6 Results for traveling time of bulk carrier along different route options along NSR and along Suez Route*

| Route | traveling-time [days:hours:minutes] | | distance [nm] | expected ice conditions | | | |
|---|---|---|---|---|---|---|---|
| | | | | winter | | summer | |
| | winter | summer | | yes | no | yes | no |
| Rotterdam to Murmansk (A1.1) | 04:14:41 | 04:14:41 | 1672.08 | | • | | • |
| Murmansk to Bering Strait via Kara Gate and sailing south of Novosiberian Island (A1.2.1) | 306:07:25 | 08:07:48 | 3017.76 | • | | • | |
| Murmansk to Bering Strait via Kara Gate and sailing north of Novosiberian Island (A1.2.2) | 296:04:36 | 08:05:06 | 2976.94 | • | | • | |
| Murmansk to Bering Strait sailing west of Novaya Zemlya and south of Novosiberian Island (A1.2.3) | 194:07:25 | 07:20:12 | 2842.60 | • | | • | |
| Murmansk to Bering Strait sailing west of Novaya Zemlya and north of Novosiberian Island (A1.2.4) | 144:03:40 | 07:17:30 | 2801.78 | • | | • | |
| Murmansk to Bering Strait via North-Pole (A1.2.5) | 703:20:49* | 246:22:32 | 2639.47 | • | | • | |
| Bering Strait to Yokohama (A1.3) | 18:09:34 | 07:13:53 | 2747.14 | | • | | • |
| Suez route via English Channel, Biscay, Mediterranean, Red Sea. Indian Ocean, Malacca Strait, South- and East-China Sea | ≈ 32 days | ≈ 32 days | ≈ 11500 | | • | | • |

*Table 7 Results for traveling time of tanker along different route options along NSR and along Suez Route*

| Route | traveling-time [days:hours:minutes] | | distance [nm] | expected ice conditions | | | |
|---|---|---|---|---|---|---|---|
| | | | | winter | | summer | |
| | winter | summer | | yes | no | yes | no |
| Rotterdam to Murmansk (A1.1) | 04:11:55 | 04:11:55 | 1672.08 | | • | | • |
| Murmansk to Bering Strait via Kara Gate and sailing south of Novosiberian Island (A1.2.1) | 11:06:23 | 08:02:47 | 3017.76 | • | | • | |
| Murmansk to Bering Strait via Kara Gate and sailing north of Novosiberian Island (A1.2.2) | 11:01:37 | 08:00:09 | 2976.94 | • | | • | |
| Murmansk to Bering Strait sailing west of Novaya Zemlya and south of Novosiberian Island (A1.2.3) | 09:23:43 | 07:15:29 | 2842.60 | • | | • | |
| Murmansk to Bering Strait sailing west of Novaya Zemlya and north of Novosiberian Island (A1.2.4) | 09:14:48 | 07:12:51 | 2801.78 | • | | • | |
| Murmansk to Bering Strait via North-Pole (A1.2.5) | 19:05:02 | 13:03:50 | 2639.47 | • | | • | |
| Bering Strait to Yokohama (A1.3) | 08:20:11 | 07:09:19 | 2747.14 | | • | | • |
| Suez route via English Channel, Biscay, Mediterranean, Red Sea. Indian Ocean, Malacca Strait, South- and East-China Sea | ≈ 32d | ≈ 32d | ≈ 11500 | | • | | • |

*Table 8 Results for traveling time of tanker along different route options along NSR and along Suez Route*

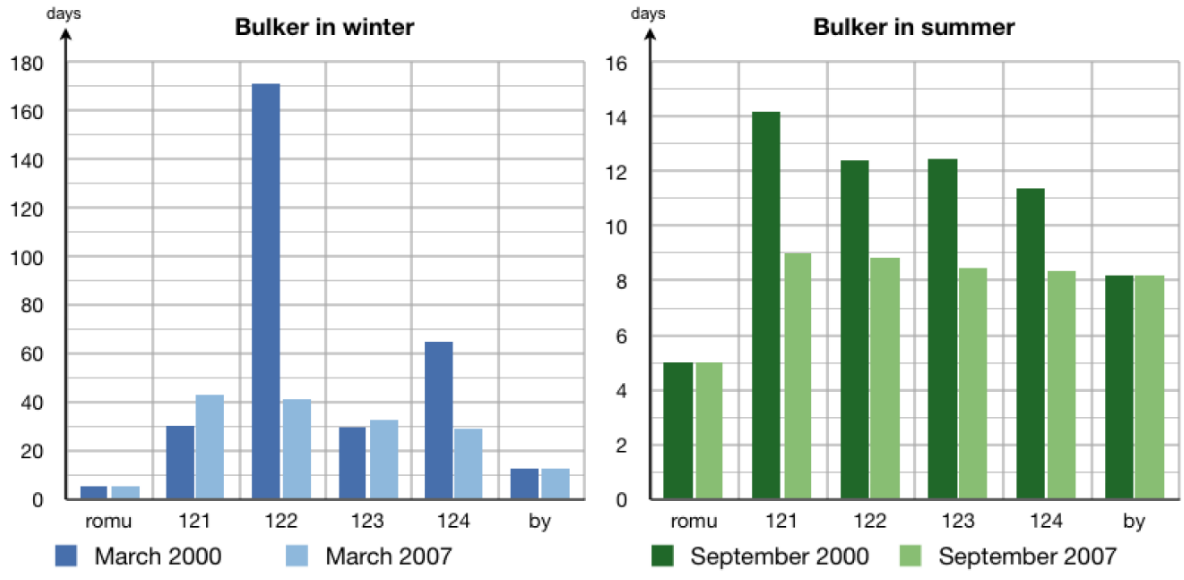


*Figure 13 Travel time of bulk carrier in March and September 2000 and 2007*

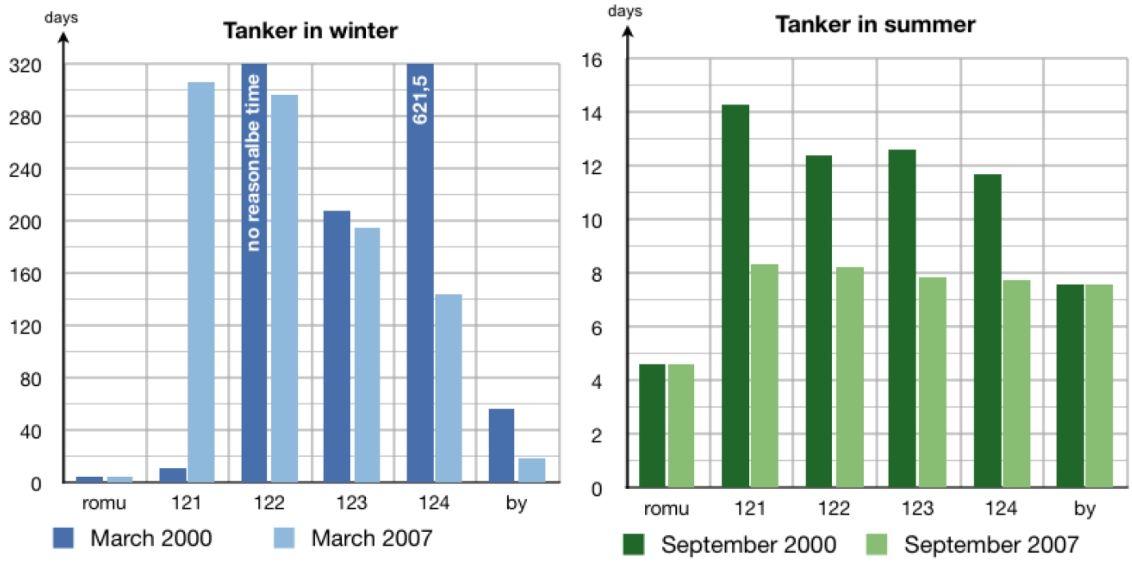


*Figure 14 Travel time of tanker in March and September 2000 and 2007*

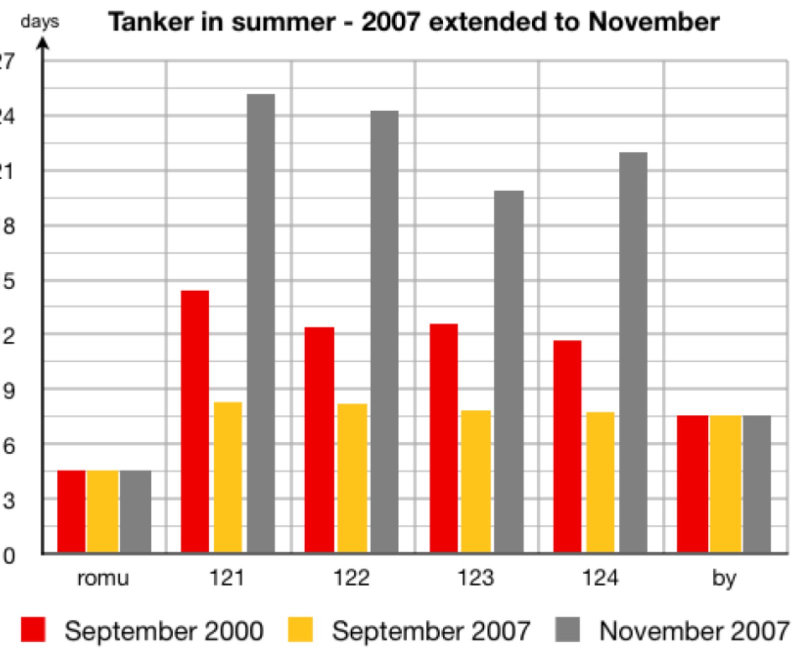


*Figure 15 Travel time of tanker in September 2000 and September + November 2000 and 2007*

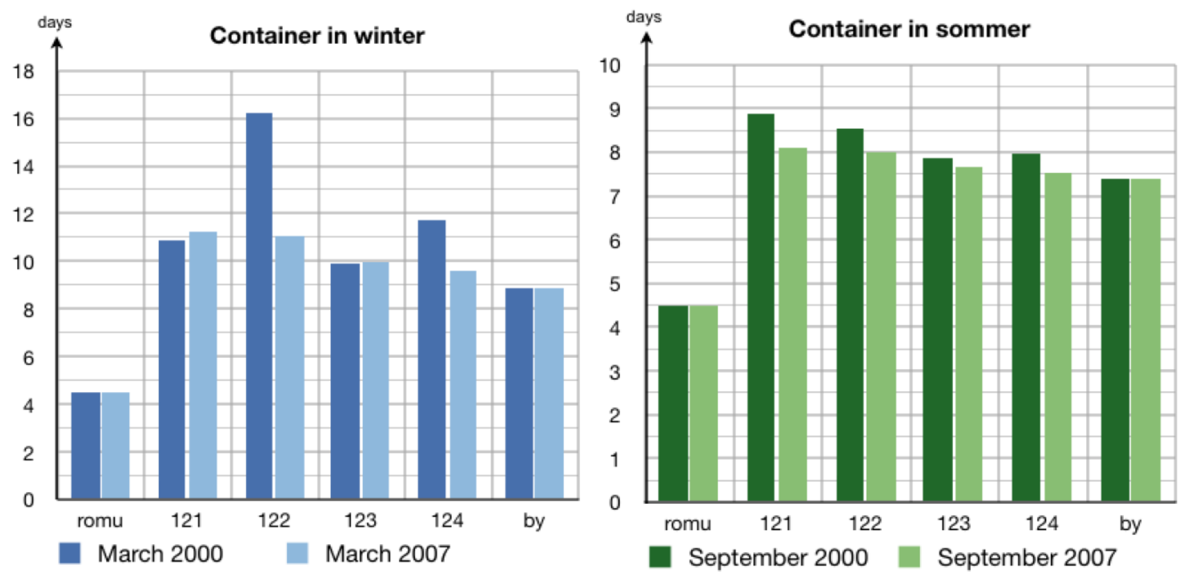


*Figure 16 Travel time of cv in March and September 2000 and 2007*

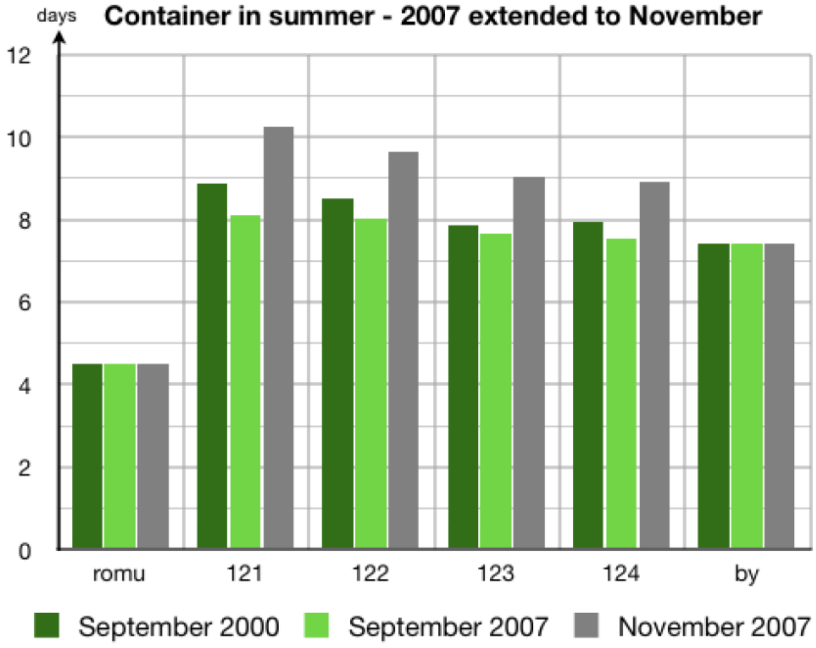


*Figure 17 Travel time of cv in September 2000 and September + November 2000 and 2007*

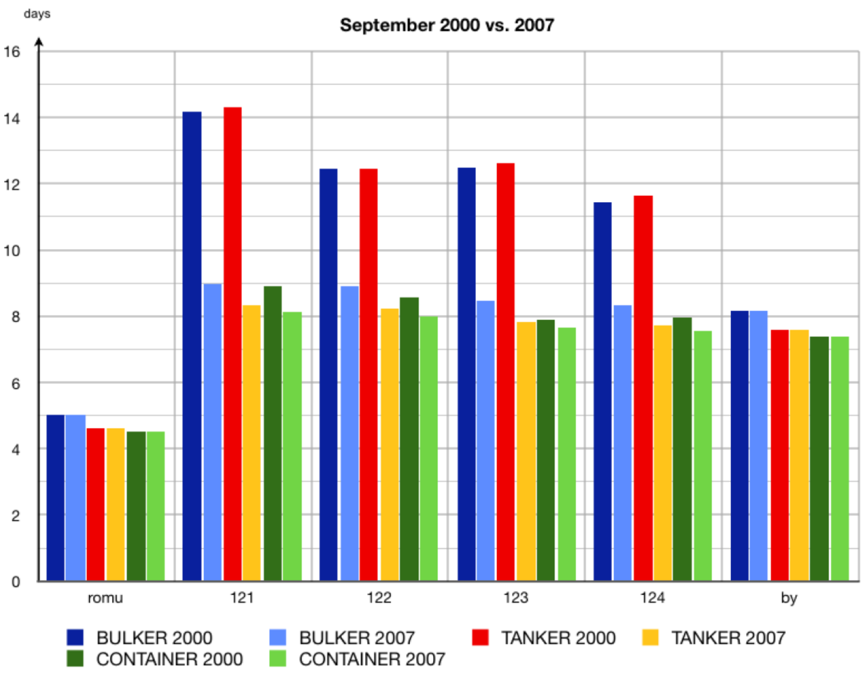


*Figure 18 Travel time of all ship types in September 2000 and September + November 2000 and 2007*

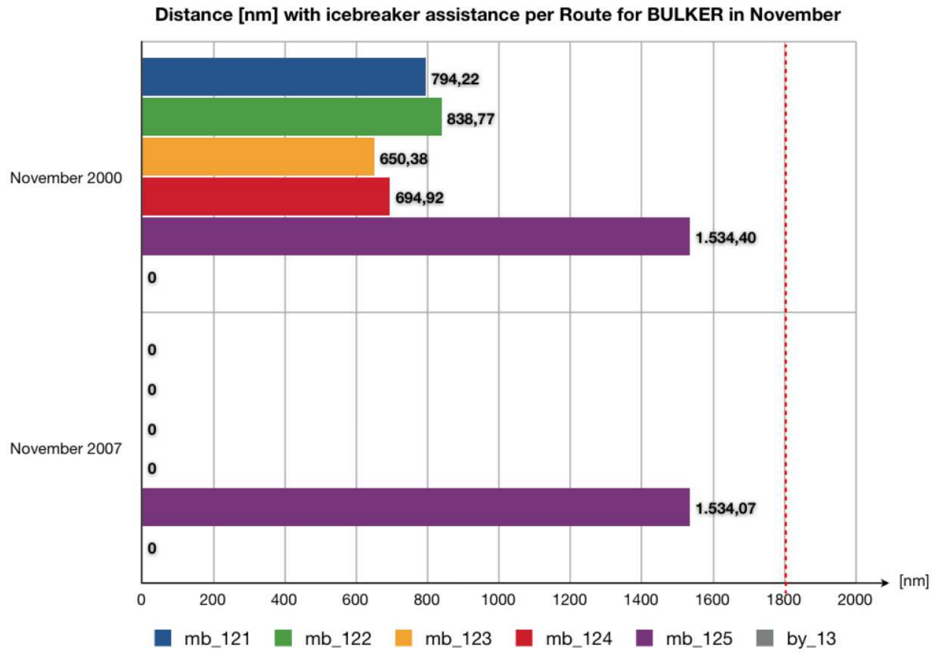


*Figure 19 Total distance with required icebreaker assistance for bulk carrier in November 2000 / 2007*

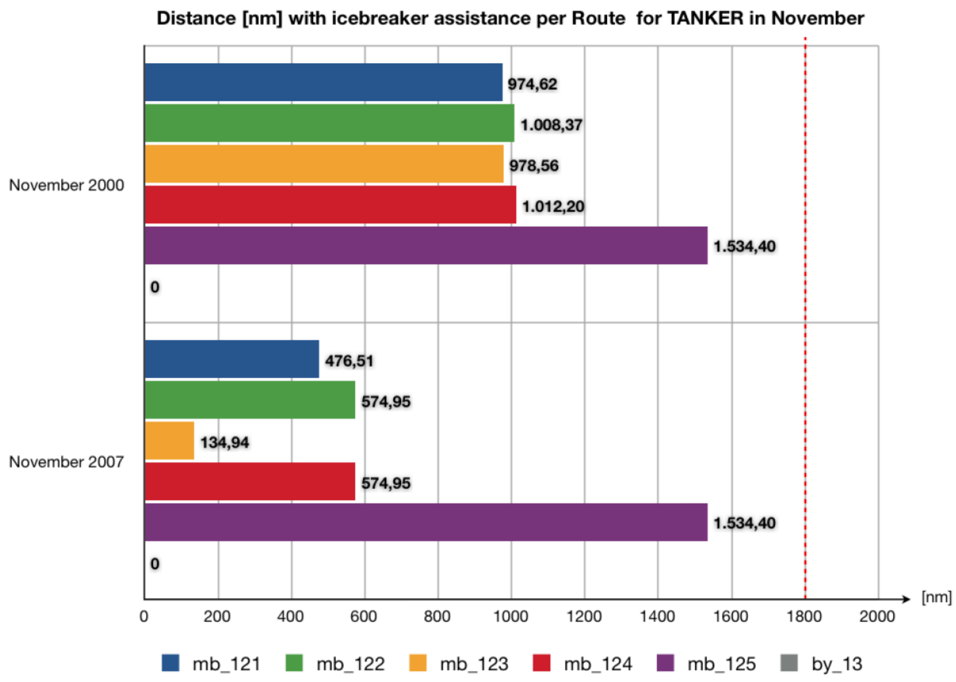


*Figure 20 Total distance with required icebreaker assistance for tanker in November 2000 / 2007*

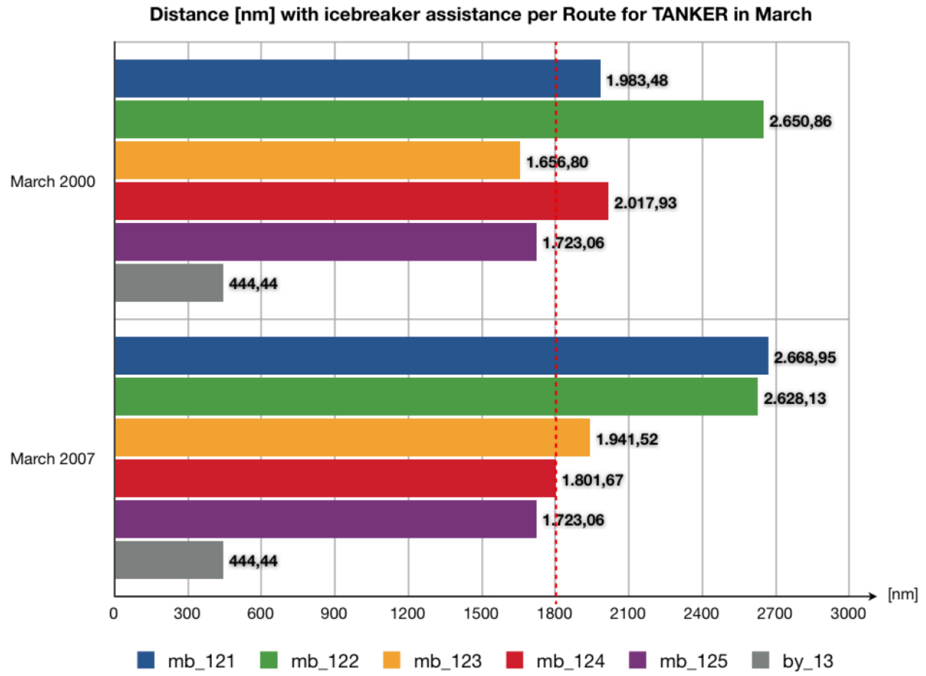


*Figure 21 Total distance with required icebreaker assistance for tanker in March 2000 / 2007*

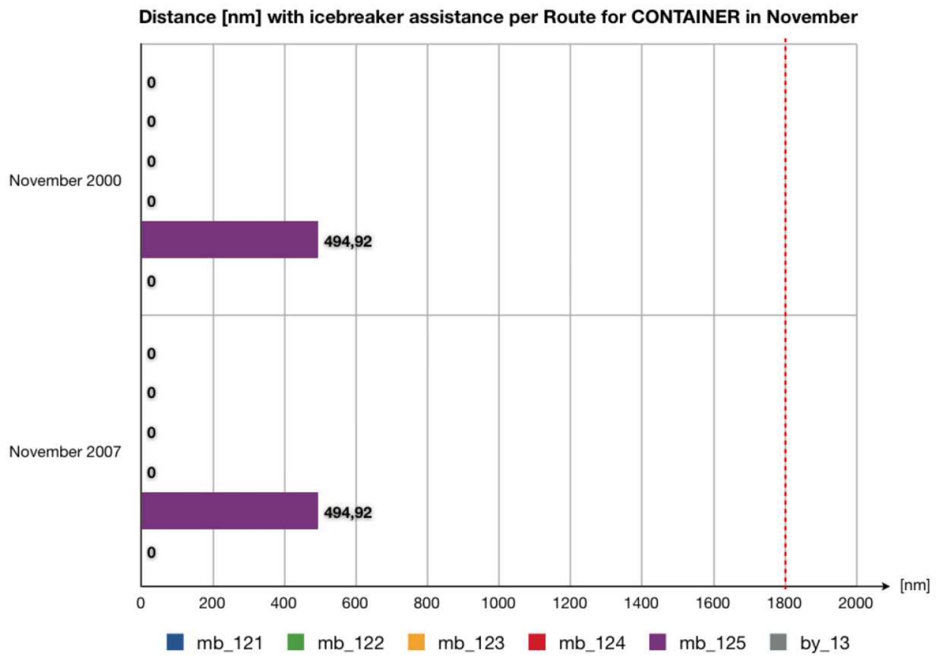


*Figure 22 Total distance with required icebreaker assistance for cv in March 2000 / 2007*

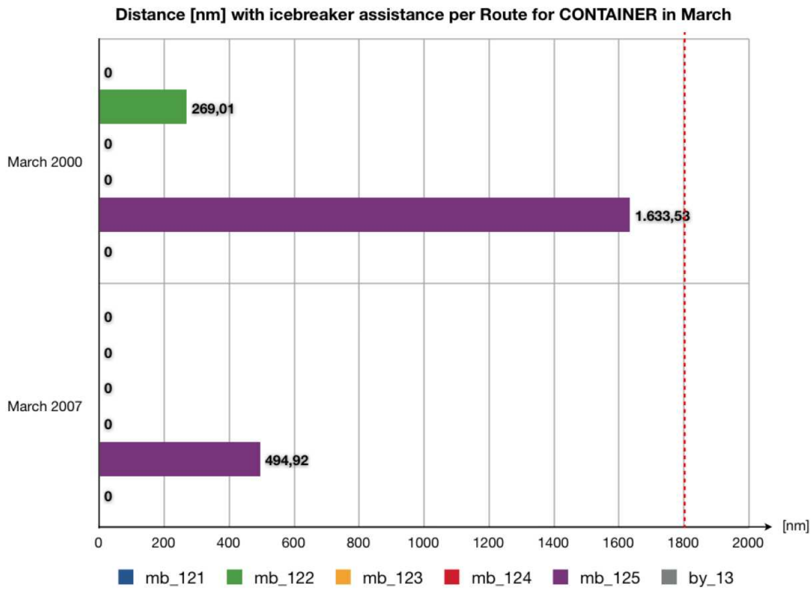


*Figure 23 Total distance with required icebreaker assistance for cv in March 2000 / 2007*

# 4. Evaluation of Traveling Time Simulation

The single methods used within the transit simulation specially the modules for resistance calculation in various ice conditions are mainly based on empiric data obtained in The Hamburg Ship Model Basin. Unfortunately only few validation data of ships travelling through ice are available as currently most of the cargo ships are travelling in September and therefore encounter only very light ice conditions. Additionally the cargo ships are guided by Russian icebreakers which would assist in case of increased ice conditions. The travel time in ice free of about 8 to 9 days calculated by the program corresponds well with the published speed record on Northern Sea Route.

Comparing the years 2000 and 2007 it is obvious that in most cases the travel time is much higher in the year 2000 with values up to four times higher in March. Still for some route options the travel time in 2007 shows the same magnitude which leads to the conclusion that the winter ice extend and quality is still comparable.

Coming to the results of September the decreasing trend in travel time is more obvious for all route options and ship types. As the minimum ice extend in 2007 is lower compared to the ice situation in September 2000 the largest decrease in travel time is determined on the southern route option no. 121. When summing up the total required travel time from Rotterdam to Yokohama it can be seen that already in the year 2000 the values are close to the alternative Suez Route travel time and that in September 2007 eight to ten days of travel time could be theoretically saved by all three ship types.

As the travel time turned out to be very low in September 2007 further calculations for November 2007 were carried out to investigate whether this period would till offer reasonable transit options. The results show that for the container vessel with the highest icebreaking capability the travel time increased only slightly compared to September and therefore the overall travel time achieved acceptable values.

Finally the results for the required distance with icebreaker assistance show clearly that autonomous transit can be extended to the freeze up period in the year 2007 compared to the year 2000. The distance for the bulk carrier even drops down to zero and the values for the tanker being the weakest icebreaking ship model in this simulation at least halve.

# 5. Conclusions and Future Prospects

The results of the performed transit simulations show a clear trend of decreased traveling time for all ship types caused by a decrease in ice extent and volume in the past decade. Further it can be seen that in recent years (2007 and thereafter) operation window for cargo transit shipping can be extended to the freeze up period (October, November). As ECMWF data could be provided by our partner AWI recently, the period for calculation could be extended to years in between 1950 and 2040. The data resolution is rather coarse and only monthly average data are available, but still the data could be useful to investigate possible long term trends in arctic shipping with special focus on NSR. Therefore it is proposed to perform additional calculations for transit time to show long term trends and potential increase of shipping. Special focus shall thereby be put on the length of possible transit period within each year in different decades.  It is therefore proposed to provide the results of these calculations in a supplement.

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