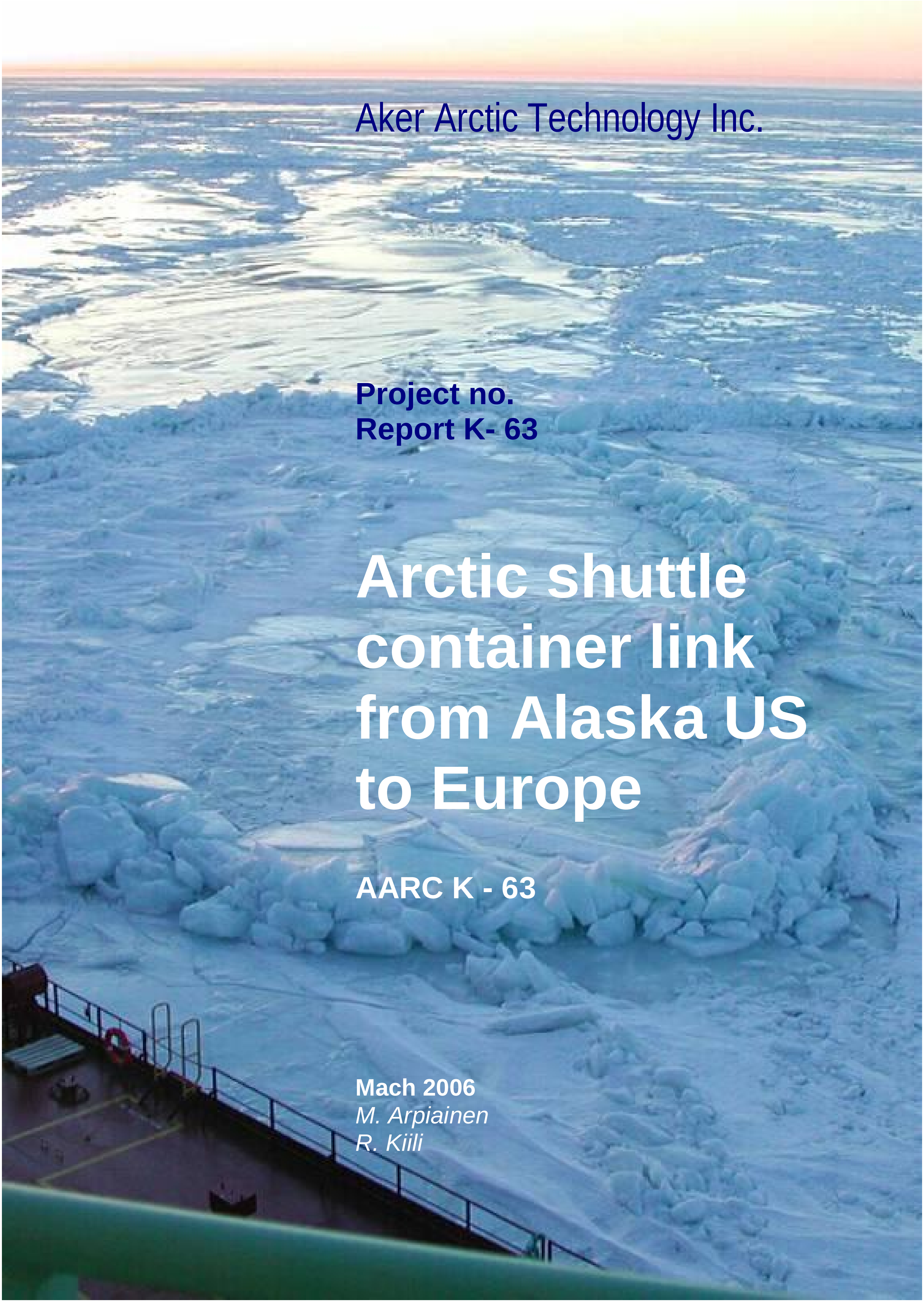

Aker Arctic Technology Inc.

Project no.
Report K- 63

Arctic shuttle container link from Alaska US to Europe

AARC K - 63

Mach 2006

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1. Background

In December 2005 the Institute of North, Alaska, contracted Aker Arctic Technology to perform a prefeasibility study to examine and evaluate the technological and economical aspects of possibility to establish a container traffic link between Aleutian Islands and Europe using the Northern Sea Route. Such a link would allow cargoes bound in either direction in trans-Pacific and trans-Atlantic trade to transship to the other ocean in the most direct manner. The study is done using the ice operation simulation programme developed by AARC. For the study two Arctic container vessel preliminary designs were developed with adequate definition in order to estimate their performance in the Arctic ice conditions and costs based on capital investment and operational expenditures.

The nominal sizes of the vessels were predetermined to be 750 TEU and 5000 TEU. The simulation has been done for two different kinds of years, ‘average winter’ and ‘severe winter’ for both vessels. The former is based on an Arctic container vessel taken into operation in 2006, as a today’s state of the art, and the latter represents a vision for a target vessel, as a future solution.

2. Arctic Container Vessel Designs

2.1 General

The two Arctic container vessel designs to be used for the simulation were developed according to the following philosophy:

As a basis the only existing example of Arctic container vessels was selected. This vessel is the ‘Norilskiy Nickel’ which has been delivered in spring 2006 for the year round transport of the products of the Norilsk mining company from Dudinka harbour to Murmansk independent of icebreaker assistance. ‘Norilskiy Nickel’ is a modern icebreaking cargo vessel applying the Double Acting Concept, of 650 TEU nominal container capacity. For the study the capacity has been upgraded to some extent, and some other modifications have also been included to adjust her to the trans-Arctic traffic.

On the upper end, the 5000 TEU design is a geometrically similar model of the ‘Norilskiy Nickel’, the stern modified for twin podded azimuthing thruster propulsion of maximum realistic size. This power of the propulsion puts her well in the ‘nuclear icebreaker category’ when the ice performance is considered. The size of the 5000 TEU design, especially the consequent large draft abandons her from the coastal route which has traditionally been used for the Northern Sea Route passages which means that she has normally to cross through the Arctic polar pack ice on the more northern route. Consequently her power, performance and ice strengthening have to be designed according to those more difficult ice conditions.

Both designs are presented and discussed in the following chapters.

2.2 Double Acting Operation Principle

Because the Double Acting Operation is quite new technology, a complex one, composed of details not usual for the traditional icebreaking vessels, and somehow in contradiction to the traditional way of thinking and experience, a short description of it is given here adjusted to this special application for trans-Arctic cargo vessels.

The Double Acting Operation principle has evolved during the last 15 years for improving the efficiency of the icebreaking vessels both in ice and open water conditions. Basically the question is of the efficiency and performance of bow propellers for ice operation which has been known for over 100 years, and has been often used for icebreakers and double ended ferries.

The double ended ferries have ‘the bow propeller effect’ by inheritance because they have propeller in both ends, and in fact the ‘ice-efficiency’ of bow propellers was first detected on them. Later on, bow propellers were intentionally installed on icebreakers for enhancing their ice capability. The efficiency of bow propellers is mainly due to their capability to flush the fore part of the hull plating with their propeller streams, which effectively reduces the ice resistance.

However, bow propellers are of lower hydrodynamic efficiency, on Arctic icebreakers they were soon experienced vulnerable in Arctic ice, and modern non-Arctic icebreakers have given up bow propellers due to their high cost.

Development of the ice capable azimuthing thrusters for icebreaker propulsion, in late 80’s, brought back the ‘bow propeller’ on the stage, now installed in the stern of the vessel , and using the stern as a ‘bow’ in the reverse ‘Double Acting’ operation mode. This way of operation has been used in extreme ice conditions by traditional icebreakers without bow propellers, which have been able to reverse in very difficult ice rubbles when the ahead operation has already become ineffective or impossible. However, the ‘Double Acting Stern’ has many advantages compared to the traditional icebreaker stern in this operation mode, or traditional bow with bow propellers, which make it multifold more effective especially in the most difficult ice conditions, ice ridges, deep rubble fields, etc.: the ‘Double Acting stern’ has no rudder or rudders in front of the propellers to impede the progress, and the azimuthing movement of the thrusters make the reversing steerable, and reach out the ice crushing effect of the propellers over a long width range, simultaneously enlarging the flushing effect both on the hull surfaces, and beyond that, even to and over the surrounding ice formations. Moreover, the very powerful steering effect of the azimuthing thrusters makes the whole stern of the vessel to swing back and forth, so that the propellers and the stern are able to create a path through the ice massives that is wider than the hull of the vessel.

The fair ice capabilities of the Double Acting Operation in astern mode allows to design the bow to be suitable for other preferences than icebreaking because the icebreaking can be done by the stern. For many vessels which often or mainly travel in open water, an efficient open water bow form with bulb can be used, which greatly enhance the efficiency and economy of operation in open water. This is not of importance if the vessel is not cruising very much in open water, which is the case for the Arctic shuttle container vessels. Consequently they have a high-efficient icebreaking bow form, which is more efficient in ahead operation when the ice is not very thick or extremely difficult.

As already can be deducted from the description above, the Double Acting Ship (DAS) concept means always adopting electric propulsion and azimuthing thrusters. Today this usually means diesel-electric machinery which is proposed for both sizes of the Arctic shuttle container vessels used in this study. Today it means also selection of the Azipod® which is the only product of this size category ice-capable azimuthing thrusters on the market, and with ABB, who is the manufacturer. Also, a remark is made that the 'maximum realistic size' thrusters for the 5000 TEU vessel have still to be developed, they do not exist yet.

2.3 750 TEU Arctic Container Vessel Design

The 750 TEU Arctic container vessel is determined to be an improved version of the 'Norilskiy Nickel', the first Arctic container vessel ever. The 'Norilskiy Nickel' is a very ice capable vessel designed according to the Double Acting Ship concept to replace the traditional 'Norilsk' or 'SA-15' type vessels from the 80's on the Dudinka - Murmansk route for the nickel products transport from Norilsk. On backwards voyages the vessels were carrying community supplies, construction materials, gas pipes, etc.

The 'SA-15' class ships were and have been able to maintain successfully the year-round traffic from Murmansk over the Kara Sea and up the Yenisei river, assisted by icebreakers. Although very capable icebreaking ships and of the highest ice class that time, they were, and are, of traditional design and have geared diesel machinery with controllable pitch proller. The introduction of the Double Acting principle on the new 'Norilskiy Nickel' is intended to make the whole transportation independent of icebreaker assistance.

The 'Norilskiy Nickel' is 169 metres long, 23.1 m wide, of 14.1 m depth, and has a deadweight of 14500 tonnes at the 9 metre 'ice draft', designed according to the Double Acting Ship concept. The machinery is diesel-electric, with one single Azipod of 13000 kW power for propulsion. The bow is of highly ice capable form, and stern designed for fair capability astern and to accommodate the large Azipod®.

Ice class of 'Norilskiy Nickel' is of category LU-7 of the Russian Maritime Register. LU-7 ice class has superseded the 'old' ULA-class which was the highest class for merchant cargo vessels, and exceeds the requirements of the old class. The SA-15 type vessels are of the old ULA- class.
As a result, one can say that the ice class of 'Norilskiy Nickel' has been enhanced according to the changed operation type.

At full power 'Norilskiy Nickel' is capable to make 17 knots speed in open water. The service speed at 9000 kW economical shaft power is abt. 15.5 knots and the range of the vessel is more than 13600 miles. In ice conditions a calculated speed of 2.5 knots can be achieved in 1.3 m thick level ice ahead and in 1.6 metre ice astern. In full scale ice trials on Yenisey river, in March 2006, all the predicted performance figures were clearly exceeded. Even more important for the targeted operation independently of icebreaker assistance, the capability to perform and penetrate in very heavy ice ridges and ridge fields proved to be excellent so that the accompanying icebreakers were in fact following the 'Norilskiy Nickel'.

Although called 'container vessel' the 'Norilskiy Nickel' is intended for transport of nickel special pallets at the first hand, and can be described as 'semi-container veessel' only for container transport. The nominal container capacity is 650 TEU and 12700 tonnes of the deadweight is specified for cargo, which means that the average weight of the containers is almost 20 tonnes, or otherwise the full cargo carrying capacity cannot be used when containers are carried.

For the purposes of the Arctic Shuttle Container Link study the 'Norilskiy Nickel' is developed to a full container vessel. This means deletion of the tween deck, which in fact is the hydraulic hatch covers, choosing normal pontoon type lift of panels for weather deck hatch covers instead of the folding hydraulic ones, and creating simultaeously space for more container rows on main deck, for a total of 815 TEU. The breadth allows for 7 containers side by side both on deck and in the hold.

In addition to the cargo space modifications, the fuel tank capacity and the fuel storages are doubled because Dudinka lays only half-way from Iceland to Aleutian islands, the more difficult part of the voyage in ice being the east part of it. For fuel stores this means increase from 1500 to 3000 tonnes, and maintaining the main dimensions the cargo deadweight reduces to 11200 tonnes, for an average weight of 13.75 tonnes per container, which is a realistic figure and allows for full utilising of the cargo deadweight.

Removal of the tween deck hatch covers makes the vessel some 400 tonnes lighter, but the same amount is expected to be added as additional steel for improved ice strengthening, because the 750 TEU container vessel is expected to meet more difficult ice than the 'Norilskiy Nickel'.

Further on, main dimensions of 'Norilskiy Nickel' can be maintained, as well as the general arrangement, hull form, machinery lay-out and power, superstructure, accommodation, etc.

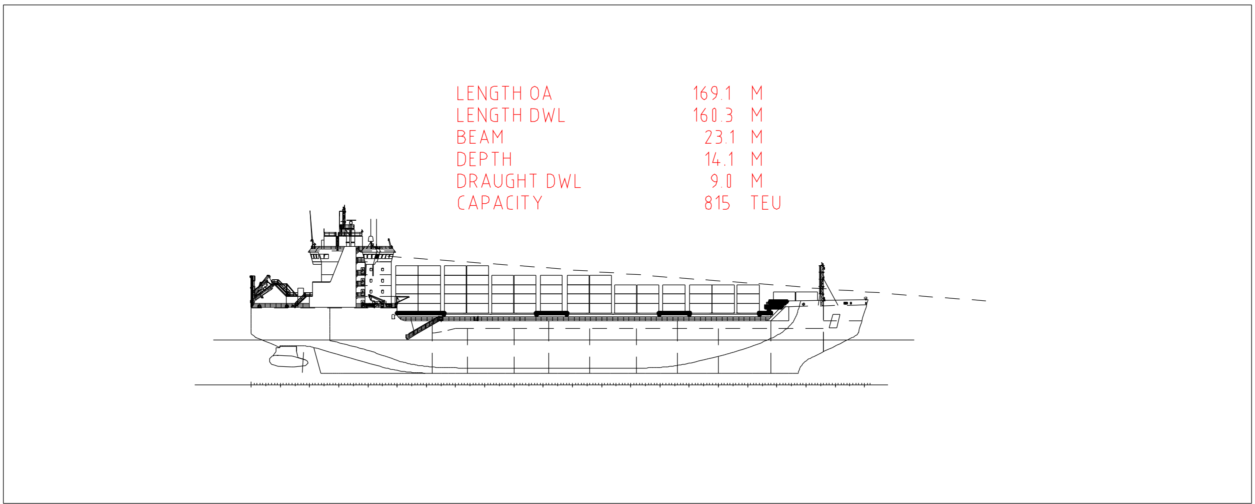


Figure 1. 750 TEU Arctic Container Vessel

The general arrangement sketch of the 750 TEU vessel is presented in figure 1, and the main characteristics in figures of the '750 TEU Arctic Container Vessel' and those of the 'Norilskiy Nickel' are presented in the table below:

	Norilskiy Nickel		Trans-Arctic Container Vessel	
Lenght over all	169	m	169	m
Length wl	160	m	160	m
Breadth	23.1	m	23.1	m
Depth	14.2	m	14.2	m
Draft	9.0	m	9.0	m
Deadweight at 9 m draft	14500	tonnes	14500	t

Cargo	12700	t	11200	t
Containers	650		815	
Fuel	1500	t	3000	t
Shaft power	13000	kW	13000	kW
Speed	17	knots	17	knots

Machinery consists of 3 diesel generators and one 13000 kW azimuthing ‘Azipod’ thruster.

Fuel is heavy fuel oil. Fuel consumption at 12 MW shaft power is abt. 61 tonnes per day.
The 3000 tonne fuel store is adequate for abt. 50 days cruising at the 12 MW shaft power, and is considered sufficient for the Arctic Shuttle Container Link traffic.

At 9000 kW ‘economy shaft power’ the daily fuel comsumption is abt. 41 tonnes, and theoretical range in open water abt. 27000 miles.

One factor which is important for every icegoing vessel which has not been mentioned yet is the draft in ballast condition. The ballast draft is important because the different characteristics of the icecapability tend to be reduced when the draft is reduced. This is why icegoing vessels should have large ballast capacity and consequently the relation between full load and ballast drafs close to 1. For the Arctic container vessels this seems not easy to be arranged, especially for the 5000 TEU vessel. However, for these vessels this may not be problematic, because it is expected that voyages in ballast condition are not going to happen, there will always be enough loaded containers going from east to west and vice versa, to guarantee that adequate immersion can be maintained both fore and aft, when the available ballast capacity is used.

Although provided with high ice capability and use of the ‘traditional’ Northern Sea Route fairways close to the Russian coast for easier ice conditions, the icebeaking capability of the 750 TEU vessel is not expected to be adequate for independent operation throughout the Northern Sea Route year round. During the most severe ice conditions icebreaker assistance is included in the trafficability simulation whenever the speed of the vessel tends to drop below 4 knots. In the study, this speed is considered lowest reasonable ‘independent operation speed’, because the slower the speed is, however at full power, the more costly the achieved miles are. Especially hard this fact hits the lowest speeds and corresponding voyage times: for instance 500 miles takes 125 hours at 4 knots, 167 hours at 3 kn, and 250 and 500 hours at 2 and 1 knot, respectively, giving time increments of 42, 83 and 250 hours per 1 knot speed reduction. Corresponding fuel consumptions at full power are 347 t, 463 t , 694 t and 1388 tonnes for the 500 mile traverse.

A more detailed general arrangement plan of the vessel is included as appendix 1, preliminary lines plan shows the hull form in appendix 2.

On the next two pages there are pictures from the ice trials of the ‘Norilskiy Nickel’ in March 2006 in the Yenisey river to give an impression of the vessel, of the ice conditions and her operation.

2.4


НОРИЛЬСКИЙ НИКЕЛЬ

2.4 5000 TEU Arctic Container Vessel Design

The 5000 TEU Arctic Container Vessel design is a further development of the 750 TEU vessel. Basically the efficient icebreaking hull form is kept as it is, but enlarged in scale 1.5 : 1. This scale puts the width of the 5000 TEU vessel to 34.65 metres, depth to 21.2 m and draft to 13.5 metres. The length would be abt. 253 metres, but the hull must be lengthened by one hold length, 28.8 m, for a total length of 281 m, to accommodate the required number of containers. In addition the spaces aft of the superstructure are used for carrying containers as much as possible, and as allowed by the visibility requirements due to the astern operation of the Double Acting concept. In addition the stern has to be modified for installation of a twin pod arrangement instead of the single one.

The width of the vessel allows to carry 12 containers side by side in holds, and 14 on deck. Height of the deck container stacks is up to 7, which is normal figure for vessels of this category. The general arrangement of the vessel is shown in figure 2.

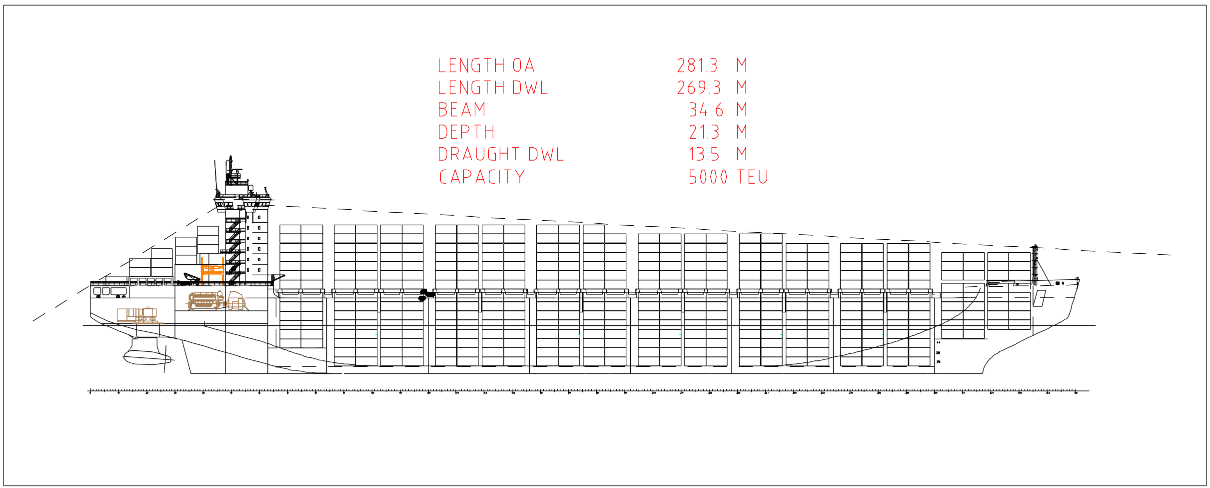


Figure 2. 5000 TEU Arctic Container Vessel

Machinery is diesel-electric, by four diesel generators, up to abt. 45 MW total power, and two Azipods of maximum size, up to 18 MW power each, take care of the propulsion. Alternatively three pods of the same total power may be used but at the expence of increased width and ice resistance, if the largest models cannot be delivered.

At full power the open water speed will be abt.19 knots. In ice conditions 2.5 knots speed can be achieved in 2.1 m thick level ice ahead and in 2.4 m thick ice astern. These figures put the 5000 TEU vessel in a performance category comparable with the nuclear icebreakers, and the very efficiency of the twin pod arrangement to break the way through the worst ice ridges and other most difficult ice formations may even exceed that.

Ice class of the 5000 TEU Arctic container vessel must be selected to fit the operation environment and the icebreaking capability of the vessel. This means an ice class higher than LU-7 of ‘Norilskiy Nickel’, i.e. LU-8 or LU-9. Until now, no vessels have been designed or built to these classes. Technologically there should not be any special problems with the highest ice classes, but how they affect to the steel weight of the vessel remains unclear and would require a more detailed design effort.

The displacement of the proposed hull is abt. 100000 tonnes. The lightweight is estimated at abt. 32000 tonnes leaves abt. 68000 tonnes for cargo and stores, and further on, over 61500 tonnes for cargo, if close to 6500 tonnes are reserved for fuel and other stores. 61500 tonnes for 5000 containers yields abt. 12.3 tonnes per container, which is an acceptable figure for large container vessels.

The draft of 13.5 metres blocks the 5000 TEU vessel out from the traditional route along the Russian Arctic coast, to the more northern routes where enough deep water can be found. This may increase the ice thickness to be broken by the 5000 TEU vessel, but her performance should be good enough for that. Moreover, she is expected to accomplish the travel independently year-round even during the ‘severe’ ice winter.

In figures the 5000 TEU Arctic Container Vessel is as follows:

Lenght over all	281	m
Length wl	269	m
Breadth	34.6	m
Depth	21.3	m
Draft	13.5	m
Deadweight at 9 m draft	68000	tonnes
Cargo	61500	t
Containers	5000	
Fuel	6000	t
Shaft power	35-36	MW
Speed	19	knots

Machinery consists of a number (3 - 4) diesel generators and two 17 - 18 MW azimuthing ‘Azipod’ thrusters.

Fuel is heavy fuel oil. Fuel consumption at 35 MW shaft power is abt. 170 tonnes per day.
The 6000 tonne fuel store is adequate for abt. 35 days cruising at 35 MW shaft power, and is considered sufficient for the Arctic Shuttle Container Link traffic during ‘light’ and ‘normal’ years. In ‘severe’ or ‘extreme’ winters the round trip time may exceed this for the most difficult winter months, and consequently more fuel is needed. At this stage of the study the available fuel tank capacity is abt. 9000 m^3 which corresponds to 8300 t maximum fuel capacity, which can be utilised whenever necessary, but with less cargo weight, lighter or less containers. With 8300 tonnes of fuel the range at full power will be abt. 50 days, 1200 hours.

Compared to the ‘normal open water 5000 TEU’ counterpart the Arctic vessel is about of same size, length, width, depth and draft. However, the displacement is bigger because of the full hull form which is easily and effectively done by the forms of the bow and of the stern. This hull form is dictated by the ice resistance factors, and possible to use because the high open water speed is not of highest importance.

Due to the ‘ice friendly’ hull form and slow open water speed requirement, surprisingly, the power of the Arctic vessel is considerably less despite the extremely high icebreaking capability. The proposed 35 to 36 MW shaft power provides for abt. 19 knots open water speed only, and may be some 70 to 80 per cent of the power usual for large open water vessels which often travel at 24 to 26 knots speed.

A more detailed general arrangement plan of the vessel is included as appendix 3, preliminary lines plan to show the hull form as appendix 4.

2.5 Terminal Operations

In this chapter the terminal operations have been considered from the vessel’s point of view.

For the economy of the vessel, and for the simulation calculations, the time used for operations in the harbour, that is manoeuvring, berthing, etc. but especially the cargo handling activities, are of interest. Harbour times add directly to the sailing time to the total roundtrip time. This is why the operations in the harbour are evaluated below.

In the simulation calculation a container handling rate 40 pieces in one hour per each crane has been included. Further it is assumed that one crane can be deployed for each hold. In the largest holds of the 5000 TEU vessel there are 744 containers, 352 in the hold and 392 on deck, when the holds are filled to the maximum. This results in disharge/loading time of abt. 20 hours, when the hatch cover pontoons have to be lifted also. Basically the same time is required then for loading the hold for the return voyage departure. Totally two days harbour time is so included in the roundtrip time in each end of the voyage for the 5000 TEU vessel. To achieve this cargo handling rate 8 cranes are required, the aftmost crane serving the small hold in front of the superstructure has time to clear the containers on aft deck also.

For the 750 TEU vessel a harbour time of one day at each end is estimated. This is composed of 8 hours discharge time, 8 hours loading time, and 8 hours for manouevring, berthing, etc. For achieving the 8 hour discharge time at least 3 cranes are foreseen.

The harbour times mentioned above, one day for the 750 TEU vessel, and two days for 5000 TEU, should be long enough to take care of bunkering and other replenisment and services at reasonable rates.

The estimates and provisions foreseen above for the terminals and their activities may not be very exceptional for large container hub ports, neither are they any concern of the vessels or their designers. Anyway a remark is made, that the 13.5 m draft of the 5000 TEU vessel is already some kind limitation for her operation in the Arctic seas, which are quite shallow, and so is it for the ports also. Today there are no ports of this water depth in the Arctic, and the whole efficient and large cargo handling chain shall be established for the Arctic Shuttle Container Link traffic, cranes, container parks for 10000 containers, trucks, terminal tractors and stackers or other equipment for moving the 10000 containers in two days onshore shall be available, and the manpower to use all the equipment.

2.6 Fee policy and icebreaker assistance of Northern Sea Route

The influence of the fairway dues on the total transport cost is very high, and so understanding the problematics of this issue is of importance. In chapter 5.1 the fairway fee system of the Northern Sea Poute is described and discussed more detailed from the cost point of view as needed for the economy calculation, in this chapter only the connection with icebreaker assistance and icebreakers is discussed.

Traditionally the costs of icebreakers and icebreaking have been funded by governments, and shipowners have been charged only on the actual assistance, when their ships have been in troubles with ice, and icebreaker has been called for help. That resulted in situation where ice icebreaker assistance was expensive, but use of the fairways was free or cheap. Because of many problems of this fee system, governments have changed to fee systems, where an even but quite high 'fairway due' is paid every time when using the national waters or fairways, irrespective if icebreakers are used or not, and consequently, icebreaker assistance has become 'free of charge'. Anyway, the costs of icebreakers are meant to be covered by the fairway dues, being in fact major part of that.

This is how the dues is applied on Northern Sea Route today, and makes the situation problematic for the study, and for the actual traffic also. Because of the high costs of the large icebreaker fleet, and small traffic volumes, the dues have risen so high that they prohibit the future growth of the traffic. Further on, the government is not the operative owner of the Russian icebreaker fleet, but the icebreakers have been handed over to the Murmansk Shipping Company which is a private company, but has thus a government supported monopoly for the icebreaking assistance in the NSR area.

The current fee system on the NSR is today simultaneously based on the idea that the fee is collected on the basis of the paying potential. So today e.g. oil and oil products and metals (nickel from Norilsk) are paying high fees. Transit cargo in this sense is a new feature for the Russian system, which so far has been tailored around the local exports.

This type of fee policy is not suitable for cargo vessels which are capable to independent operation, as the fee should be paid whether the icebreaker assistance is needed or not. Neither does it take into account the ship-owners who want to use own icebreakers to secure the continuous transportation independent of other parties.

For the study, and for the Arctic Container Vessels, this makes the situation difficult, because they are proposed to be independent of icebreakers, partly or totally. Creating a 'new' system with low fairway due and high icebreaker fee would be one solution.

From the actual icebreaker assistance point of view the 750 TEU and 5000 TEU vessels differ from each other in many ways.

First, as proposed, the 750 TEU vessel needs assistance, the larger vessel not. This is from the technical standpoint, but there might be other factors, political or commercial, which dictate the use of icebreakers anyway.

Second, the large vessel will use two icebreakers, if icebreakers are used. This is because of the large width of the vessel, which clearly exceeds that of the largest icebreakers. Traditionally two icebreakers were then employed for the assisting. Of course, the 5000 TEU vessel does not need any icebreakers, but the use of them might be required by law, and in this case two icebreakers can be argumented.

Third, the 5000 TEU vessel may traffic outside the territorial waters of Russia so that the Russian legislation and fees can be considered not applicable for her. However, Soviet Union and Russia have claimed national supremacy extended from the Arctic coast to the North Pole.

Fourth, the development of the Russian icebreaker fleet is difficult to foresee. Today the building of icebreakers has been seized for over 15 years already, the latest large nuclear unit under construction during the collapse of Soviet Union lays still unfinished. Neither is there any need for building more vessels, but the former icebreaker building programmes from 80'ies still exist, and life extension programmes for the operating units are developed. This development may lead to a situation, where there are not enough icebreakers for the Arctic Shuttle Container Link purposes, and building of the new ones is eagerly seen financed by the foreign container vessel operator.

One can speculate with the fees by different approaches, but for the time being, the only certain aspect is, that the icebreaker/fairway due system today is uncertain, not feasible, and may continue to be so for the future.

As a conclusion, a year round transit system based on independent ships, will from the Maritime Administration point of view call for arranging some type of back-up preparedness for the safety reasons and some fee level need to be counted for. The actual level of the transit fees will, however, remain a highly political issue.

2.7 Safety and Redundancy Issues and Icebreaker Assistance

Safety is and has always been an important issue for seafaring. For Arctic navigation it may be even more important and may be composed and includes factors which are not familiar for non-Arctic shipping. The issues concerning safety are reflected and discussed in this chapter.

Pure good performance is always some kind of safety enhancement issue, and especially so is it for vessels operating in Arctic ice. To have 'extra' performance in 'normal' conditions leaves always some margins for the extreme situations when the really difficult ice conditions hit. In the Arctic there always will be ice and ice conditions exceeding the capabilities of any vessel built yet.

Another point in having good or 'extra' performance is that some of it may be lost, and there still is 'enough left' for safe operation at reduced power or other operational capability.

Consequently, the ice performance is the first and most important issue to be discussed. In addition, the 'base vessel' of the both Arctic Container Vessels designs, the 'Norilskiy Nickel', has completed her ice trials and proven full scale performance test results for the smaller 750 TEU vessel are available.

'Norilskiy Nickel' exceeded clearly all performance predictions made for her making over 2 knots speed in the 1.5 m thick level ice ahead and over 3 knots astern. Even more important, the performance in channels, rubbles and ridges, ice conditions which are more difficult than level ice, proved to be 'as expected' or even 'better than expected', and consequently she was evaluated to meet the requirements of independent operation without icebreaker assistance on the Murmansk -

Dudinka route. However, on this test voyage the ‘Norilskiy Nickel’ was forced to have an assisting icebreaker and paid for it. En route to Dudinka she was following in the channel broken by the icebreaker, on the ‘home’ voyage she vent first and the icebreaker followed.

The results of ‘Norilskiy Nickel’ confirm the performance predictions made for the Arctic Container Vessel designs. Probably even an improved performance can be expected.

Concerning the safety these figures already give one first aspect included in the Double Acting design compared to the traditional one: operating normally in ahead mode in ice conditions up to the ‘normal maximum’ she still has a plenty more left if ‘something happens’. In this incident she may start operating astern and may perform as well or even better than in ahead mode, possibly at slower speed if the speed ahead was substantially high. The ‘traditional counterpart’ has not this option: she loses ahead performance in proportion to the lost power, and has only very limited capability to reverse due to the poor reverse/ahead thrust relation. In fact this disadvantage in many cases turns around the whole ‘good performance is safety’ idea, fair ahead performance makes it possible to cruise ahead in so bad situations, that getting out is very difficult or impossible. Of course the assisting icebreaker will help ‘the traditional vessel’ in these circumstances.

As already mentioned in the general description of Double Acting Operation Principles in chapter 2.2 the Double Acting vessel is much more less affected by the ice compression, ‘glue ice’, or other very difficult ice conditions than the traditional vessel.

The other way to reflect the ‘good performance is safety’ slogan is to consider how the good performance is maintained, that is the reliability and redundancy issue. For both reliability and redundancy a lot has been built in already when Double Acting Concept and corresponding Double Acting propulsion and machinery have been selected. That fact includes that the number of prime movers, diesel engines, is normally 3 or 4 compared to 1 or 2 on ‘traditional’ single screw vessel. The diesel engines often are ‘the weak link’ of the propulsion chain, most of the normal failures attacking the engines or their systems. So, normally increased number of diesel engines is considered an improvement for reliability and redundancy. Even when the number of engine troubles increases with the increasing number of engines, the redundancy and safety are improved, the number of engines running, or power in use after engine failure will be higher.

Secondly, the main electrical network is normally devided in two, or can be devided, so that failure in one part does not disturb the other, but at least half power can be used after failure.

The last item in the propulsion train, the propeller, or the Azipod in the ‘Double Acting case’, is not easy to compare. However, the controllable pitch propeller with the pitch control mechanism for the traditional vessel is more vulnerable to damages than the fixed pitch propeller of stainless steel of the Azipod. The propeller motor itself inside the Azipod is simple and reliable, of proven technology. In addition, in a single Azipod vessel the motor is of double winding type, devided in two halves, so that half power is maintained after failure of the other half or the power control system feeding it. Also, the form of the aft ship can be made of such form that it protects better the propeller and the Azipod against the ice flowing to the propeller from ahead.

The power control system is also divided in two, each part feeding the half of the propeller motor of its own.

In case even more redundancy is desired, it is easily added by dividing the main engines, main switchboards and frequency converters in separate rooms with a dividing bulkhead. In a twin Azipod installation the Azipods also can be installed in separate rooms.

Considering the icebreaker assistance, in the chapter discribing the Arctic Container Vessels, it is proposed that the smaller 750 TEU vessel will use icebreaker assistance on a periodical basis, depending on the severity of the 'ice winter', location of the most difficult 'ice legs' of the voyage, etc. due to her ice performance. The 5000 TEU vessel would not need assistance due to her high ice capability, but may be forced to use it for other reasons. Being there for any reason, the icebreaker or the icebreakers are an addition to the safety margins of the vessels, otherwise left alone amidst the large Arctic Ice Region, hundreds or thousands of miles away of nearest places of help, if something really serious happens.

Finally it is reminded that the icebreakers themselves are nor invulnerable and they do also have breakdowns due to the same reasons than Arctic Containner Vessels. It is preseen that the 5000 TEU vessel may have to help or assist the icebreakers. However, generally it is always more safe to have two vessels in difficult ice conditions instead of one, or three instead of two.

Today, the actual procedure is that the vessels crossing the NSR shall use icebreaker assistance, both in general and in particular, some straits are specially mentioned for obligatory icebreaker assistance, due to the difficult navigation circumstances and safety. Actually the safety is the reasoning and motivation behind the rules, and it is clearly understandable considering the ice conditions, the existing and former ships and their performance, and the history of shipping on the NSR. How the situation would or could be changed when /if the merchant vessels have much higher ice performance, same or even better performance than the icebreakers, or do not use the straits, or navigate outside the territorial waters will remain unclear.

Generally, for the 'overall structural safety' the NSR Rules include regulations, requirements and definitions for the design and constructions of ships which each vessel has to comply with to have a permit to enter the NSR.

On the 'software side' the main safety item are the masters and ice pilots and the experience of them. An experienced master who knows the different ice conditions and how to manage with them, who can 'read' the signs of the nature, and knows the capabilities, limits and shortcomings of his ship, is the best insurance for safety in the Arctic, too. He can do more and better on a less powerful and less capable vessel in a safe and reliable way than an inexperienced colleague with a more powerful one. The important role of the experience is the motivation of the NSR rules in appointing an experienced 'ice pilot' onboard each vessel.

3. Ice Conditions

3.1 Introduction

Sea ice is a complex entity requiring many descripting attributes. Ice concentration is a measure of the mean areal density of ice in an area, while stage of development classifies the ice in terms of how it is formed and/or age. The main classes are new ice, first-year ice and old ice, but each of these have sub-classes. The terms used to describe stage of development also indicate the thickness of ice, but ice thickness may also be given explicitly. Other descriptions for sea ice are: forms of ice (floe size etc.), arrangement (ice massif, ice edge), pack-ice motion processes (diverging, compacting, shearing), deformation processes (fracturing, hummocking, ridging), openings in the ice (crack, fracture zone, lead, polynya), ice surface features (level, deformed, rafted, ridge, hummock, bare/snow covered ice, etc.) and stages of melting. Ice descriptions with pictures can be found in attached document: ‘Selected pages from: Merenkulkulaitoksen julkaisuja: Sea Ice Nomenclature’.

Sea ice includes any form of ice found at sea which has originated from the freezing of sea water, and has two main sub-divisions: pack ice and fast ice. Sea ice which forms and remains fast along the coast are called fast ice. Seaward of the fast ice boundary, the pack ice may experience openings (leads, polynyas) and converging areas where the ice crushes together to form pressure ridges. During the freezing period, new ice is continually being produced in the leads. Ice in the transition stage between new and first-year ice (10-30 cm thick) is called young ice. Sea ice which has survived at least one summer melt is called old ice, but may be sub-divided into second-year and multi-year ice.

Difficult ice-conditions often prohibit the use of the shortest route between two points, and lead to the need of ice-breaker assistance. It also can cause damage to vessels, detours and reduced speeds. The ice-conditions vary greatly between the different parts of the NSR, and between seasons and years.

During severe winter parts of the NSR are not completely ice-free even during the most favourable summer month. The areas at each end of the NSR - the south-western Kara Sea and the south-eastern Chukchi Sea – have the lightest ice-conditions (along with the eastern Laptev Sea around the Lena river mouth), with the eastern East Siberian Sea having clearly the most difficult ice conditions. This corresponds with navigational experience, where the East Siberian Sea has been seen as the most difficult sea to navigate, and also being the main bottleneck for transit navigation.

The reason for the difficult conditions in the East Siberian Sea is the mighty Ayon ice massif, consisting of thick and hardened multiyear ice, and which can extend almost to shore even during summer due to currents and winds.

Sailing during the winter season (November-May), is generally much more difficult than in the summer season, due to the thicker and more dense ice-cover. An important, special feature of winter navigation is the fast ice - stable, immovable ice which is “clinging” to the coastline. Fast ice is very difficult to pass through, and normally it is preferable to avoid it by using northerly routes. If offshore winds prevail, one will often during winter find open leads at the edge of the fast ice - so called polynyas, which are very suitable for navigation.

Again, it is clear that it is the Kara Sea that offers the easiest conditions for navigation. Here, the extension of the fast ice is normally small, but the existence of polynyas is also relatively normal. The only areas where polynyas are not often found, are the eastern East Siberian Sea and the Chukchi Sea. This is again mainly due to currents pushing ice from the central Arctic Basin towards the coast, thus creating extremely difficult ice conditions. The fact that both Severnaya Zemlya and the New Siberian Islands normally become enveloped by the fast ice, will often force ships to choose a route north of these archipelagos, routes which may expose the ships to extremely harsh ice conditions.

The ice conditions along the NSR are dynamic, leading to large annual, seasonal and regional variations. In the winter months November to April the whole region is covered by very dense drifting ice and fast ice. Seaward of the fast ice boundary, the ice cover is in constant motion due to currents and winds. Large ice fields observed in the same regions each summer are called ice massifs. Taymyr, Ayon and Wrangel massifs are the most important obstacles to ship traffic along the NSR since the massifs contains significant concentrations of multi-year ice and frequently heavily hummocked ice is present. The summer season for the region occurs roughly from June to September, when ice cover melts significantly, diminishing in both extent and strength. The greatest seasonal fluctuation occurs at the east and west ends of the route. Fast ice begins to form in mid-October in the fresh water of the river estuaries and expands to cover most of the continental shelf up to 500 km from the mainland.

3.2 Kara Sea

In the Kara Sea the ice formation starts in September in the northern sea regions and in October in the southern part. From October to May almost the entire sea is covered with ice of different type and stage of development. In June to September the ice concentration is low in the Kara Sea, especially in the western part where drifting thick ice may be present. In the eastern part, especially the Severnaya Zemlya massif, the ice concentration is higher and the ice consists mainly of thick first-year ice. When seasonal ice minimum is reached by mid September the entire Kara Sea south of 75°N is normally ice free. In extramely mild summers, the Kara Sea may become ice free as far North as 80°N. The coastal zone is occupied by fast ice which is non-uniformly developed.

3.3 Laptev Sea

The Laptev Sea has the largest expance of fast ice in the world from January to June. The fast ice thickness typically reaches 200 cm due to mean midwinter air temperature of -30°C and can grow up to 250 cm during severe winters. The amount of old ice in the Laptev Sea is limited due to wind directions and ocean currents. The total area of summer melt is particularly extensive due to the reduced amount of old ice. In the western part the ice drift is southwards and large masses of ice are deposited along the coast of Sevarnaya Zemlya and the Taymyr Peninsula. along with the eastward ice deposition from the Kara Sea, the Vilkitski Strait and the Taymyr coast presents a serious challenge to navigation at all times of the year.

3.4 East-Siberian Sea

The East-Siberian Sea is the shallowest of the Eurasian seas. the broad continent shelf allows fast ice, averaging from 170-200 cm thick, to extend as far as 500 km outward from the coast. In winter the prevailing wind direction is from south producing weak ice conditions and potential navigation lanes at the outer edge of the fast ice as they do in the Kara and Laptev Seas. East-Siberian Sea has the highest fraction of old ice and the Ayon massif has more than 60% of old ice on average and the average thickness may be 250 cm in the winter months. In summer the winds shift to northerly and the ocean currents favour the influx of ice from the north resulting in the permanence of the Ayon massif. Winter freeze-up begins in the north in September and is usually complete by mid-October.

3.5 Chuckchi Sea

The Chukchi Sea is almost ice covered from early December to mid-May. The seasonal variations in the ice conditions are large resulting in loosing about 80% of its maximum winter extent in the summer season. Important factors influencing the variability are the bathymetry, wind, currents, air temperature and the presence of Wrangel Island. Ocean currents and wind tend to transport old ice from the Arctic to the Longa Strait under great pressure, which sometimes presents the greatest obstacle on the route.

4. Transit Simulations

In order to evaluate the transport feasibility, the vessels capability to maintain speed in the specified route must be determined. Therefore the simulation technique developed at AARC was applied. This simulation programme can accurately calculate the vessels speed in changing ice conditions.

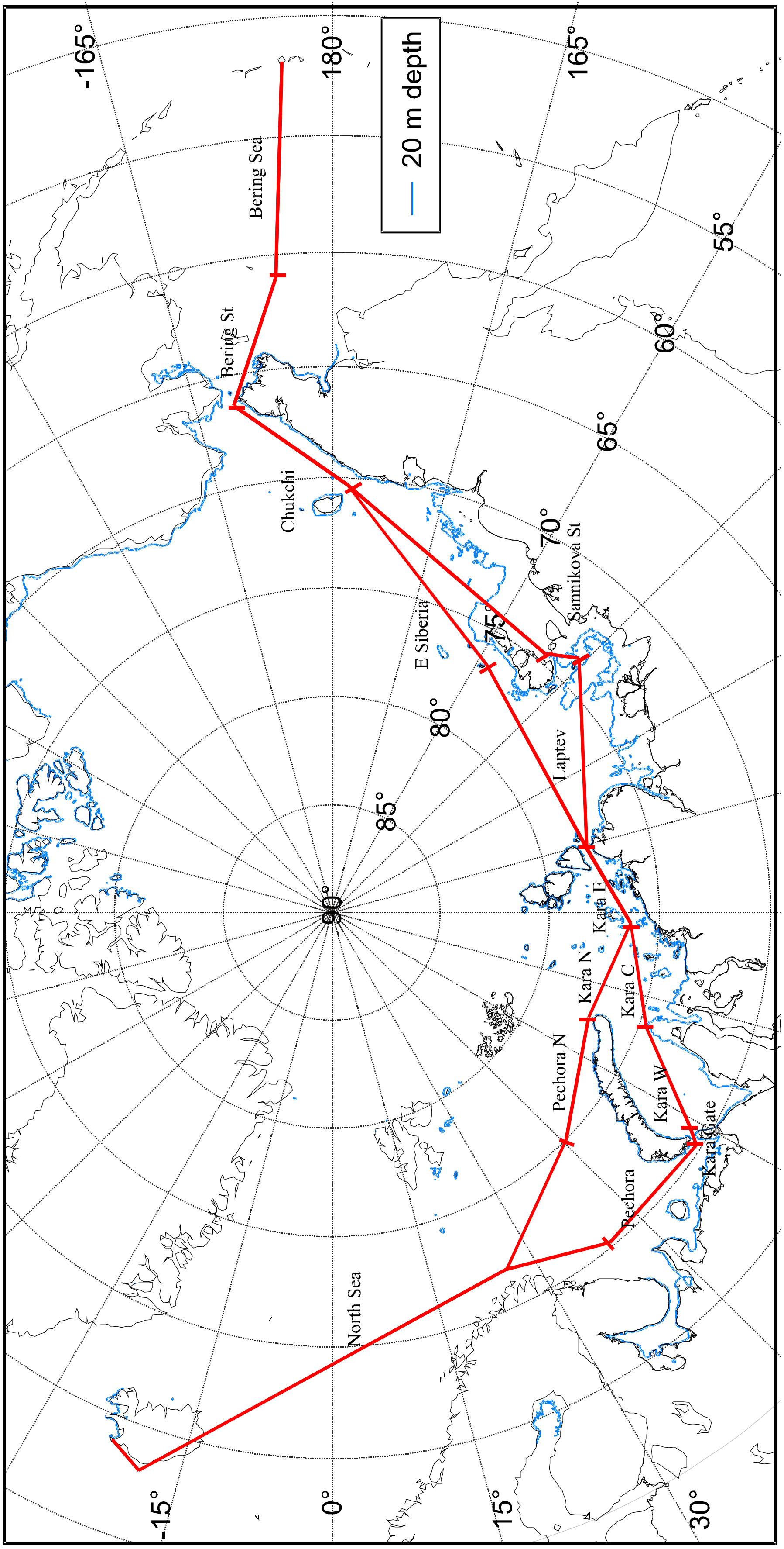
4.1 Routes

The route from Adak, Alaska to Iceland can be seen in Figure 3. The whole route is divided into separate legs which are also identified in the Figure. All legs have different, monthly changing ice conditions throughout the winter. Due to depth limitations, the 5000 TEU vessel is forced to sail outside or in limits of the 20 meter depth curve seen in Figure 3.

The smaller 750 TEU vessel is assumed to sail thru Sannikova Strait, even it is approximately 130 nautical miles longer route than around it. Route thru Sannikova Strait can be faster on favourable ice condition season, when openings are formed in the ice field near the boundary of fast ice.

The route option around northern coast of Novaya Zemlya is approximately 260 nautical miles shorter than thru Kara Gate. For simulation cases the shorter route around Novaya Zemlya is selected. In reality, the final route selection is always made based on current weather and ice conditions for easiest navigation.

Figure 3. Used routes thru Northern Sea Route



Lengths of each legs on different routes are shown in Tables 1, 2 and 3.

Table 1. Route for 5000 TEU vessel around Novaya Zemlya.

Leg	Bering Sea	Bering St	Chukchi	E Siberia	Laptev	Kara E	Kara N	Pechora N	North Sea	Total
Length [nm]	552	356	370	622	577	238	283	342	1623	**4963**
Length [km]	1023	659	685	1152	1069	442	523	633	3006	**9191**

Table 2. Route for 750 TEU vessel around Novaya Zemlya and thru Sannikova Strait.

Leg	Bering Sea	Bering St	Chukchi	E Siberia	Sannikova St	Laptev	Kara E	Kara N	Pechora N	North Sea	Total
Length [nm]	552	356	370	711	91	523	238	283	342	1623	**5089**
Length [km]	1023	659	685	1316	169	969	442	523	633	3006	**9425**

Table 3. Optional route for 750 TEU and 5000 TEU vessel thru Kara Gate.

Leg	Bering Sea	Bering St	Chukchi	E Siberia	Laptev	Kara E	Kara C	Kara W	Kara Gate	Pechora	North Sea	Total
Length [nm]	552	356	370	622	577	238	285	302	50	354	1519	**5225**
Length [km]	1023	659	685	1152	1069	442	528	559	93	656	2813	**9677**

4.2 Ice profiles

So called ‘ice profiles’ which imitates the true ice conditions along the route legs were prepared based on ice charts (source: I.P. Romanov, 1993, Atlas, Morphometric Charasteristics of Ice and Snow in the Arctic Basin, St. Petersburg) and AARC ice database. Resulting ice profiles consists of level ice and ice ridges. Level ice thickness variation corresponds to measured distribution in natural ice fields. Ridge height distribution also imitates ridge field distribution in nature. Example ice profile can be seen in Figure 4, and it is generated with following properties:

Level ice thickness	1.8	m
Ice concentration	98	%
Mean ridge thickness	8.0	m
Ridge density	5	1/km

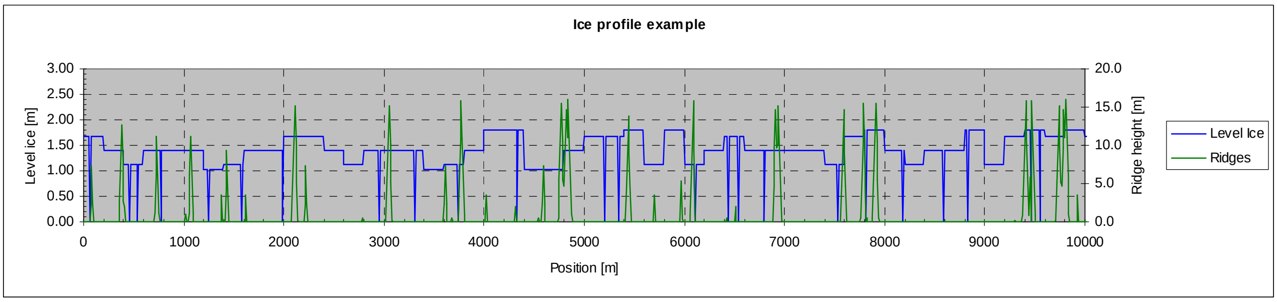


Figure 4. Example ice profile.

Ice profile properties for each leg in each month to both types of winters are presented in appendixes 5 and 6.

4.3 Simulation

The ships average speed through level ice and ridges according to generated ice profile is solved by simulation. Simulating the ships movement is basically solving the acceleration of the ship based on net thrust and ice resistance (level ice and ridge resistance) at small time intervals. Speed profile in generated ice profile above can be seen on Figure 5.

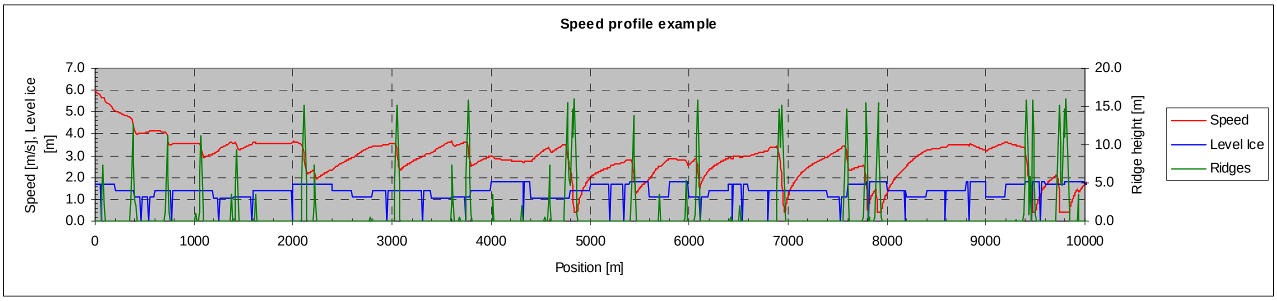


Figure 5. Simulated speed profile thru example ice profile with 5000 TEU vessel, astern-mode. Average speed is 2.3 m/s, 4.5 knots.

Transit simulations were made for two types of winters, average and severe winter.

4.4 Results

As a result of simulations, average speed in each leg in each month is solved. As the ships are Double Acting type ships, average speed for faster operating mode (ahead/astern) for each leg was selected. In Figure 6, total one-way sailing time thru whole route is presented. Numerical detailed division of results are presented in Appendix 7. In Table 4 is shown the results of simulation to 5000 TEU Carrier on average winter.

Table 4. Average speeds and times for different legs to 5000 TEU vessel on average winter.

Leg	Bering Sea	Bering St	Chukchi	E Siberia	Laptev	Kara E	Kara N	Pechora N	North Sea	Total
Length [nm]	552	356	370	622	577	238	283	342	1623	**4963**
Length [km]	1023	659	685	1152	1069	442	523	633	3006	**9191**
Avg. Speed [kn]										
Jan	19.0	16.2	9.7	7.3	13.5	9.6	10.6	14.1	19.0	
Feb	19.0	15.4	7.3	4.1	11.6	5.5	8.9	13.9	19.0	
Mar	19.0	14.6	3.2	3.4	9.9	3.2	7.7	13.3	19.0	
Apr	19.0	13.9	3.4	3.0	7.6	3.5	7.8	13.0	19.0	
May	19.0	13.7	3.5	2.9	7.8	4.5	8.0	13.1	19.0	
Jun	19.0	14.5	3.8	3.1	9.2	4.5	9.4	13.8	19.0	
Jul	19.0	19.0	16.4	9.6	14.0	14.3	16.2	17.7	19.0	
Aug	19.0	19.0	19.0	15.0	17.2	19.0	19.0	19.0	19.0	
Sep	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	
Oct	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	
Nov	19.0	19.0	15.9	15.3	15.0	15.9	16.6	17.3	19.0	
Dec	19.0	17.3	12.9	11.8	11.3	13.1	13.8	15.3	19.0	
Time [h]										Total
Jan	29.1	22.0	38.1	84.9	42.8	24.7	26.7	24.3	85.4	**378.0**
Feb	29.1	23.1	50.6	153.3	49.6	43.0	31.9	24.5	85.4	**490.5**
Mar	29.1	24.4	115.3	182.5	58.5	73.5	36.6	25.6	85.4	**631.0**
Apr	29.1	25.6	107.6	209.5	75.9	68.2	36.1	26.2	85.4	**663.5**
May	29.1	25.9	105.3	214.5	73.9	52.6	35.1	26.0	85.4	**648.0**
Jun	29.1	24.6	98.4	200.4	62.4	52.7	30.0	24.8	85.4	**607.8**
Jul	29.1	18.7	22.6	64.6	41.1	16.7	17.5	19.3	85.4	**315.0**
Aug	29.1	18.7	19.5	41.5	33.5	12.5	14.9	18.0	85.4	**273.1**
Sep	29.1	18.7	19.5	32.7	30.4	12.5	14.9	18.0	85.4	**261.2**
Oct	29.1	18.7	19.5	32.7	30.4	12.5	14.9	18.0	85.4	**261.2**
Nov	29.1	18.7	23.2	40.7	38.5	15.0	17.0	19.8	85.4	**287.5**
Dec	29.1	20.6	28.7	52.6	50.9	18.2	20.4	22.3	85.4	**328.2**

For 750 TEU vessel, icebreaker assistance limit speed is selected to be 4 knots. In other words, if the ships average speed in some leg is below 4 knots, then it is assisted thru the leg with speed of 4 knots. Amount of needed icebreaker assistance is calculated with this selection. The 5000 TEU vessel is assumed to sail independently thru the whole route in every month.

In normal ice navigation biggest ridges are always avoided by navigating thru the easiest lane in the ice field. This can increase the sailed distance a bit, but the speed advantage gets bigger and overall navigation gets faster.

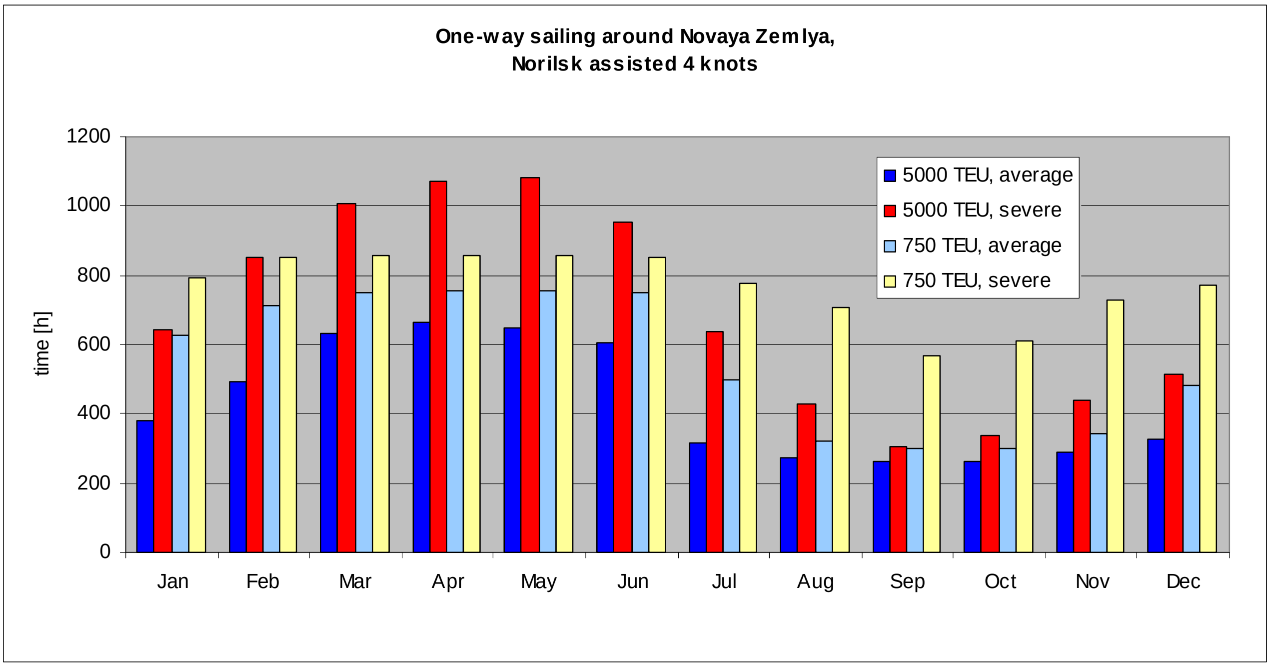


Figure 6. One way total sailing times from Alaska to Iceland in each month for different types of winters.

One-way open water time for the whole route for 5000 TEU vessel is almost 11 days (260 hours), and for 750 TEU vessel 12½ days (300 hours), with corresponding speeds of 19 knots and 17 knots. During winter months sailing time is more than double on average and for severe winter it can grow up to four times longer than open water time. This kind of severe winter case is estimated to occur only once in 5-10 year period.

4.5 Cargo Transport Capability

Cargo transport capability for 5000 TEU vessel on average winter is calculated in Table 5. It is assumed that loading and unloading of the ship is done at both ends of the route. Total time for two loadings/unloadings is estimated to be 96 hours. For 750 TEU vessel two loadings and unloadings is assumed to take 40 hours.

For 5000 TEU vessel in open water months transport capability is 11805 TEU:s, as in winter month it is lowered to 5130 TEU:s. Total transported TEU number in average year is 102278 pieces.

Table 5. Cargo transport calculations for 5000 TEU vessel on average winter.

Cargo capasity	TEU	5000

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
One way sailing	h	378	490	631	663	648	608	315	273	261	261	287	328	
Roundtrip sailing	h	756	981	1262	1327	1296	1216	630	546	522	522	575	656	
Two loadings & unloadings	h	96	96	96	96	96	96	96	96	96	96	96	96	
Mean roundtrip time	h	852	1077	1358	1423	1392	1312	726	642	618	618	671	752	
Number of ships	pcs	1	1	1	1	1	1	1	1	1	1	1	1	
Mean loading frequency	h/load	426	538	679	711	696	656	363	321	309	309	335	376	
Loading availability in month	h	730	730	730	730	730	730	730	730	730	730	730	730	
Loadings per month	pcs	1.71	1.36	1.08	1.03	1.05	1.11	2.01	2.27	2.36	2.36	2.18	1.94	**20.5**
Trips/ship	pcs	0.9	0.7	0.5	0.5	0.5	0.6	1.0	1.1	1.2	1.2	1.1	1.0	
Cargo per month	**TEU**	**8568**	**6778**	**5375**	**5130**	**5245**	**5565**	**10056**	**11368**	**11805**	**11805**	**10880**	**9702**	**102278**

In Figure 7 transport capability for all cases is presented. Capability to transport cargo is calculated for one ship. Two vessel fleet is able to transport twice the amount of cargo accordingly.

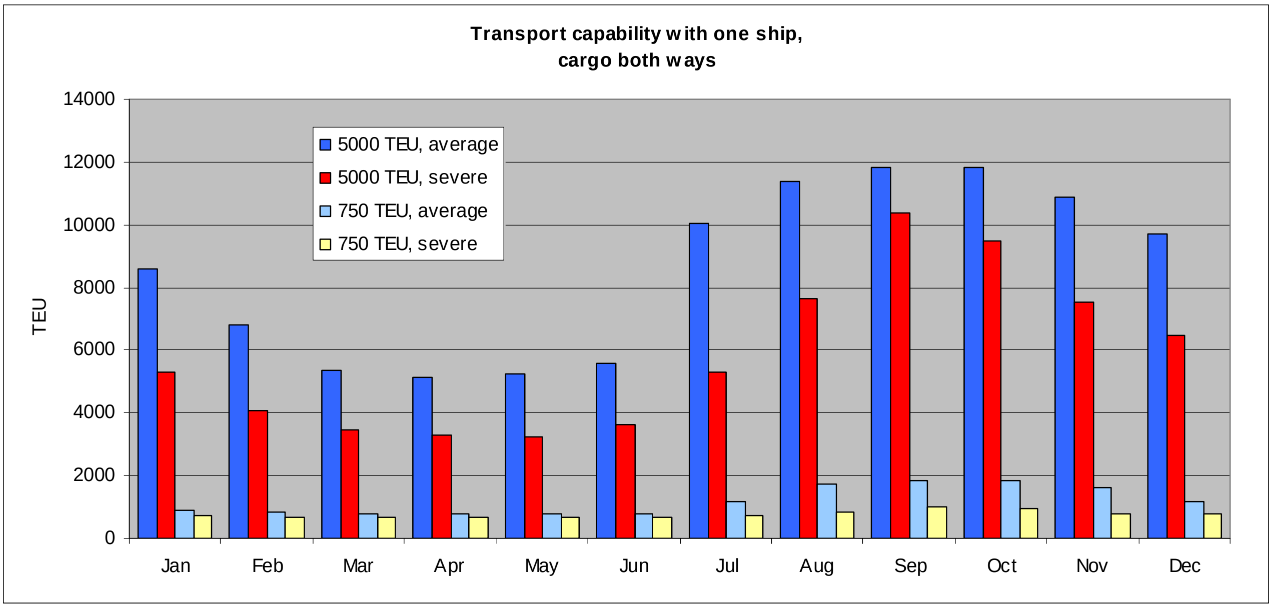


Figure 7. Transport capability for both vessels on average and severe winter.

5. Transport costs

Operational and capital costs of ships are evaluated in Table 6. Fuel consumption is calculated roughly by dividing the sailing time into independent and assisted operation. Power usage in independent operation is 100% and in assistance it is lower, 70%. Operation percentage, 100%, means that ships have no downtime included for example to dockings, etc.

5.1 Fee policy at Northern Sea Route

Today the basis for the fee system in NSR is that the cargo vessels operating in the area should pay the fairway dues. These dues are used to cover the cost of operating all the icebreaker fleet. The cost are to cover operation, maintenance and investment costs of the state icebreaker fleet. The cargo volume today is much lower than it used to be in the past. Today it is only about 2 million tons when it has been 6.5 million tonnes at late 80's.

The Russian government has only minor help to overall cost via budget funds. This has resulted today in a situation where the fee per tonne is very high. The fees are categorized for different cargo types and for container cargo it is 936 Russian Rubles per one ton of containers nominal gross mass, which converts to 33.7 USD/ton. For 20 ton nominal mass container, fee would be 674.4 USD/TEU. It is rather evident that this fee level will not be feasible to any commercial transport.

This type of fee policy is not suitable for cargo vessels which are capable to independent operation, as the fee should be paid whether the icebreaker assistance is needed or not. Neither it does take into account the ship-owners who want to use own icebreakers.

One can speculate with the fees by different approaches. One is to directly calculate the yearly cost with today's fees.The second is to lower the rate to correspond the increased cargo volume at NSR. The third approach will be that the fee is low and it is not assumed to cover any Russian icebreaker fleet costs since independent Double Acting ships are used.

The possible future systems for the fees for the Northern Sea Route has been discussed within the EU-funded R&D project "ARCOP" (www.arcop.fi). Within this project the Central Research Institute of Marine Fleet in Russia presented the paper on the current plans, but unfortunately the plans are not on a realistic basis. Also the discussion within ARCOP has shown, that the discussion on general level does not lead to any reasonable outcome. Thus it is recommended that the discussions with the Russian authorities will be started on the basis of a concrete project. It is already today known that some type of special agreements between the shipping companies and authorities can be and have been made.

Table 6. Operational and capital costs of transportation.

Ship type	5000 TEU	5000 TEU	750 TEU	750 TEU		
Winter type	Average	Severe	Average	Severe		
					unit	
General values						
Loadings/Year	20.5	14.0	17.5	11.3		
Payload	5000	5000	815	815	TEU	
Number of ships in fleet	1	1	1	1	pcs	
Fuel costs for fleet						
Operation % of yearly hours	100.0 %	100.0 %	100.0 %	100.0 %		
Sailing hours total	7778	8090	8410	8534	h	
Independent sailing hours	7778	8090	5584	3328	h	
Assisted sailing hours	0	0	2826	5206		
Loading & unloading time	48	48	20	20	h/one-way	
Loading & unloading time/year	982	670	350	226	h	
Power usage (independent)	35000	35000	13000	13000	kW	
Power usage (assisted)	24500	24500	9100	9100	kW	70% of full power
Total used energy	272235	283153	98313	90641	MWh	
Fuel consumption	180.0	180.0	185.0	185.0	g/kWh	
Total fuel consumption	49002	50967	18188	16769	ton/year	
Fuel price	250	250	250	250	$/ton	
Fuel cost	12251	12742	4547	4192	k$/year	
MDO & Lub oil cost	270	280	100	92	k$/year	(1% of fuel consumption @ 550 $/ton)
Fleet fuel cost total	**12520**	**13022**	**4647**	**4284**	k$/year	
Operational costs						
Insurance cost	800	800	800	800	$/day	
Administration	1100	1100	1100	1100	$/day	
Pay-roll	4300	4300	3000	3000	$/day	
Ship expenses	4300	4300	3000	3000	$/day	technical, drydocking, supplies
Daily running costs	10500	10500	7900	7900	$/day	
Operational costs total	**3833**	**3833**	**2884**	**2884**	k$/year	
Round trip based costs						
Fairway dues	0	0	0	0	k$/year	
Cargo handling	0	0	0	0	$/year	
Costs per year for fleet	**0**	**0**	**0**	**0**	k$/year	
Capital cost of fleet						
Building cost of ship	195000	195000	100000	100000	k$	
Term of pay	20	20	20	20	years	
Interest rate	0.08	0.08	0.08	0.08		
Cost per year	**19861**	**19861**	**10185**	**10185**	k$	
TOTAL YEARLY COST						
Operational costs	16353	16855	7531	7168	k$	
Capital costs	19861	19861	10185	10185	k$	
Total yearly cost	**36214**	**36716**	**17716**	**17353**	**k$**	
Delivered cargo per year	102278	69784	14244	9196	TEU	
Costs per TEU	354	526	1244	1887	$/TEU	

As a sensitivity comparison, costs to two additional destination ports at western end of the route are calculated. These ports are Murmansk and Rotterdam. Total yearly cost of transportation to these ports is presented in table 7.

Table 7. Total cost effect to additional ports.

Ship type	5000 TEU	5000 TEU	750 TEU	750 TEU	
Winter type	Average	Severe	Average	Severe	unit
Total cost, Iceland					
Operational costs	16353	16855	7531	7168	k$
Capital costs	19861	19861	10185	10185	k$
Total yearly cost	36214	36716	17716	17353	k$
Delivered cargo per year	102279	69785	14244	9196	TEU
Costs per TEU	**354**	**526**	**1244**	**1887**	**$/TEU**
Total cost, Murmansk					
Operational costs	16020	16698	7425	7057	k$
Capital costs	19861	19861	10185	10185	k$
Total yearly cost	35882	36559	17611	17242	k$
Delivered cargo per year	123779	79933	17242	10201	TEU
Costs per TEU	**290**	**457**	**1021**	**1690**	**$/TEU**
Total cost, Rotterdam					
Operational costs	16387	16872	7542	7181	k$
Capital costs	19861	19861	10185	10185	k$
Total yearly cost	36248	36733	17727	17366	k$
Delivered cargo per year	100034	68664	13934	9079	TEU
Costs per TEU	**362**	**535**	**1272**	**1913**	**$/TEU**

Transportation cost per TEU is lowered when transporting cargo to port of Murmansk. This is caused by savings in operational costs (fuel) and by increase in amount of delivered cargo. Total distance to Murmansk is approximately 1270 nm shorter than to Iceland. Distance to Rotterdam is a bit longer compared to port in Iceland, and correspondingly costs are bit higher.

6. Summary

The result of the study proposes that tranport cost from Aleutian Islands to Iceland via the Northern Sea Route would be from 354 $/TEU and 526 $/TEU for the large 5000 TEU vessel, for ‘average year’ and ‘severe year’ respectively, and 1244 $/TEU and 1887 $ /TEU for the smaller 750 TEU vessel.

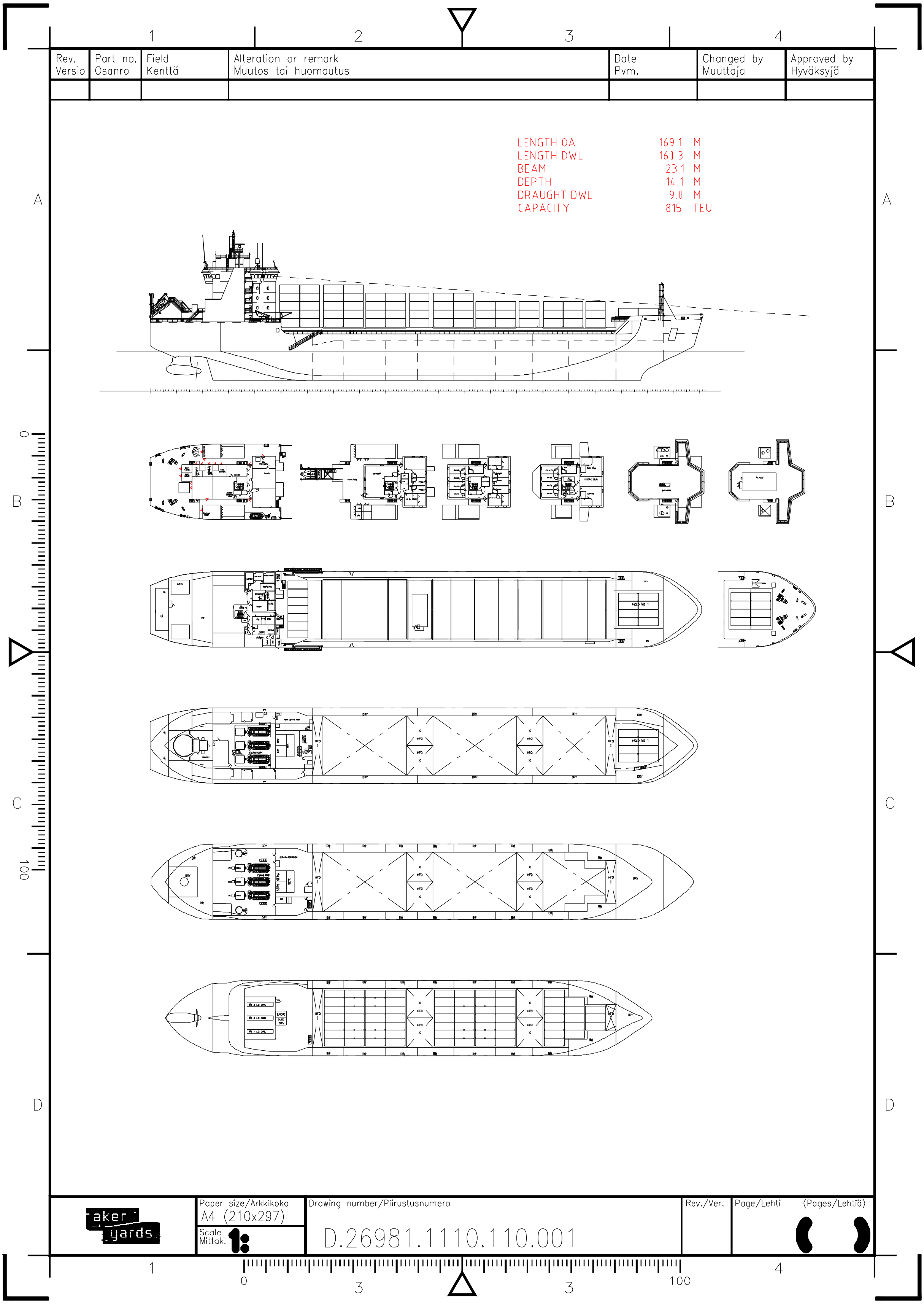
This result suggests that the latest developments of icebreaking and ship technologies, Double Acting operation which improves greatly the icebreaking capability and reduces required power and cost, and could make the operation independent of icebreakers, have indeed brought the Trans-Arctic commercial cargo traffic well in a feasible situation compared to the prevalent tariffs on the ‘southern route’ which is today abt. 1500 $ / TEU, from Japan to Europe or vice versa.

However, this result is seen strictly from the vessel point of view, and is applicable for just the Trans-Arctic leg of the voyage only. In addition, there are many other important factors affecting the overall result than the ‘cost due to the Arctic vessel’ which is the focus of this study. These are the fairway/icebreaker cost, and the harbour or terminal cost, which have been briefly mentioned and discussed in the study. The third factor, not mentioned yet, is the ‘feeder link cost’ inherited by the vessels and links which move the containers from the Arctic Shuttle Container Link terminals to and from the areas where they are actually destined to.

All of these factors are unclear, uncertain, and difficult to estimate. Most adverse of them might be the fairway due, of which a current estimate of 900 to 1000 USD/TEU can be given, for traffic going on today. The second could be the cost for building and running the terminals which could be in the same category than the cost of the vessels. Of course the terminals for the large and effective 5000 TEU vessel are much more expensive than those for the 750 TEU vessel, but cost per container may be lower for the larger traffic volume.

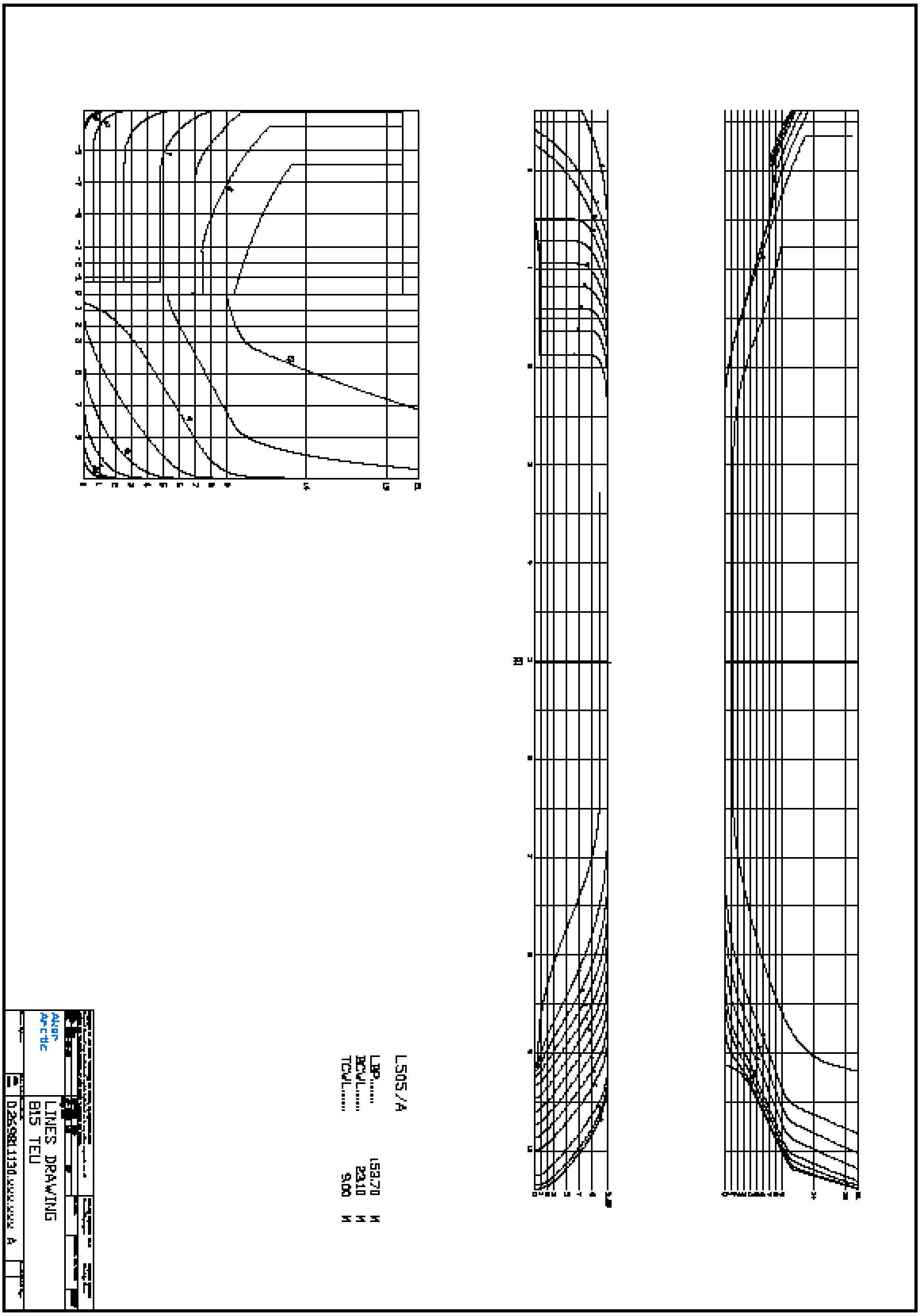
Of less importance and even more difficult to clarify and estimate may be the feeder link cost. Even the existing system using the southern route includes feeder links to the container hub ports, and how this picture would be changed for the Arctic Shuttle Container Link remains to be clarified. However it is expected that extra costs compared to the prevalent system could be created.

Appendix 1. 750 TEU Arctic Container Vessel General Arrangement

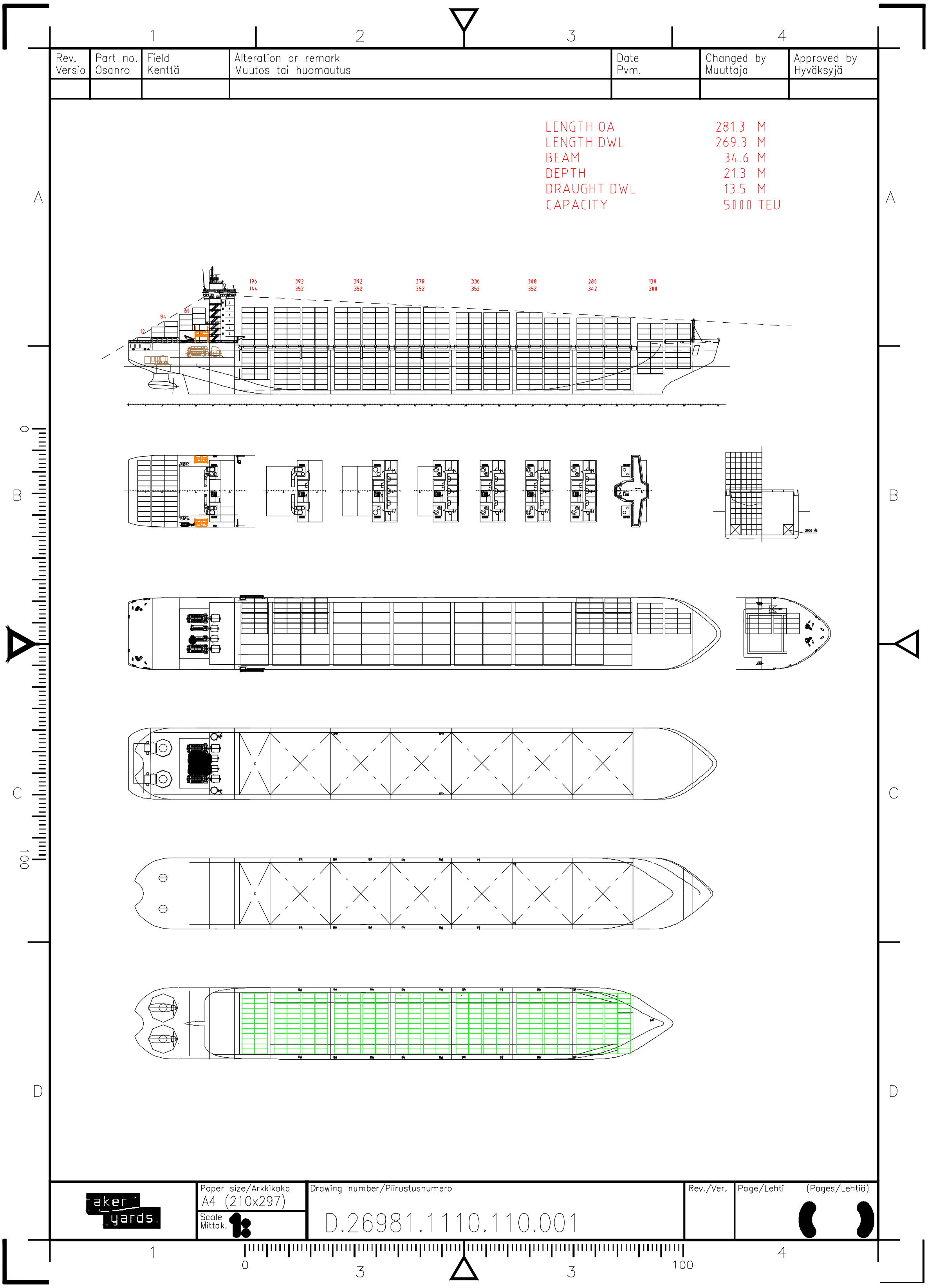


Preferred for innovation

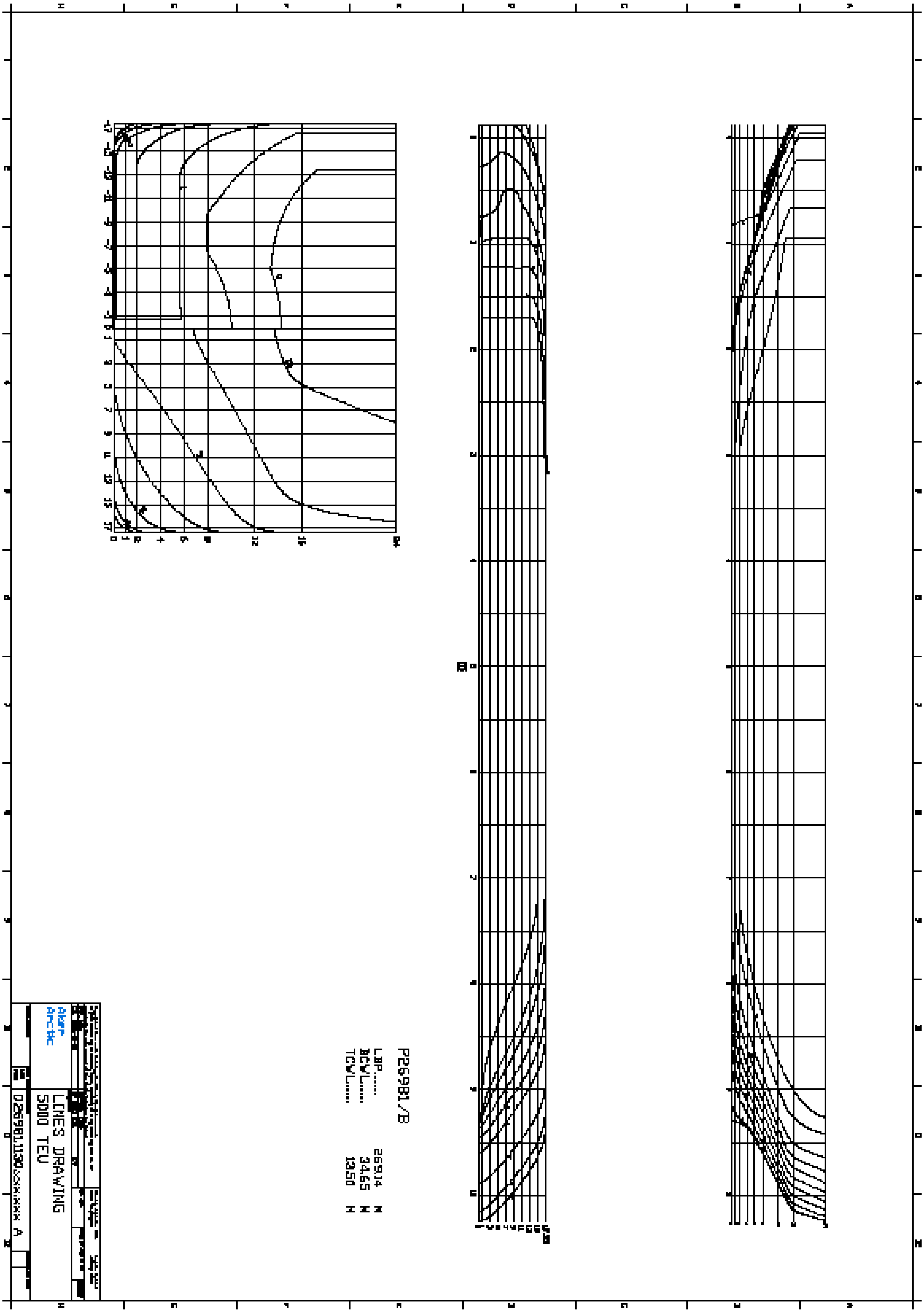
Appendix 2. 750 TEU Arctic Container Vessel Lines Plan



Appendix 3. 5000 TEU Arctic Container Vessel General Arrangement



Appendix 4. 5000 TEU Arctic Container Vessel Lines Plan



Appendix 5. Ice properties for average winter.

Leg ID	Bering Sea	Bering St	Chukchi	E Siberia	Laptev	Kara E	Kara C	Kara W	Kara Gate	Pechora	North Sea	Kara N	Pechora N	Sannik. St
Dist [nm]	552	356	370	622	577	238	285	302	50	354	1519	283	342	91
Dist [km]	1023	659	685	1152	1069	442	528	559	93	656	2813	523	633	169
Jan														
Level ice thickness [m]	0	0.3	1.1	1.5	0.6	1.0	0.9	0.6	0.5	0.4	0	1.1	0.6	1.4
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	3	5	6	5.5	6	4	4	4	3	0	4	4	3
Ridges per kilometre	0	3	5	4	3	5	2	2	6	2	0	2	2	4
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb														
Level ice thickness [m]	0	0.4	1.4	1.8	0.8	1.2	1.2	0.8	0.6	0.5	0	1.3	0.6	1.7
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	4	6	8	7	8	5	5	6	4	0	5	5	4
Ridges per kilometre	0	3	5	4	3	5	2	2	6	2	0	2	2	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar														
Level ice thickness [m]	0	0.5	1.6	2.0	1	1.4	1.3	1	0.7	0.6	0	1.5	0.7	1.9
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	4	9	9	7	10	5	5	6	4	0	5	5	4
Ridges per kilometre	0	3	5	4	3	5	2	2	6	2	0	2	2	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr														
Level ice thickness [m]	0	0.6	1.8	2.2	1.3	1.4	1.3	1	0.7	0.6	0	1.5	0.7	2
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	4.5	9	9.9	7.7	10	5.6	5.6	6.7	4.5	0	5.6	5.6	4
Ridges per kilometre	0	3	5	4	3	5	2	2	6	2	0	2	2	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May														
Level ice thickness [m]	0	0.6	1.8	2.2	1.3	1.4	1.3	1	0.7	0.7	0	1.5	0.7	2
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	4.5	9	9.9	7.7	10	5.6	5.6	6.7	4.5	0	5.6	5.6	4
Ridges per kilometre	0	3	5	4	3	5	2	2	6	2	0	2	2	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jun														
Level ice thickness [m]	0	0.5	1.7	2.1	1.2	1.3	1.2	0.9	0.6	0.6	0	1.3	0.6	1.9
Concentration [%]	0	95	95	95	95	95	95	95	95	95	0	98	98	95
Mean ridge thickness [m]	0	4.5	9	9.9	7.7	10	5.6	5.6	6.7	4.5	0	5.6	5.6	4
Ridges per kilometre	0	3	5	4	3	5	2	2	6	2	0	2	2	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jul														
Level ice thickness [m]	0	0	0.5	1.1	0.7	0.8	0.7	0.7	0.4	0	0	0.7	0.4	0.8
Concentration [%]	0	0	30	80	70	40	40	20	30	0	0	40	30	70
Mean ridge thickness [m]	0	0	9	9.9	7.7	10	5.6	5.6	6.7	0	0	5.6	5.6	4
Ridges per kilometre	0	0	5	4	3	5	2	2	6	0	0	2	2	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug														
Level ice thickness [m]	0	0	0	1	0.5	0	0	0	0	0	0	0	0	0.4
Concentration [%]	0	0	0	30	30	0	0	0	0	0	0	0	0	30
Mean ridge thickness [m]	0	0	0	9.9	7.7	0	0	0	0	0	0	0	0	4
Ridges per kilometre	0	0	0	4	3	0	0	0	0	0	0	0	0	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sep														
Level ice thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concentration [%]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean ridge thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ridges per kilometre	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct														
Level ice thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concentration [%]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean ridge thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ridges per kilometre	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov														
Level ice thickness [m]	0	0	0.3	0.4	0.5	0.3	0.2	0.1	0	0	0	0.3	0.2	0.4
Concentration [%]	0	0	85	85	85	85	85	85	0	0	0	85	85	85
Mean ridge thickness [m]	0	0	4	5	5	5	3	3	0	0	0	3	3	3
Ridges per kilometre	0	0	5	4	3	5	2	2	0	0	0	2	2	4
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec														
Level ice thickness [m]	0	0.2	0.8	0.9	1	0.7	0.6	0.4	0.3	0.3	0	0.7	0.5	0.8
Concentration [%]	0	85	85	90	90	85	85	85	85	85	0	85	85	90
Mean ridge thickness [m]	0	2	4	5	5	5	3	3	4	3	0	3	3	3
Ridges per kilometre	0	3	5	4	3	5	2	2	6	2	0	2	2	4
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 6. Ice properties for severe winter.

Leg ID	Bering Sea	Bering St	Chukchi	E Siberia	Laptev	Kara E	Kara C	Kara W	Kara Gate	Pechora	North Sea	Kara N	Pechora N	Sannik. St
Dist [nm]	552	356	370	622	577	238	285	302	50	354	1519	283	342	91
Dist [km]	1023	659	685	1152	1069	442	528	559	93	656	2813	523	633	169
Jan														
Level ice thickness [m]	0	0.9	1.7	2	1.6	1.8	1.5	1.3	1.1	0.5	0	1.6	1.2	1.7
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	4	7	7	6	7	6	5	6	4	0	6	4	6
Ridges per kilometre	0	4	7	6	5	7	3	3	7	3	0	3	2	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb														
Level ice thickness [m]	0	1	1.8	2.3	1.8	2	1.6	1.4	1.2	0.6	0	1.7	1.3	2
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	6	10	8	7	8	8.8	8	10	6	0	8	5	6
Ridges per kilometre	0	4	7	6	5	7	3	3	7	3	0	3	3	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar														
Level ice thickness [m]	0	1.1	1.9	2.4	2	2.1	1.7	1.5	1.3	0.7	0	1.8	1.4	2.2
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	6	10	9	8	9	8.5	8	10	6	0	9	6	6
Ridges per kilometre	0	4	7	6	5	7	3	3	7	3	0	3	3	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr														
Level ice thickness [m]	0	1.2	2	2.6	2.1	2.2	1.8	1.5	1.3	0.7	0	1.8	1.4	2.3
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	6	10	10	8.5	10	8.5	8	10	6	0	9	6	6
Ridges per kilometre	0	4	7	6	5	7	3	3	7	3	0	3	3	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May														
Level ice thickness [m]	0	1.2	2	2.6	1.8	2.2	1.8	1.5	1.3	0.7	0	1.8	1.4	2.3
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	6	10	10	8.5	10	8.5	8	10	6	0	9	6	6
Ridges per kilometre	0	4	7	6	5	7	3	3	7	3	0	3	3	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jun														
Level ice thickness [m]	0	1.1	1.9	2.5	1.7	2.1	1.7	1.4	1.2	0.6	0	1.7	1.3	2.1
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	6	10	10	8.5	10	8.5	8	10	6	0	9	6	6
Ridges per kilometre	0	4	7	6	5	7	3	3	7	3	0	3	3	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jul														
Level ice thickness [m]	0	0.8	1.2	1.7	1.3	1.5	1.2	0.8	0.8	0.4	0	1.3	0.8	1.6
Concentration [%]	0	90	90	90	90	90	90	90	90	90	0	85	80	90
Mean ridge thickness [m]	0	6	10	10	8.5	10	8.5	8	10	6	0	9	6	6
Ridges per kilometre	0	4	7	6	5	7	3	3	7	3	0	3	3	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug														
Level ice thickness [m]	0	0.3	0.8	1.2	0.8	1.1	0.8	0.6	0.6	0	0	1.1	0.5	1.2
Concentration [%]	0	60	80	80	80	80	75	65	60	0	0	70	50	75
Mean ridge thickness [m]	0	6	10	10	8.5	10	8.5	8	10	0	0	9	6	6
Ridges per kilometre	0	4	7	6	5	7	3	3	7	0	0	3	2	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sep														
Level ice thickness [m]	0	0	0.4	0.9	0.6	0.6	0.5	0.1	0.3	0	0	0.6	0.2	0.8
Concentration [%]	0	0	50	50	50	50	40	40	40	0	0	50	30	50
Mean ridge thickness [m]	0	0	10	10	8.5	10	8.5	8	10	0	0	8	4	5
Ridges per kilometre	0	0	7	6	5	7	3	3	7	0	0	3	2	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct														
Level ice thickness [m]	0	0	0.9	1.1	1	0.9	0.8	0.3	0.2	0	0	0.8	0.3	1
Concentration [%]	0	0	80	80	80	80	80	80	80	0	0	80	80	80
Mean ridge thickness [m]	0	0	6	6	5	7	5	3	4	0	0	5	2	4
Ridges per kilometre	0	0	7	6	5	7	3	3	7	0	0	3	2	4
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov														
Level ice thickness [m]	0	0.4	1.3	1.4	1.4	1.3	1.2	1	0.5	0.2	0	1.2	0.6	1.4
Concentration [%]	0	95	95	95	95	95	95	95	95	95	0	95	95	95
Mean ridge thickness [m]	0	3	6	6	5	7	5	3	4	3	0	5	3	5
Ridges per kilometre	0	4	7	6	5	7	3	3	7	3	0	3	2	4
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec														
Level ice thickness [m]	0	0.8	1.6	1.7	1.5	1.6	1.4	1.2	1	0.4	0	1.4	0.9	1.6
Concentration [%]	0	98	98	98	98	98	98	98	98	98	0	98	98	98
Mean ridge thickness [m]	0	3	6	6	5	7	5	3	4	3	0	5	3	5
Ridges per kilometre	0	4	7	6	5	7	3	3	7	3	0	3	2	5
Channel thickness [m]	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7. Detailed results of simulations.

5000 TEU around Nov. Zemlya

AVERAGE WINTER

Leg	Bering Sea	Bering St	Chukchi	E Siberia	Laptev	Kara E	Kara N	Pechora N	North Sea	Total
Length [nm]	552	356	370	622	577	238	283	342	1623	**4963**
Length [km]	1023	659	685	1152	1069	442	523	633	3006	**9191**
Avg. Speed [kn]										
Jan	19.0	16.2	9.7	7.3	13.5	9.6	10.6	14.1	19.0	
Feb	19.0	15.4	7.3	4.1	11.6	5.5	8.9	13.9	19.0	
Mar	19.0	14.6	3.2	3.4	9.9	3.2	7.7	13.3	19.0	
Apr	19.0	13.9	3.4	3.0	7.6	3.5	7.8	13.0	19.0	
May	19.0	13.7	3.5	2.9	7.8	4.5	8.0	13.1	19.0	
Jun	19.0	14.5	3.8	3.1	9.2	4.5	9.4	13.8	19.0	
Jul	19.0	19.0	16.4	9.6	14.0	14.3	16.2	17.7	19.0	
Aug	19.0	19.0	19.0	15.0	17.2	19.0	19.0	19.0	19.0	
Sep	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	
Oct	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	
Nov	19.0	19.0	15.9	15.3	15.0	15.9	16.6	17.3	19.0	
Dec	19.0	17.3	12.9	11.8	11.3	13.1	13.8	15.3	19.0	
Time [h]										Total
Jan	29.1	22.0	38.1	84.9	42.8	24.7	26.7	24.3	85.4	**378.0**
Feb	29.1	23.1	50.6	153.3	49.6	43.0	31.9	24.5	85.4	**490.5**
Mar	29.1	24.4	115.3	182.5	58.5	73.5	36.6	25.6	85.4	**631.0**
Apr	29.1	25.6	107.6	209.5	75.9	68.2	36.1	26.2	85.4	**663.5**
May	29.1	25.9	105.3	214.5	73.9	52.6	35.1	26.0	85.4	**648.0**
Jun	29.1	24.6	98.4	200.4	62.4	52.7	30.0	24.8	85.4	**607.8**
Jul	29.1	18.7	22.6	64.6	41.1	16.7	17.5	19.3	85.4	**315.0**
Aug	29.1	18.7	19.5	41.5	33.5	12.5	14.9	18.0	85.4	**273.1**
Sep	29.1	18.7	19.5	32.7	30.4	12.5	14.9	18.0	85.4	**261.2**
Oct	29.1	18.7	19.5	32.7	30.4	12.5	14.9	18.0	85.4	**261.2**
Nov	29.1	18.7	23.2	40.7	38.5	15.0	17.0	19.8	85.4	**287.5**
Dec	29.1	20.6	28.7	52.6	50.9	18.2	20.4	22.3	85.4	**328.2**

SEVERE WINTER

Leg	Bering Sea	Bering St	Chukchi	E Siberia	Laptev	Kara E	Kara N	Pechora N	North Sea	Total
Length [nm]	552	356	370	622	577	238	283	342	1623	**4963**
Length [km]	1023	659	685	1152	1069	442	523	633	3006	**9191**
Avg. Speed [kn]										
Jan	19.0	11.7	4.4	3.6	6.1	3.5	7.0	9.8	19.0	
Feb	19.0	10.7	2.5	2.4	4.5	2.9	6.0	8.9	19.0	
Mar	19.0	9.4	2.3	2.1	3.0	2.4	5.0	8.1	19.0	
Apr	19.0	8.7	2.4	2.0	2.6	1.9	4.5	7.8	19.0	
May	19.0	9.0	1.9	1.8	3.3	2.1	5.0	8.0	19.0	
Jun	19.0	9.6	2.2	2.2	4.0	2.2	5.0	8.4	19.0	
Jul	19.0	11.8	3.9	3.8	6.2	3.0	7.8	12.5	19.0	
Aug	19.0	16.4	6.8	6.6	10.2	5.6	11.5	16.4	19.0	
Sep	19.0	19.0	13.8	12.7	14.2	13.7	15.8	18.2	19.0	
Oct	19.0	19.0	11.1	10.9	11.7	10.7	13.5	16.8	19.0	
Nov	19.0	15.5	7.5	7.0	8.4	5.7	9.9	14.3	19.0	
Dec	19.0	12.7	5.3	5.8	7.0	4.5	8.4	11.9	19.0	
Time [h]										Total
Jan	29.1	30.5	84.6	172.9	94.3	68.3	40.6	34.8	85.4	**640.5**
Feb	29.1	33.2	150.7	257.8	128.6	83.2	47.1	38.4	85.4	**853.5**
Mar	29.1	38.1	162.4	298.5	192.7	99.6	56.6	42.3	85.4	**1004.6**
Apr	29.1	40.8	152.8	307.2	224.8	122.8	62.6	43.8	85.4	**1069.2**
May	29.1	39.6	191.0	345.0	175.1	115.4	57.0	42.7	85.4	**1080.3**
Jun	29.1	37.0	164.6	286.2	144.4	108.2	56.1	40.5	85.4	**951.4**
Jul	29.1	30.2	95.2	163.7	92.4	78.6	36.0	27.4	85.4	**638.1**
Aug	29.1	21.7	54.2	94.8	56.8	42.6	24.5	20.8	85.4	**430.0**
Sep	29.1	18.7	26.7	48.9	40.7	17.4	17.9	18.7	85.4	**303.8**
Oct	29.1	18.7	33.2	57.1	49.2	22.4	20.9	20.3	85.4	**336.3**
Nov	29.1	23.0	49.1	89.1	68.6	41.6	28.4	23.9	85.4	**438.3**
Dec	29.1	28.0	69.1	106.4	82.0	53.1	33.8	28.7	85.4	**515.7**

750 TEU Carrier around Novaya Zemlya

AVERAGE WINTER

Leg	Bering Sea	Bering St	Chukchi	E Siberia	Sannikova St	Laptev	Kara E	Kara N	Pechora N	North Sea	Total
Length [nm]	552	356	370	711	91	523	238	283	342	1623	**5089**
Length [km]	1023	659	685	1316	169	969	442	523	633	3006	**9425**
Avg. Spd [kn]											**Assisted**
IB Assisted under	**4.0**	**kn**									**[nm]**
Jan	17.0	13.8	4.3	4.0	4.6	9.1	4.5	6.1	10.3	17.0	**710.6**
Feb	17.0	12.2	4.0	4.0	4.0	4.8	4.0	4.7	10.4	17.0	**1409.9**
Mar	17.0	11.3	4.0	4.0	4.0	4.0	4.0	4.0	9.1	17.0	**2215.8**
Apr	17.0	10.1	4.0	4.0	4.0	4.0	4.0	4.0	8.6	17.0	**2215.8**
May	17.0	9.9	4.0	4.0	4.0	4.0	4.0	4.0	9.1	17.0	**2215.8**
Jun	17.0	10.8	4.0	4.0	4.0	4.0	4.0	4.1	9.6	17.0	**1933.2**
Jul	17.0	17.0	13.5	4.0	10.0	9.7	6.0	13.4	16.0	17.0	**710.6**
Aug	17.0	17.0	17.0	12.0	15.6	15.1	17.0	17.0	17.0	17.0	**0.0**
Sep	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	**0.0**
Oct	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	**0.0**
Nov	17.0	17.0	13.6	12.4	13.3	11.9	12.6	14.5	15.4	17.0	**0.0**
Dec	17.0	15.4	8.6	6.6	8.7	6.0	9.0	10.3	12.3	17.0	**0.0**

Time [h]											**Total**	**Assist.**	**Indep.**
Jan	32.5	25.8	86.2	177.7	20.0	57.4	53.1	46.0	33.3	95.5	**627.4**	**177.7**	**449.8**
Feb	32.5	29.2	92.4	177.7	22.8	109.6	59.6	60.6	32.9	95.5	**712.7**	**352.5**	**360.2**
Mar	32.5	31.6	92.4	177.7	22.8	130.8	59.6	70.6	37.6	95.5	**751.1**	**553.9**	**197.1**
Apr	32.5	35.2	92.4	177.7	22.8	130.8	59.6	70.6	39.5	95.5	**756.7**	**553.9**	**202.7**
May	32.5	36.1	92.4	177.7	22.8	130.8	59.6	70.6	37.5	95.5	**755.5**	**553.9**	**201.5**
Jun	32.5	33.0	92.4	177.7	22.8	130.8	59.6	69.7	35.7	95.5	**749.7**	**483.3**	**266.4**
Jul	32.5	20.9	27.4	177.7	9.1	53.8	39.7	21.0	21.4	95.5	**498.9**	**177.7**	**321.2**
Aug	32.5	20.9	21.7	59.2	5.9	34.6	14.0	16.6	20.1	95.5	**321.1**	**0.0**	**321.1**
Sep	32.5	20.9	21.7	41.8	5.4	30.8	14.0	16.6	20.1	95.5	**299.3**	**0.0**	**299.3**
Oct	32.5	20.9	21.7	41.8	5.4	30.8	14.0	16.6	20.1	95.5	**299.3**	**0.0**	**299.3**
Nov	32.5	20.9	27.3	57.3	6.8	44.1	18.9	19.5	22.2	95.5	**345.0**	**0.0**	**345.0**
Dec	32.5	23.1	42.9	107.8	10.5	87.0	26.5	27.3	27.7	95.5	**480.8**	**0.0**	**480.8**

SEVERE WINTER

Leg	Bering Sea	Bering St	Chukchi	E Siberia	Sannikova	Laptev	Kara E	Kara N	Pech N	North Sea	Total		
Length [nm]	552	356	370	711	91	523	238	283	342	1623	**5089**		
Length [km]	1023	659	685	1316	169	969	442	523	633	3006	**9425**		
Avg. Spd [kn]											**Assisted**		
IB Assisted under	**4.0**	**kn**									**[nm]**		
Jan	17.0	7.3	4.0	4.0	4.0	4.0	4.0	4.0	5.5	17.0	**2215.8**		
Feb	17.0	4.2	4.0	4.0	4.0	4.0	4.0	4.0	4.0	17.0	**2215.8**		
Mar	17.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	17.0	**2913.6**		
Apr	17.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	17.0	**2913.6**		
May	17.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	17.0	**2913.6**		
Jun	17.0	4.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	17.0	**2557.5**		
Jul	17.0	6.3	4.0	4.0	4.0	4.0	4.0	4.0	9.2	17.0	**2215.8**		
Aug	17.0	13.9	4.0	4.0	4.6	4.5	4.0	4.4	14.1	17.0	**1318.7**		
Sep	17.0	17.0	4.6	4.1	11.4	7.7	5.1	12.1	16.6	17.0	**0.0**		
Oct	17.0	17.0	4.5	4.1	7.8	6.1	4.0	9.3	14.8	17.0	**238.4**		
Nov	17.0	12.8	4.0	4.0	4.0	4.0	4.0	4.7	11.1	17.0	**1933.2**		
Dec	17.0	8.2	4.0	4.0	4.0	4.0	4.0	4.0	7.7	17.0	**2215.8**		
Time [h]											**Total**	**Assist.**	**Indep.**
Jan	32.5	48.5	92.4	177.7	22.8	130.8	59.6	70.6	61.6	95.5	**792.0**	**553.9**	**238.1**
Feb	32.5	85.7	92.4	177.7	22.8	130.8	59.6	70.6	84.9	95.5	**852.5**	**553.9**	**298.6**
Mar	32.5	89.0	92.4	177.7	22.8	130.8	59.6	70.6	85.4	95.5	**856.4**	**728.4**	**128.0**
Apr	32.5	89.0	92.4	177.7	22.8	130.8	59.6	70.6	85.4	95.5	**856.4**	**728.4**	**128.0**
May	32.5	89.0	92.4	177.7	22.8	130.8	59.6	70.6	85.4	95.5	**856.4**	**728.4**	**128.0**
Jun	32.5	87.0	92.4	177.7	22.8	130.8	59.6	70.6	85.4	95.5	**854.3**	**639.4**	**215.0**
Jul	32.5	56.1	92.4	177.7	22.8	130.8	59.6	70.6	37.0	95.5	**775.0**	**553.9**	**221.1**
Aug	32.5	25.7	92.4	177.7	20.0	115.0	59.6	64.6	24.3	95.5	**707.2**	**329.7**	**377.5**
Sep	32.5	20.9	79.7	173.4	8.0	68.0	46.4	23.4	20.6	95.5	**568.6**	**0.0**	**568.6**
Oct	32.5	20.9	81.5	172.0	11.7	85.4	59.6	30.3	23.1	95.5	**612.6**	**59.6**	**553.0**
Nov	32.5	27.9	92.4	177.7	22.8	130.8	59.6	59.9	30.7	95.5	**729.8**	**483.3**	**246.5**
Dec	32.5	43.5	92.4	177.7	22.8	130.8	59.6	70.6	44.6	95.5	**770.0**	**553.9**	**216.0**