BACHELOR THESIS – ME 141502

Comparing Total Fuel Consumptions of a Ship between East Asia and European Countries Travelling the Conventional Route Versus the North-East Passage

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DOUBLE DEGREE PROGRAM OF
MARINE ENGINEERING DEPARTMENT
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember
Surabaya
2018

SKRIPSI – ME 141502

Perbandingan Konsumsi Bahan Bakar sebuah Kapal ketika Beroperasi dari Negara Asia Timur ke Negara Eropa melalui Jalur Pelayaran Suez dan Jalur Pelayaran Artik

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2018

APPROVAL FORM

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BACHELOR THESIS

Submitted to Comply One of the Requirement to Obtain a Bachelor of Engineering

on

Department of Marine Engineering

Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

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July 2018

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Declaration of Originality and Compliance of Academic Ethics

I hereby declare that this thesis contains original research work by the undersigned candidate, as part of his B.Eng (Bachelor of Engineering) at Double Degree Program Marine Engineering Department studies.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

Reinhart Yosafat

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"Comparing total fuel consumption of a ship between East Asia and European Countries travelling the conventional route versus the North-East Passage."

Surabaya, August 1st 2018

Signature

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Executive Summary

Global Warming is the most compelling environmental issues in the world recently. Almost a century, the temperature increased 0,74° Celsius and made the ice in North and South Pole melt in high rate [2].
Some people say that global warming brings the negative effect for the society, however businessman especially in shipping and logistic industries believe that the melting ice process will shorten the distance between East Asia Countries and European Countries. Melting ice in Artic Sea, open a new route, called Northeast Passage. Using Northeast Passage will reduce distance and time of the voyage.
The big idea of this thesis is to compare 2 routes between Northeast Passage and Suez Canal for delivering cargoes from East Asia countries to European Countries or vice versa. Comparing total resistance, total fuel consumption and total cost for bunkering and additional charges are the main topic on this bachelor thesis.
Results of this bachelor thesis, total fuel consumption for conventional route is 5810,231215 tons with operational hours of a vessel is 596,15 hours and the total fuel consumption per hour is 9,74625 tons / hour. By using Northeast Passage, a vessel can reduce 1900 nautical miles or saves 17% from the normal distance. There are 2 methods for calculating the resistance of the ship when passing through ice condition, Lindqvist and Riska method. If a vessel wants to save 20% of their fuel consumption (Lindqvist method : 4621,58 tons ; Riska Method : 4670,82 tons) compared to conventional route, a vessel just only save 5% of their operational hour (needs 565,367 hours to travel Northeast Passage). Then, if a vessel wants to speed up and save 11% (528,03 hours) of the operational hour it reduces the saving of fuel consumption to 9% (Lindqvist Method 5270,615 tons ; Riska Method 5322,38 tons).
Bunkering Plan at conventional route is occurred at Hongkong Port, Port Klang and Piraeus Port with price 463 USD, 460 USD and 467 USD respectively. Suez Canal is controlled by a country so a vessel needs to pay some money for passing through the canal. The total price that needed to be paid for conventional route is 2.997.496,754 USD.Northeast Passage is considered as International water because there is too much complexity about the declaration. So, there is no taxes for a vessel when passing through the passage. Bunkering is occurred at Hamburg and one of Port in Russsian Coastline with price 447 USD at Hamburg and 400 USD at Russian. 1962466 USD needs to be paid for a vessel passing through Northeast Passage from Hamburg to Hongkong. The usage of Northeast Passage can saves 35% of expense or equivalentto 1035031 USD.

Keyword: Global Warming, Northeast Passage, Ice Route, Ice Resistance, Fuel Oil Consumption.

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ABSTRAK

Isu pemanasan global menjadi isu linkungan paling fenomenal beberapa tahun terakhir. Selama satu dekade terakhir, suhu bumi naik secara konsan sebesar 0,74 ° Celsius dan membuat Kutub Utara dan Kutub Selatan meleleh [2].

Beberapa orang berasumsi bahwa pemanasan global memberikan dampak buruk kepada manusia. Tetapi, seorang pengusaha yang secara spesifik bergerak di bidan logistic dan pelayaran menyadari bahwa efek melelehnya es di kutub dapat memperpendek jarrah tempuh dari Negara di Asia Timur menuju Eropa. Melelehnya es di Kutub Utara, membuka jalur baru yang disebut Pelayaran Jalur Artik.

Ide dalam penelitian ini adalah membandingkan 2 rute, yaitu rute konvensional melalui terusan Suez dan menggunakan Jalur Artik yang menghubungkan negara Asia Timur dan Eropa. Membandingkan total tahanan kapal, kebutuhan bahan bakar serta perbandingan harga bahan bakar kapal menjadi topik utama dalam penelitan ini.

Hasil dari penilitian ini, total bahan bakar yang dibutuhkan pada jalur Suez adalah 5810,231215 ton dengan waktu tempuh 596,15 jam maka dalam 1 jam pengoperasian membutuhkan 9,74625 ton bahan bakar. Dengan menggunakan jalur Artik, sebuah kapal dapat memangkas jarak perjalanan sebesar 1900 mil laut atau setara 17% dari jalur konvensional. Ada 2 metode umum untuk menghitung tahanan kapal ketika beroperasi pada kondisi es, metode Lindqvist dan Riska.

Ketika kapal ingin menghemat 20% bahan bakar (Lindqvist method : 4621,58 tons ; Riska Method : 4670,82 tons) dibandingkan dengan rute konvensional, sebuah kapal hanya mampu menghemat 5% dari waktu operasional (membutuhkan 565,367 jam untuk melewati Jalur Artik). Kemudian, ketika kapal menaikan kecepatan dan menghemat 11% waktu operasional (528,03 jam), kapal mampu mengehmat bahan bakar sampai 9% dari jalur konvensional (Lindqvist Method 5270,615 tons ; Riska Method 5322,38 tons).

Pembelian bahan bakar kapal di jalur konvensional dilakukan di Hongkong, Port Klan dan Piraues dengan harga $463,$460 dan $467 berurutan. Terusan Suez dimiliki oleh sebuah negara, oleh karena itu kapal harus membayar pajak ketika melewatinya. Biaya yang harus dikeluarkan untuk melewati jalur konvensional adalah $2.997.496,754. Jalur Artik dianggap sebagai perairan internasional, sehingga tidak ada pajak. Pembelian bahan bakar dilakukan di Hamburg dan perairan Rusia dengan harga $ 447 dan $400 berurutan. Total biaya yang dikeluarkan adalah $1.962.466 . Penggunaan Jalur ini bisa menghemat biaya sebesar 35% atau setara $1.035.031 .

Kata Kunci: Pemanasan Global, Pelayaran Jalur Artik , Tahanan Kapal dalam kondisi es, Konsumsi Bahan Bakar.

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PREFACE

First of all, I would like to thank to God for every single His grace and peaceful that given to the author, so author can finish this Bachelor Thesis with title "Comparing total fuel consumption of a ship between East Asia and European Countries Travelling the Conventional Route Versus North-East Passage" well.

This Bachelor Thesis is submitted to comply one of the requirement to obtain Bachelor Engineering Degree in Double Degree Program Department of Marine Engineering, Faculty of Marine Technology, Institute Teknologi Sepuluh Nopember – Hochschule Wismar , Germany. There were so many obstacles that author may had during the process for finishing the Bachelor Thesis. So, it's necessary for the author to say thank and gratitude for anyone who support me during this process.

1. My beloved Father and Mother, my sister and all my family who always give me support and motivation whenever I need to look forward for my success.
2. Prof. Dr.-Ing Jürgen Siegl and Dipl.-Ing Gerrit Tuschling as my 1st Supervisor and 2nd Supervisor in Rostock, Germany for the support and guidance during the process of my Bachelor Thesis.
3. Ir. Hari Prastowo M.Sc. as my supervisor in Institut Teknologi Sepuluh Nopember Surabaya, who gives me a suggestion in the beginning of the process.
4. All of my friends for supporting me, helping me, giving advice and suggestion and also motivating me during the process of Bachelor Degree.
5. My beloved, Jane Amanda Susanto, who always be author's number one supporter in every condition.

Hopefully, this Bachelor Thesis can help readers to expand their knowledge and give inspiration for whoever needs it. Author realizes that this Thesis is not perfect, so author is looking forward for any suggestions and critics for authors development in writing skills.

Rostock, May 30th 2018
Author

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List of Abbreviations

Symbol	Explanation	Unit
h_i	Ice Thickness	m
K_i	Thermal Conductivity	W/m K
L_f	Latent heat from fusion	J/kg
S_i	Ice Salinity	ppt
v_b	Brine volume	-
σ_b	Flexural Strength	N/mm^2
E	Elastic Modulus	kN/ mm^2
Ø	Angle between the waterline and bow	degree
α	Angle between the waterline and longitudinal axis	degree
μ	Frictional Coefficient	-
F_v	Crushing Force	N
R_c	Crushing Resistance	N
R_b	Breaking by Bending Resistance	N
R_s	Submersion Resistance	N
∇	Volume Displacement	m^3
Lwl	Length of Waterline	m
B	Breadth	m
T	Draught	m
Cb	Coefficient Block	-
Δ	Displacement	ton
S	Wetted Surface Area	m^3
Fn	Froude Number	-
Vs	Service Speed	m/s
Rn	Reynold Numbers	-
v	kinematic viscosity	m^2/s
Rf	Fricition Resistance	N
EHP	Effective Horse Power	kW
THP	Thrust Horse Power	kW
ηH	Hull Efficiency	-
DHP	Delivered Horse Power	kW
ηrr	Rotative Relative Efficiency	-
ηo	Propulsion Efficiency	-
Pc	Propulsive Coefficient	-
SHP	Shaft Horse Power	kW

ηs	Shaft efficiency	-
BHPscr	Brake Horse Power	kW
BHPmcr	Brake Horse Power maximum rating	kW
SFOC	Specific Fuel Oil Consumption	g / kWh

CHAPTER I
INTRODUCTION

1.1. Background

Nowadays, the temperature of surfaces around the world increased dramatically. It was happened because of global warming effects. By increasing of surfaces temperature, ice melts in very high rate. Scientists believe that the effect of global warming can melt the ice of Arctic sea and continue with flooding in several places around the world because of sea level rises when ice melts [2].

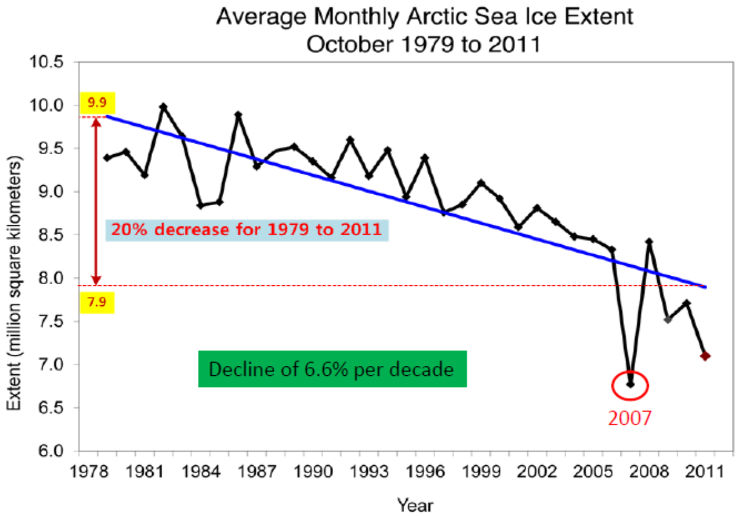

Figure 1 Changes in Artic Sea Ice Extent Since 1979-2011 (Source:[2])

Northeast Passage is a new route for shipping industries, connects European and Asia Pacific Countries, along the Arctic Ocean coasts of Norway and Russia. Northeast Passage is one of several Arctic Maritime Routes for shipping, the others being the Northwest Passage (along Canada's and Alaska's coasts) and the Transpolar Route (going through the North Pole). Northeast Passage was established in 1878 by David Melgueiro, a Portuguese Navigator. However, this route was extremely dangerous because of its environmental condition, extremely cold.

For this past decade, global warming was the most famous issues relating environment. Global warming makes ice at North Pole melts and follows by the opening of shipping route, called Northeast Passage. The Northeast Passage is a shorter route to connect Northeast Asia with Europe, compared to the existing routes through Suez Canal, Panama Canal, and Cape of Good Hope.

It is undeniable that the development of Northeast Passage will reduce shipping operational time by reducing the distance between East Asia and Europe and may lead to reduce operational costs especially in fuel cost. Generally speaking, costs for fuel has a big contribution for total cost of operation of ship. Maritime shipping is highly sensitive to bunker fuel costs as they represent between 45 and 50 percent of operating costs. For Post – Panamax Plus (> 10.000 TEUs), fuel charges account for 50% of their annual operating costs [3].

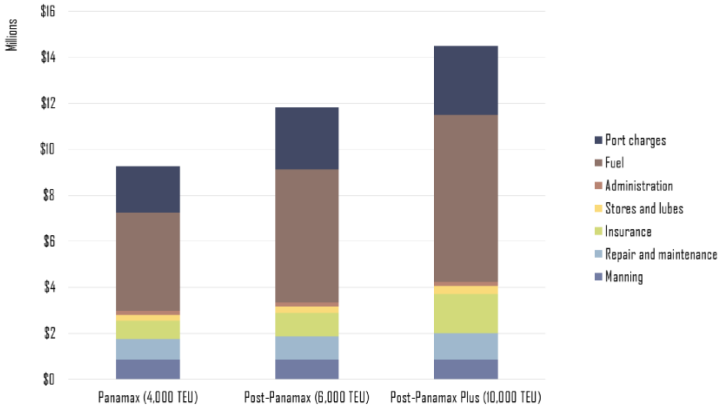

Figure 2 Proportion of Operating Cost for Shipping (Source:[3])

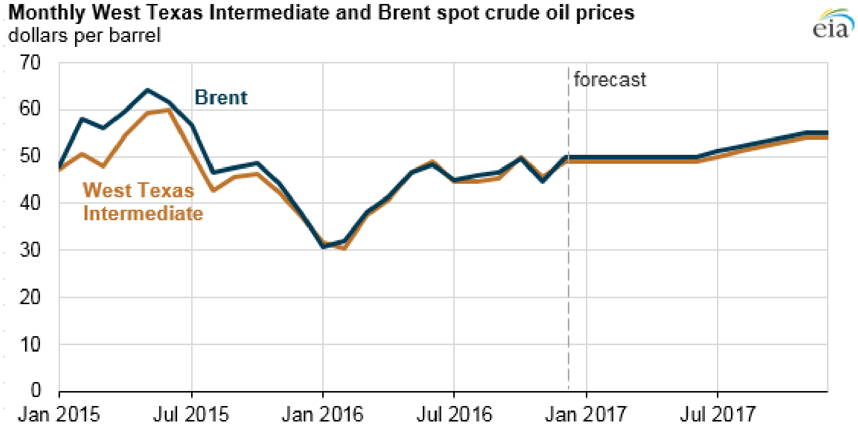

Figure 3 Bunkering Cost Prediction (Source: [3])

Meanwhile, Shipping Companies, generally use Suez Canal as their main route to deliver their cargoes from East Asia to Europe or vice versa. However, Northeast Passage have a lot of problem especially in environmental conditions. Although global warming melts some of ice in Arctic Sea, there are still some ices that still in solid particle. The existence of ice, will increase the ship resistance because solid particle has a higher viscosity rather than the liquid form. In addition, ship needs additional equipment like ice breaker to remove ice from her path. Ice also may be harmful for the durability of ship hull because of their solid form.

Figure 4 Comparison between NEP and Conventional Route (Source:[2])

It is true that by using Northeast Passage for the operation will reduce the distance for delivering cargoes from East Asia to Europe countries. However, it needs more consideration especially in increasing ship resistance that relating to fuel costs and also in safety consideration. By knowing the total resistance of ship, the total fuel consumption will be known and the suitable routes can be chosen.

1.2. Statements of Problems

Based on the description above the statement of problem of this thesis are;

1. How to calculate ship resistance when it operates at Conventional Route?
2. How to calculate ship resistance when it operates at Northeast Passage?
3. How to calculate fuel consumption of the ship when it operates at Conventional Route?
4. How to calculate fuel consumption of the ship when it operates at Northeast Passage?
5. What is the most suitable route for transporting cargoes from East Asia to Europe?

1.3. Research Limitations

The limitations of this thesis are:

1. This thesis is focusing on the ship resistance and fuel oil costs when it operates at Northeast Passage.
2. Safety consideration is not included.
3. This thesis is also focusing on route from Hongkong Port to Hamburg Port
4. Infrastructure which support the operation like bunkering at Northeast Passage is considered feasible.
5. The recommendations on the final conclusion is only related in fuel consumptions.
6. The object is considered to have fulfilled the requirement from IMO about Ship that operates in Polar waters.

1.4. Research Objectives

The objectives of this thesis are;

1. Determine the total ship resistance when it operates at Northeast Passage.
2. Determine the total fuel consumption when it operates at Northeast Passage.
3. Selecting the most efficient route in terms of fuel costs for delivering cargoes from East Asia to Europe or vice versa.
4. Selecting the most efficient speed for North-East Passage.

1.5. Research Benefits

The benefits of this thesis are:

1. Knowing which route has the most efficient in economic to transport cargoes.
2. Minimizing costs for transporting cargoes
3. Improving the export volumes for countries in East Asia and Europe.
4. Reducing number of exhaust gases and will improve the quality of air by using less fuel oil consumption.

CHAPTER II
STUDY LITERATURE

2.1. Northeast Passage

Northeast Passage connects European Continent with East Asia Countries by Northern Atlantic, along the Arctic Ocean coasts of Norway and Russia. This route is an alternative route for shipping company for delivering their cargoes to East Asia from European Port. The Northeast Passage transverses the Barents Sea, Kara Sea, Laptev Sea, East Siberian Sea and Chukchi Sea. Scientist believe this route also has amount of natural resources like oil and gas and hasn't been explored.

Figure 5 NEP(blue) and Conventional Route(red)
(Source: [2])

The Northeast Passage is a shorter route to connect East Asia with Western Europe, compared to the existing routes like Suez Canal and Cape of Good Hope. Here by the table of distance comparison between Port of Rotterdam and Port in Asia.

Table 1 Distance between Asia Countries and Rotterdam Port

	To Rotterdam, via:				
From	Cape of Good Hope	Suez Canal	NEP	Difference Between Suez Canal & NEP	
Yokohama, Japan	14.448 nm	11.133 nm	7010 nm	37 %	4123 nm
Busan, South Korea	14.084 nm	10.744 nm	7667 nm	29%	3007 nm
Shanghai, China	13.796 nm	10.557 nm	8046 nm	24%	2511 nm
Hongkong, China	13.014 nm	9701 nm	8594 nm	11%	1107nm
Ho Ch Minh City, Vietnam	12.258 nm	8887 nm	9428 nm	-6%	-541 nm

For the corporate players in bulk shipping of relative low-value raw materials, cost savings for fuel may appear as a driver to explore the Northern Sea Route for commercial transits, and not necessarily reduces lead time. The northeast passage allows economies of scale compared to another route, with vessel draught and beam limitation. Environmental demands faced by the maritime shipping industry may emerge as a driver for developing the Northeast Passage. Increased awareness of environmental benefits and costs for both the Northeast Passage and Suez will probably be important factors in this respect. In 2012, 46 sailed the Northeast Passage and 85% from the population were carrying gas or oil as tankers vessel [1]. However, the development of this route is not followed with the development of Russian coastal line especially for the city in Russia coastal that has a capability to be a transit port for bunkering. The political issue is the biggest problem of this route. Policy of Russian government may not develop this route well.

Figure 6 Tanker operates in Northeast Passage
(Source: [1])

The physical characteristics of Northeast Passage also variative especially about the depth along the route. The Northeast Passage is described as running through the Kara, Laptev, Vostochno (East Siberia), Chukchi Seas. The Northeast Passage can be entered from the west through the Yugorskiy Shar Strait or the Karskiye Vorota Strait, or by passing north of the Novaya Zemlya Islands and from the east through the Beiring Strait. Open water depths for the Northeast Passage vary from between 10 to 200m. Different route options require transiting one or more of the many straits along the route. The water depths in the straits are as follows [1]:

- Kara Strait- 50m
- Matisena and Lenina – no less than 25m
- Vilkitskogo – 50 to 250m
- Shokalskogo – 200 to 250m
- Yugorskiy Shar – 13m
- Sannikova – 13 to 15m
- Dmitriya Lapteva – 8 to 9m
- Beiring – 30 to 50m

The environment of Northeast Passage is unpredictable. But in general, the condition of Northeast Passage is extremely cold because of the location is on North Pole. Global warming effects the ice at North Pole. This has resulted in a decline in the extent of the sea ice coverage by 30%. Northeast Passage can be divided into three principal climatic areas:

- Atlantic Sea (Barents Sea, western of Kara Sea) → Frequent Storms in winter and dull weather with frequent fogs and precipitation in summer.
- Siberian Area (eastern of Kara, Laptev Sea, and western of East Siberian Sea) → influenced by Siberian Low in winter. Air temperatures here tend to be lower than in surrounding areas in winter and higher in summer near the continental coast although the northern parts of the area remain cool even during summer.
- Pacific Area (eastern part of the East Siberian Sea, Chuckchi Sea) → in winter it is influenced by Pacific weather systems. Air temperature is higher and wind strength, and the amount of precipitation in this area are greater than in the surrounding areas. Summer can be stormy with wide fluctuations in temperatures and periods of dense fog.

Figure 7 Map of Russian Coastline
(Source: [1])

Before operating in Northeast Passage, shipping company must consider some elements:

- Air Temperature

  In summer condition, the air temperature is close to 0° Celsius. In autumn, temperatures drop below 0° Celsius with regional variations. In the northern parts of Kara and Laptev seas and in the central part of East Siberian Sea, this transition occurs in late August. [1]

- Visibility
  Northeast Passage is particularly susceptible to frequent fogs during the summer months, reducing the visibility. Fog is most frequent near the edge of concentrated ice. Fog may cover large areas of the NSR and may persist for long periods. The more hazardous whiteout condition occurs when the sky and snow assume a uniform whiteness, making the horizon indistinguishable. These occur most frequently in spring and autumn when the sun is near the horizon and the sky is overcast. Optical Haze, can also be experienced in the area. It occurs when layers of colder and warmer air interact in a convective pattern, refracting light in a manner that causes objects to appear blurred. [1]
- Noise
  Atmospheric conditions can allow noise to travel much further. Cold surfaces temperatures hold sound waves captive. Under the right combination of air temperature, wind speed and surrounding surface normal conversations can carry over distances up to 3 km. [1]
- Wind
  Direction, speed and persistence of wind can influence the success of navigating. Blizzards may be encountered early June and late October in the season with their incidence being higher in the northern parts of the region. In eastern and western of the passage, the number of days with blizzard during winter months averages around 12 to 14. [1]
- Sea Level Variations
  All arctic seas are characterized by the pronounced seasonal level variations, the minimum level (0,2 m on average) is occurred in March until April and the maximum (0,4 m on average) in October until December. [1]
- Waves
  Depends on the speed and direction of the wind, water depth and the presence and distribution of ice. The most severe sea states (wave heights of 4 to 5m) usually develop in early autumn (September and October) but by November the seas, except the Southern part of the Chukchi Sea, are almost completely covered by ice. [1]
- Ice
  In years with heavy ice conditions, arctic sea is almost covered with drifting ice in summer. In years with light ice conditions, the ice edge withdraws towards the northern sea boundaries. Ice cover normally begins melting around mid-June. Refreezing in the northern part of Kara and Laptev Seas and in the northern part of Chukchi Sea doesn’t usually begin until mid to late September.

By late October, ice thickness reaches on average 25 to 30 cm. by December it will reach 70 to 90 cm. The thickest level of ice is 140 to 210 cm, occurs in May prior to the opening of the traditional period of activity on Northeast Passage.

Sea ice is generally classified by age and thickness:

- New ice (up to 10 cm thickness)
- Young (10 to 30cm thick)
- First year ice (> 30 cm) but has not survived a summer melt season.
- Multiyear ice (survived a summer melt season and have a range from 2-4 m in thickness)
- Ridges are formed when sheet ice forms into piles as a result of wind or currents. Ridges can be several meters thick, forming a significant barrier to navigation.
- Fast ice is ice that forms along the coastline and extends seawards in generally shallow water.
- Drift ice forms in open water and moves under the influence of wind and currents.

The most important characteristics of ice conditions in summer is the location and amount of concentrated ice. Winds and currents can drive ice to move fast and ice situations may change quickly. [1]

2.2. Sea Ice Characteristics

This section will explain the differences of sea ice types and to clarify that. This section has a purpose to give a brief knowledge about the topic.

2.2.1. Sea Ice Types

Sea Ice is divided into some groups depending on its age and the location of the ice. On the figure below, ice is divided based on how far the location of ice from the nearest land. Based on distance classification, ice can be divided into 2 main groups, Fast Ice Zone and Pack Ice Zone [6]. Fast Ice Zone is the area where the sea ice is firmly connected to the seafloor, while the Pack Ice Zone is the area where the ice is more or less drifting free.

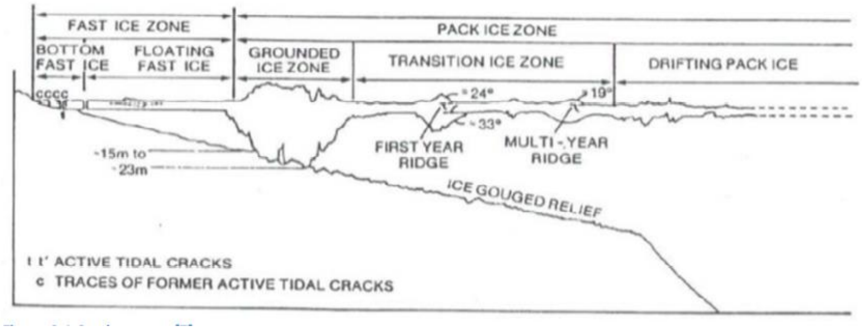

Figure 8 Sea Ices Zone
(Source :[6])

2.2.2. Physical & Mechanical Properties

Physical properties that will be reviewed are ice thickness, salinity, density and brine volume, porosity. The mechanical properties reviewed are flexural strength and Elastic Modulus for Ice.

a. Ice Thickness

Ice thickness is an important parameter when calculating the ice resistance of ship. The thickness is determined by the average air temperature, the freezing time, wind speed, ocean heat flux, snow type and thickness, and surface radiation balance.

The thickness of ice can be found from the *Stefan Equation*

Equation 1 Stefan Equation for Ice Thickness

$$h_i = \sqrt{\frac{2K_i}{\rho_{ice}L_f}[T_b - T_a]t_{freeze}}$$

This equation is only applicable for first-year ice, and will always overpredict the ice thickness, since it does not consider snow cover insulation, wind and ocean heat flux. However, for this bachelor thesis, the value of ice thickness is known, around 10 – 20 cm.

b. Ice Salinity and Density

Salinity of the ice depends on the age of the ice, density and ice thickness.

Equation 2 Ice Salinity Formulation

$$S_i[ppt] = 4{,}606 + \frac{91{,}603}{h_i[cm]}$$

Where S_i is the average salinity of the ice sheet in parts per thousand and hi is the ice thickness in meter. For older ice year, the salinity will be lower since the majority of the salt has been drained from the ice. In arctic sea water the salinity varies generally between 30 ppt and

34 ppt during winter, however in summer the salinity is around 25-30 ppt. [12]. For density, the density influences submersion resistance, which is an important part of the total resistance. The density for first year ice is influenced by both temperature and salinity.

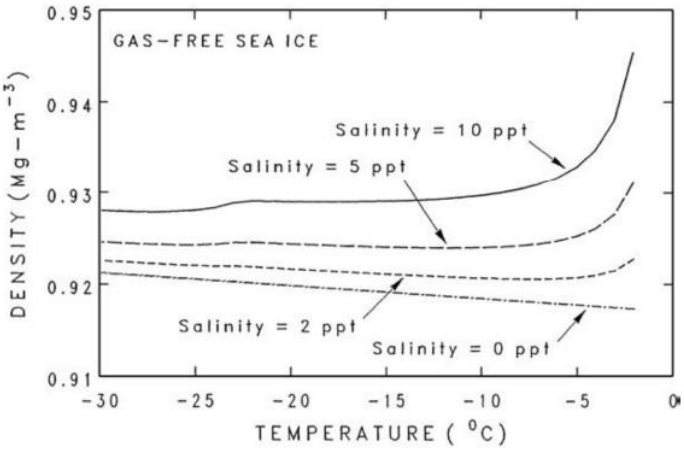

Figure 8 Density as a Function of Temperature for Different Salinities (Source: [6])

c. Brine Volume in Ice

Brine cells happens when the crystals start to freeze together. Brine volume of sea ice is related to the strength of the ice. A lot of investigation has shown that with decreasing brine volume the strength of the ice increases. T is temperature in Kelvin. The brine volume is a function of salinity and temperature of ice. The formula of brine volume is:

Equation 3 Brine Volume in Ice Formulation

$$v_b = S\left(\frac{49{,}185}{|T|} + 0{,}532\right)$$

d. Total Porosity of Ice

in some cases, there can be useful to know the amount of gas in the ice. The air volume can be important in some cases, for instance when the brine drainage has occurred. This is more relevant for older ice. The total porosity of ice can be expressed as:

Equation 4 Total Porosity of Ice

$$v_T = v_b + v_a$$

Where v_a is the relative air volume.

e. Flexural Strength

The flexural strength is a measure of how a material resists bending before failure. Several studies have been attempting to determine the flexural strength as a function of the brine volume. The following relationship between brine volume and flexural strength has been suggested by for first year ice.

Equation 5 Flexural Strength Formulation

$$\sigma_b = 1{,}76\ \exp(-5{,}88\ .\sqrt{v_b})$$

Where σ_b is the flexural strength of ice (in N/mm^2) and v_b is the brine volume fraction.

f. Elastic Modulus for Ice

The ratio of the stress t the strain is called elastic modulus, E. The elastic modulus increases linearly as a function of the brine volume. The figure below is a test by Langleben and Pounder at 1963 to calculate the elastic modulus as a function of brine volume for first year sea ice.

In the end, elastic modulus can be expressed: (See appendix figure 20)

Equation 6 Elastic Modulus for Ice Formulation

$$E = 10 - 0{,}0351\ V_b$$

2.3. Ice Resistance Calculation Methods

2.3.1 Ship Angles

When operates in ice condition, sometimes, ship needs to have an action with ice to make a path for the ship. The angle of a ship when broke an ice is needed to calculate the resistance of ship when operates in ice. There are 3 main angles that needed. The angle between the waterline and bow is the stem angle (Ø). the waterline entrance angle (α) is the angle between the waterline and longitudinal axis of the ship.

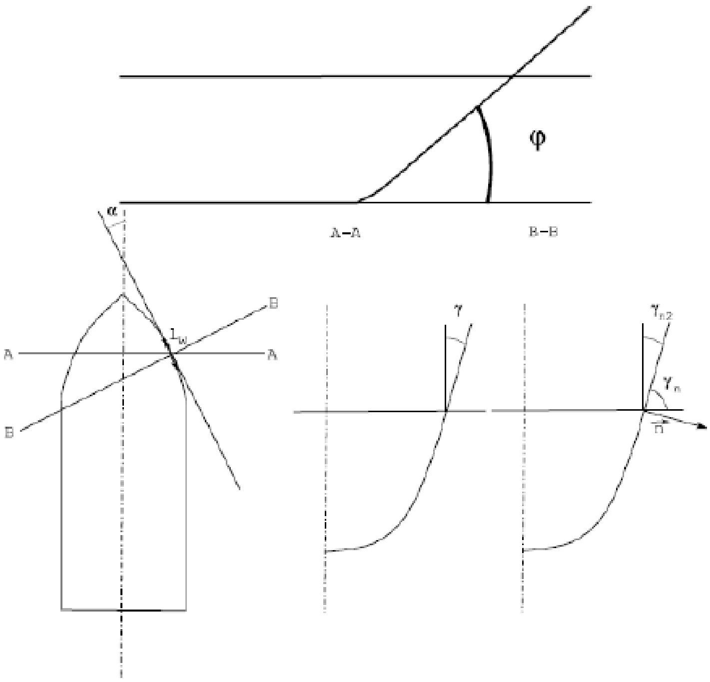

Figure 9 Definition of Angles
(Source: Lindqvist, G. 1989. Straightforwad Method for Calculating of Ice Resistance of Ships.)

2.3.2 Ice Resistance

The total ship resistance when operates in ice condition can be assumed to be the sum of open water resistance and ice resistance.

Equation 7 Formula for Ice Resistance

$$R_{tot} = R_i + R_{ow}$$

To calculate ice resistance, there are 2 methods that presented by Lindqvist (1989), Riska et al (1997). Those formulas are developed by researchers with connection to either Finland and Sweden, and they are based on tests done in the waters between Finland and Sweden. Those formulas can be used just for the condition of first year ice.

2.3.2.1. Lindqvist Method

The model was presented in 1989 and presents a rather simple way of estimating the resistance due to ice. the resistance is divided into crushing, bending-induced breaking and submergence. The model gives resistance as a function of main dimensions, hull form, ice thickness, ice strength and friction.[6]

- Crushing
  Crushing is the main force component at the stern, where the contact area between the hull and the ice is not large enough to give bending failure before crushing occurs. The crushing force is difficult to measure. The vertical force acting on the ice can be estimate as:

  Equation 8 Formula for Crushing Force

  $$F_v = 0{,}5.\sigma_b.{h_i}^2$$

  Where σ_b is ice strength in bending and h_i is ice thickness.
  Then, the crushing resistance can be derived while analyzing the crushing process and use geometrical consideration as:

  Equation 9 Crushing Resistance Formula

  $$R_c = F_v \frac{\tan\emptyset + \mu.\dfrac{\cos\emptyset}{\cos\cos\varphi}}{1-\mu.\dfrac{\sin\emptyset}{cos\varphi}}$$

- Breaking by bending
  The bending failure of ice will be induced when a sufficiently large contact area between the ice floe and the ship hull is present. When the hull comes into contact with a corner of the floe, ice is crushed until shearing failure occurs. The formulation for bending resistance is given:

  Equation 10 Breaking by Bending Resistance Formulation

  $$R_b = \frac{27}{64}\sigma_b B \frac{{h_{ice}}^{1,5}}{\sqrt{\frac{E}{12(1-v^2)g\rho_{water}}}}\left(\frac{\tan\varphi + \mu\cos\emptyset}{(\sin\alpha\cos\varphi)}\right)\left(1+\frac{1}{\cos\varphi}\right)$$

- Submersion
  The submersion resistance exists of 2 components, the loss of potential energy and the frictional resistance. In level ice the ship hull will almost be completely covered in ice, since ice is lighter than water it is lifted against the ship hull. The resistance from the normal force is calculated through the potential energy and the total submergence resistance be:

Equation 11 Submersion Formulation

$$R_s = (\rho_{water} - \rho_{ice}).g.h\,tot.B.k$$

Where h tot is the total ice and snow thickness and k

$$k = \left\{T.\frac{B+T}{B+2T} + \mu.\left[\left(0{,}7.L - \frac{T}{\tan\emptyset} - \frac{B}{4\tan\alpha}\right) + T\cos\emptyset\cos\varphi\sqrt{\frac{1}{sin^2\emptyset} + \frac{1}{tan^2\alpha}}\right]\right\}$$

- Speed dependency

  This model assumes that all resistance components increase linearly with speed and uses empirical constants to account. The velocity term is made dimensionless by dividing it with the square root of acceleration of gravity times a length relevant for the resistance. The formula for the total resistance of ice according to Lindqvist model is:

  Equation 12 Lindqvist Ice Formulation

$$R_{ice} = (R_c + R_b)\left(1 + 1{,}4\frac{v}{\sqrt{gh_{ice}}}\right) + R_s\left(1 + 9{,}4\frac{v}{\sqrt{gL}}\right)$$

2.3.2.2. Riska et Al Method

Riska's resistance calculations are based on a set of coefficients. Those coefficients are derived from many full-scale tests of different ships. All test where located in the Baltic area. The ice resistance is then expressed as: [12]

Equation 13 Ice Resistance Riska Method

$$R_{ice} = C_1 + C_2 v$$

Where:

$$C_1 = f_1\frac{1}{2\frac{T}{B}+1}BL_{par}h_i + (1 + 0{,}0021\emptyset).\left(f_2Bh_i^{\,2} + f_3L_{bow}h_i^{\,2} + f_4BL_{bow}h_i\right)$$

$$C_2 = (1 + 0{,}063\emptyset)\left(g_1h_1^{\,1{,}5} + g_2h_1B\right) + g_3h_i\left(1 + 1{,}2\frac{T}{B}\right).\frac{B^2}{\sqrt{L}}$$

L,B,T are respectively length, breadth, and draught. V is vessel speed, h_i is ice thickness and $\emptyset$ is the stem angle in degrees. L_{par} and L_{bow} are the length of the parallel side section and length of the bow respectively. This formulation assumes a linear relationship between vessel speed and ice thickness, the same as Lindqvist. Riska does not normalize the velocity which Lindqvist does.

The coefficients used in the formulas are given (see appendix table 4):

2.4. Open Water Resistance

There are two definitions that can define what is ship resistance. First one, a force that required to tow a ship in a normal condition (calm water and constant speed) is a ship resistance [4]. Second, a force that acting on a ship in such way as oppose in motion. However, sometimes ship will not operate in calm weather. The condition of weather can also change the value of ship resistance itself although the ship is operated in same speed. The resistance will be equal to the component of the fluid forces acting parallel to the axis of motion of the ship. There are some factors relating the total of ship resistance. (see appendix figure 21)

- Frictional Resistance : component of resistance obtained by integrating the tangential stresses over the wetted surface of the ship in the direction of motion.
- Residuary Resistance : a quantity obtained by subtracting from the total resistance of a hull, a calculated friction resistance obtained by any specific formulation.
- Viscous Resistance : component of resistance relating to energy expended due to viscous effects.
- Pressure Resistance : component of resistance that obtained by integrating the normal stresses over the surface of a body in the direction of motion
- Viscous Pressure Resistance: component of resistance obtained by integrating component of the normal stresses due to viscosity and turbulence.
- Wave making Resistance : component of resistance associated with the energy expended by generating gravity waves.
- Wave breaking Resistance: component relating with the breakdown of the ship bow wave.

Ship resistance just a simple number that looks normal, but behind this number, there are many factors that taken into that account, and also a lot of determination and decision taken based on this number.

Resistance of ship play an important role in determining the ship propulsion systems, including determine the main engine that will be used, fuel consumption is selected to suit the business expectations of the owner ship, the greater the resistance, the greater the required engine power, the greater the cost of fuel , vice versa. Simply, the resistance of ship is a fluid style that works in a way that opposes the motion of ships, ship resistance is total resistance of frictional resistance, air resistance, appendages resistance, wave making resistance, and the rest of the resistance [4].

Factors that required in the process of determining the ship resistance and frictional resistance of ship are:

a. Calculating Volume Displacement

Displacement is the volume of displaced water volume and one of the important variables in the calculation of ship resistance.

$$\nabla = Lwl \times B \times T \times Cb$$

Where Lwl is length of water line, B is breadth, T is draught and Cb is Coefficient Block of the vessel

b. Calculate the Displacement

$$\Delta = Lwl \times B \times T \times Cb \times \rho$$

where ρ is density of sea water (1,025 tonnes / m^3)

c. Calculate Wet Surface Area (S)

Wet surface area is total area of the surface of hull that submersible in the sea water. Wet Surface area for merchant ship can be calculated using the following formula [4]

$$S = 1{,}025 \times Lpp \times (Cp \times B + 1{,}7 \times T)$$

Where Cp is coefficient prismatic of the vessel.

d. Calculate the Froude Number

$$Fn = \frac{Vs}{\sqrt{gL}}$$

e. Calculate the Reynold Number

Reynolds number is a dimensionless value that measures the ratio of inertial forces to viscous forces and describes the degree of laminar of turbulent flow.

$$Rn = \frac{Vs \times Lwl}{v}$$

v is kinematic coefficient

f. Determine the frictional coefficient

Because of the effect of increasing roughness in hull that caused by marine growth that which attached on the hull, so necessary to give the coefficient, and the coefficient is frictional coefficient

$$Cf = \frac{0{,}075}{(\log Rn - 2)^2}$$

While the frictional resistance (Resistantion Friction) itself can occur due to friction on wet surface ship with the media which passed, because all the fluid has a viscosity value, so that make the friction occur.

$$Rf = 0{,}5 \times Cf \times v^2 \times S$$

ρ = density of sea water
Vs = service speed of the ship
S = wetted surface area

The amount of drag that happen must be able to handle by the thrust of the vessel that generated from propulsor ship. There is some sense of power that is often used in the estimate of the power requirements on ship propulsion systems, there are:

a. Effective power (EHP)

Effective power (EHP) is the amount of power needed to handle drag of the hull , so that the ship can move from one place to another with a service speed at Vs.

$$EHP = RT \times Vs$$

RT = total ship Resistance [kN]
Vs = service speed ship [m/s]

b. Thrust Power (THP)

Thrust Power (THP) is the amount of power generated by the work of ship propulsor to push the hull .

$$THP = \frac{EHP}{\eta H}$$

EHP = Effective power [kN].
ηH = Efficiency Hull

c. Delivery Power (DHP)

Delivery Power (DHP) is the power absorbed by the ship's propeller to produce Push Power of PT.

$$DHP = \frac{EHP}{Pc}$$

Where:

$$Pc = \eta_H \times \eta rr \times \eta o$$

1. Hull Efficiency (ηH)

$$\eta H = \frac{(1 - t)}{(1 - w)}$$

- Wake Friction (w)
  Wake friction is a comparison between speed of ship and speed of water that going through the propeller. By the formula from Taylor, so we can get:
  $$w = 0{,}5Cb - 0{,}05$$
- Thrust Deduction Factor Calculation (t),
  $$t = k \times w$$
  (k value is between 0.7-0.9, Principle of Naval Architecture pages 158)

2. Rotative Relative Efficiency (ηrr)
   Because this ship assumed use the single screw propeller so the value is around 1.0-1.1. *(Principle of Naval Architecture page 152)*
3. Propulsion Efficiency (ηo)
   This is open water efficiency, the efficiency from propeller while doing the open water test. The value is between 40-70%.
4. Propulsive Coefficient (Pc)
   $$Pc = \eta H \times \eta rr \times \eta o$$
   So we get the Deliver Horse Power like:
   $$DHP = \frac{EHP}{Pc}$$

d. Shaft Power (SHP)
   Propeller power / thrust power will be forwarded to the main engine via shaft (shaft).
   $$SHP = \frac{DHP}{\eta s}$$
   ηs = Efficiency of the shaft (98-97%)

e. Break Power (BHPscr)
   Break Power is the power generated by the main engine with the type of marine diesel engines. In break power is also influenced by the transmission system like the use of the gear box.
   $$BHPscr = \frac{SHP}{\eta g}$$
   ηg = efficiency of the gear box (98-97%).

f. Break Power (BHPmcr)
   $$BHPmcr = \frac{BHPscr}{0{,}85}$$

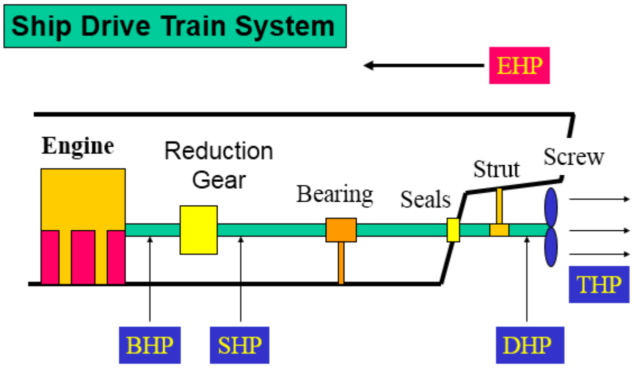

Figure 10 Scheme of Power Distribution

The greater BHP power that we needed, then we need greater engine to meet the power, and if the engine power greater, automatic fuel consumption of engine or SFOC will be greater.

To calculate the fuel consumption can be done with the following formulation:

$$Fuel\ Oil\ Mass = P\ \times SFOC \times t \times C \times 10^{-6}$$

Fuel Oil Mass = total fuel oil that needed [ton(s)]

P = Power of main engine [kW]

SFOC = Specific Fuel Oil Consumption [g/kWh]

t = ship operation time [hour(s)]

C = Constant addition of fuel [1.3-1.5]

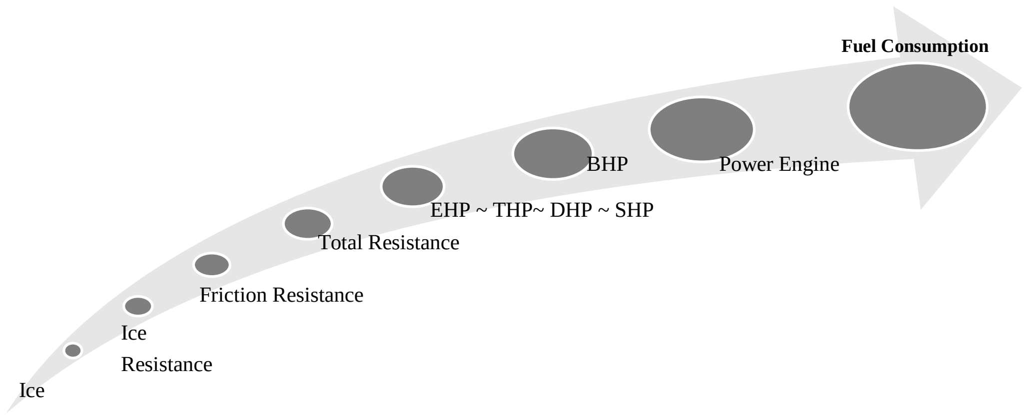

Figure 11 Effect of Ice to Fuel Consumption

From the figure above, ice has an important role for increasing the value of total resistance of the ship. For instance, ice makes the additional resistance for a ship called ice resistance. The total ship resistance has a greater value than the conventional route if a ship operates in ice condition. If total resistance of a ship increase, it also has an impact to increase a power of the engine so a ship can reach the service speed. However, by increasing the power of the engine, it costs a ship for using more fuel consumption than the conventional one.

CHAPTER III
METHODOLOGY

3.1 Methodology Flow Chart

The adopted methodology will be shown in the flow chart below.

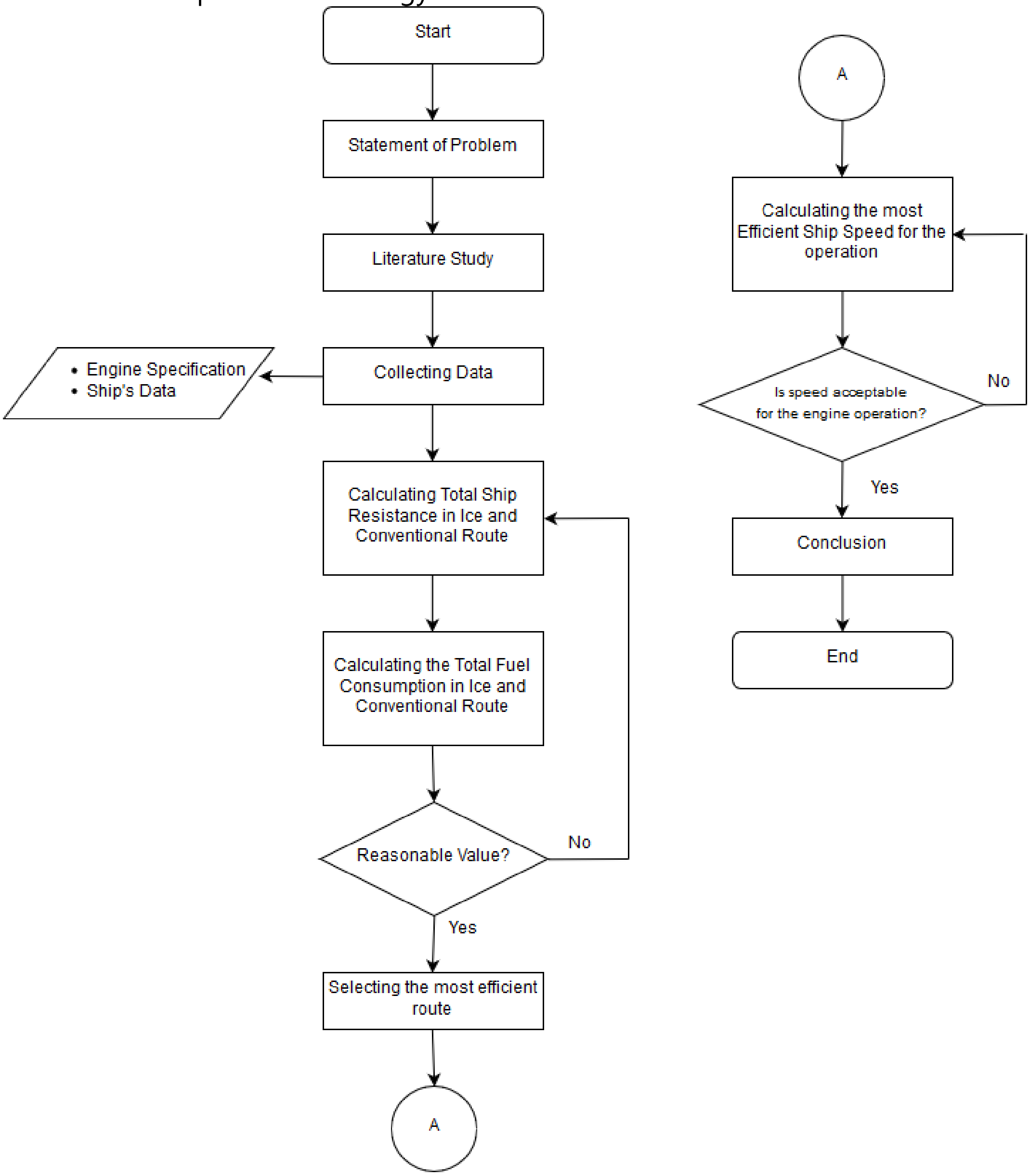

Figure 12 Methodology Flowchart

3.2 Definition of Methodology Flowchart

a. Statement of Problems

This stage is an early stage to construct the thesis. In this stage, questions and problems are being prepared specifically in order to determine the specific objectives of this thesis. The content of the thesis is to overcome the statement of the problems mentioned earlier and it will be done by collect some information about the problems. Therefore, the purpose of this thesis can be understood in this stage.

b. Literature Study

Right after the problems is raised, a literature study is performed. In this stage, literature will be use to connect the problems with existing theories and facts from various sources. Since this thesis is an implementation of many aspects discipline, various literature topics is required to be constructed into one project. The study of literature is done by reading papers, journals, thesis, media and literature books that relates and able to support this thesis.

c. Collecting Data

After literature study which support the thesis has been done, collecting data is being performed. Data collection is done by gather information to develop the conceptual design, most of data is available from the total engine specification and the Ship data like Lpp, B, T, etc. when it operates.

d. Calculating Total Ship Resistance in Ice and Conventional Route

The next stage after collecting data is calculating total of ship resistance when it operates in Ice Condition and Conventional Route. There is a way to find out the total ship resistance of ship when it operates in ice. Using 2 formulas are the most common way to find out the total of ship resistance when it operates in ice. The formula was developed earlier and related with the ice condition.

e. Calculating Total Fuel Consumption in Ice and Conventional Route

This stage is calculating the total fuel consumption of the ship. It can be discovered by knowing the total of ship resistance. The purpose of knowing total fuel consumption is calculating the total fuel cost during the operation and we can choose the lowest expense in fuel cost proportion

f. Selecting the most Efficient Route
In this stage, the data from 2 routes are being considered. From those consideration, the result is selecting the most efficient route for being applied to the ship. The consideration is limited by total fuel cost that needed by a ship during the operation.
g. Calculating the most efficient Ship Speed for Operation
After complying all those requirements and already selecting the suitable route, the process to find out the most efficient ship speed during the operation being important. The difference of ship speed when doing the operation can increase the ship resistance and make the operation not efficient. Selecting ship speed also consider the total output power and rotation of the engine itself.

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CHAPTER IV
DATA ANALYSIS & CALCULATION

4.1 General Data of the Ship

Table 2 General Data

Name	:	XXXX	
Type	:	Container Ship	
LoA	:	366	m
Lpp	:	351,5	m
B	:	51,2	m
T(max)	:	15,5	m
Vmax	:	25,1	kN
DWT	:	155470	
GT	:	150853	
Cb	:	0,65	
Cm	:	0,98	
Cp	:	0,66	
Voyage Plan	:	Hong Kong - Hamburg	

4.2 Collecting Data for the Ship

This thesis using Automatic Idenification System (AIS) that already installed on the ship, collecting the data like draught and velocity from each route. On this thesis, writer divide the voyage plan into 8 main routes for the conventional route and 7 main routes for the ice route.

Voyage Plan for Conventional Route:

Table 3 Voyage Plan for Conventional Route

Route I	Hong Kong – Nansha
Route II	Nansha – Shekou
Route III	Shekou – Tj. Pelepas
Route IV	Tj. Pelepas – Port Klang
Route V	Port Klang – Suez
Route VI	Suez - Piraeus
Route VII	Piraeus – Antwerp
Route VIII	Antwerp - Hamburg

Voyage Plan for Ice Route:

Table 4 Voyage Plan for Ice Route

Route I	North-Norwegian Sea
Route II	Barents Sea
Route III	Kara Sea
Route IV	Laptev Sea
Route V	East Siberian Sea
Route VI	Chucki Sea
Route VII	Bering-East China Sea

For the conventional route, AIS is used to track every minute the movement of the ship, so the position, velocity, and draught of the ship can be received in real time.

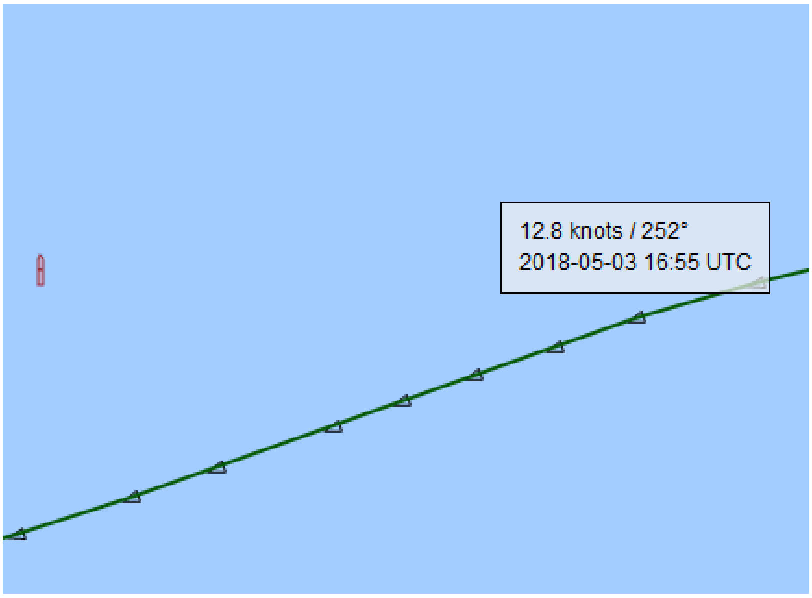

Figure 13 Collecting Data from AIS

After collecting the data every minute from the AIS, grouping the data into sub main parts is the next step for this bachelor thesis.

Table 5 Grouping the Data

	LTC (UTC+8)	T(m)	Vs(knot)
Preparation I	5:27	12,8	0,5
	5:36	12,8	2,2
	5:50	12,8	1,1
	5:53	12,8	4
Leaving	5:58	12,8	8,9
	6:01	12,8	10,2
	6:06	12,8	12,1
	6:08	12,8	14,5
	6:23	12,8	13
	6:25	12,8	11,7
	6:29	12,8	9,8
	6:35	12,8	10

4.3 Calculating Total Resistance for Conventional Route

After grouping the data, the average speed of vessel will be gotten. Total operational time of the vessel also be gotten from each part. For instance, the data below:

Table 6 Data from Hong Kong - Nansha

Approaching	10:08	12,8	11,4	13
	10:24	12,8	12,4	
	10:33	12,8	13,3	
	10:49	12,8	13,3	
	11:18	12,8	10,5	
	11:30	12,8	7,6	

The data above is taken from Hong Kong – Nansha route. The vessel was approaching to the Nansha Port. From the data above, the average velocity of the vessel when approaching Nansha Port is 13 knots and the total operational time for the approaching part is 1 hour 22 minutes. From the data above, the next step is calculating the total resistance for this part.

Calculation Step:

- $\nabla = Lwl \times B \times T \times Cb$
  = 351,5 x 51,2 x 12,8 x 0,65
  = 149733,4 m^3
- $\nabla^{1/3}$ = 53,10143
- $L/\nabla^{1/3}$ = 6,619408

- Fn $= \frac{v}{\sqrt{g \times L}}$
  $= \frac{13 \times 0,514}{\sqrt{9,8 \times 351,5}}$
  = 0,114

6,5	0,41
6,62	***0,4028***
7	0,38

To figure out value of Cr, firstly volume displacement of the vessel must be known to get the value of volume displacement power by one third. From the calculation the value is 6,62 for $\frac{L}{V^{1/3}}$. Meanwhile, the graph just shown the value for Cr when $\frac{L}{V^{1/3}}$ 6,5 or 7,0 so, interpolation is needed to get the value. See appendix on figure 15 - 16.

- 10^3Cr = 0,4028
- B/T = 51,2 / 12,8
  = 4
- 10^3 Cr B/T Correction = 10^3Cr + 0,16(B/T - 2,5)
  = 0,6428
- LCB Standard = -0,1
  LCB is longitudinal center of gravity of a ship. The value of LCB is gotten from the drawing of the vessel.
- LCB = -1,2 (value is gotten from the graph, see appendix figure 17)
- Delta LCB =-1,7 – (-0,1)
  = -1,6
- (d10^3Cr/dLCB)= 0,15 (value is gotten from the graph, see appendix figure 18)

- 10^3 Cr LCB Correction = d10^3Cr/dLCB x ABS (Delta LCB)
  = 0,24
- 10^3 Cr Correction = 10^{3Cr} + 10^3 Cr B/T Correction + 10^3 Cr LCB Correction
  = 1,2856
- Cr Correction = 0,0012856
- Rn $= \frac{v \times L}{kinematic\ viscocity}$
  Kinematic viscosity when 17 Celsius = 0,000001133
  = 2073012357
- Cf $= \frac{0,075}{(\log Rn - 2)^2}$

= 0,00140101

- Ca = -0,0003

L	10^3 C_A
≤100m	0,4
= 150m	0,2
= 200m	0
= 250m	-0,2
≥300m	-0,3

- Caa = 0,00007
- Cas = 0,00004
- C total = Cr correction + Cf + Ca + Caa + Cas
  = 0,00237901
- S = $1{,}025 \times Lpp \times (Cp \times B + 1{,}7 \times T)$
  = 20074,9254 m^2
- R = 0,5 × Density × C total × S × (Vs^2)
  = 1096698,182 N
- Sea Margin = 0,2 × R
  = 219339,6 N
- R total = R + Sea Margin
  = 1316,03782 kN

With a same approach, the total resistance will be figured out.

- Hong Kong – Nansha

For this route, there are 5 steps with a vary range of velocity, starts from 1,5 – 9,6 m/s. This route has a sea margin of 20%. The total resistance of vessel when passing through this route has a range from 78 kN to 2614 kN.

Table 7 Total Resistance for Hong Kong - Nansha

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R total (kN)
Preparation	2,57	172,993353	34,59867	207,592024
Leaving	7,0418	1206,733091	241,3466	1448,07971
On Going	9,6632	2178,765588	435,7531	2614,51871
Approaching	6,682	1096,698182	219,3396	1316,03782
Arrived	1,542	65,27469784	13,05494	78,3296374

- Nansha – Shekou

For this route, there are 12 steps with a vary range of velocity, starts from 2,2 – 8 m/s. This route has a sea margin of 15%. The total resistance of vessel when passing through this route has a range from 144 kN to 1854 kN. For further information please see appendix of Table 35.

- Shekou – Tj. Pelepas
  For this route, there are 9 steps with a vary range of velocity, starts from 0,3 – 11,2 m/s. The vessel travels 2 water zones with different temperature, the first one 17°Celsius and the second one 22°Celsius. The temperature differences make this route has 2 values for water density. This route has a sea margin of 10%. The total resistance of vessel when passing through this route has a range from 3,4 kN to 3369 kN. For further information please see appendix of Table 36.
- Tj. Pelepas – Port Klang
  For this route, there are 8 steps with a vary range of velocity, starts from 0,4 – 10 m/s. The vessel travels at water zone with temperature around 28°Celsius. This route has a sea margin of 20%. The total resistance of vessel when passing through this route has a range from 6,9 kN to 2933 kN. For further information please see appendix of Table 37.
- Port Klang – Suez
  For this route, there are 12 steps with a vary range of velocity, starts from 0,6 – 10,3 m/s. The vessel travels at 3 different water zones with temperature from 18 - 28°Celsius, so it has 3 different value for water density. This route has a sea margin of 15%. The total resistance of vessel when passing through this route has a range from 13 kN to 3016 kN. For further information please see appendix of Table 38.
- Suez – Piraeus
  For this route, there are 11 steps with a vary range of velocity, starts from 0,72 – 10,7 m/s. The vessel travels at water zone with temperature from 18°Celsius. This route has a sea margin of 15%. The total resistance of vessel when passing through this route has a range from 17,5 kN to 2570 kN. For further information please see appendix of Table 39.
- Piraeus – Antwerp
  For this route, there are 18 steps with a vary range of velocity, starts from 1,9 – 10,6 m/s. The vessel travels in 4 different water zones with temperature from 6-18°Celsius. This route has a sea margin of 10%. The total resistance of vessel when passing through this route has a range from 121 kN to 3104 kN. For further information please see appendix of Table 40.
- Antwerp – Hamburg
  For this route, there are 19 steps with a vary range of velocity, starts from 0,68 – 10 m/s. The vessel travels in 2 different water zones with temperature from 1-6°Celsius. This route has a sea margin of 20%. The total resistance of vessel when passing through this route has a range from 17 kN to 2856 kN. For further information please see appendix of Table 41.

For conventional route, the speed of the ship and the state of the sea (Sea Margin) becomes the most dominant thing to determine how much the total ship resistance. Every route has its own percentage because of the roughness and condition of the sea itself. If condition of the sea has a high wave the sea margin will have a greater number. On this route the sea margin is 10% -20% depends on the condition of the water.

4.4 Calculating Total Fuel Consumption on Conventional Route

After getting the value of total resistance of the ship, the next step is calculating the total fuel consumption of the ship when the operation on conventional route. This ship is using 12K98MC -C7 by MAN B&W with maximum power at 72.240 kW and SFOC at 177 g/kWh.

To calculate total fuel consumption of the ship, an example is needed. Take a look at figure below.

Table 8 Total Fuel Consumption on Route Hong Kong – Nansha

	LTC (UTC+8)	T(m)	Vs(knot)	Average	Total time	Vs (m/s)	R total	ea margin	T + Sea marg	EHP (kW)	DHP(kW)	SHP (kW)	BHP (kW)	BHP MCR	(W_{HFO}) ton
Leaving	5:58	12,8	8,9	13,7	0:40	7,0418	1206733,091	241346,6	1448079,709	10197,09	17012,012	17359,2	17359,2	20422,5829	2,635875
	6:01	12,8	10,2												
	6:06	12,8	12,1												
	6:08	12,8	14,5												
	6:23	12,8	13												
	6:25	12,8	11,7												
	6:29	12,8	9,8												
	6:35	12,8	10												

Calculation Step:

- $EHP = \frac{Rtotal(Newton) \times Vs(\frac{m}{s})}{1000}$

  $= \frac{1448079{,}709\ N \times 7{,}0418\ m/s}{1000} = 10197{,}09\ kW$

- $DHP = \frac{EHP}{Pc}$

  $Pc = \eta H \times \eta rr \times \eta o$

  $\eta H = (1 - t) \div (1 - w)$

  $w = 0{,}5 \times Cb - 0{,}05$

  $= 0{,}275$

  $T = k.w\ where\ k\ 0{,}8 - 0{,}9$

  $= 0{,}2475$

  $\eta H = (1 - 0{,}2475) \div (1 - 0{,}275)$

  $= 1{,}037931$

  $\eta rr = 1{,}05$

  $\eta o = 55\%$

  $Pc = 1{,}037931 \times 1{,}05 \times 0{,}55$

  $= 0{,}599405$

  $DHP = \frac{10197{,}09\ kW}{0{,}599405}$

  $= 17012{,}012\ kW$

- $SHP = \frac{DHP}{\eta s}$

  $\eta s = Efficiency\, of\, the\, shaft$ (98 – 97%)

  $= 17359{,}2\, kW$
- $BHPscr = SHP$

  $= 17359{,}2\, kW$
- $BHPmcr = \frac{BHPscr}{0{,}85}$

  $= 20422{,}5829\, kW$
- $W\, FO = BHPmcr \times SFOC \times time(hr) \times 1{,}1 \times 10^{-6}$

  $= 2{,}635875\, ton$

With a same approach, the total fuel consumption for each route will be figured out.

- Hong Kong – Nansha Port

  This route is divided into 5 parts, with the range power of engine between 1068 – 50599kW. The total fuel consumption for this route is 42,86 tons. The operational time for this route is 6 hours with total fuel consumption per hour around 7,1 ton/hour.

Table 9 Total Fuel Consumption HK - Nansha

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	207,59202	533,511	890,06	908,23	1068,5	0,107
II	1448,0797	10197,0	17012	17359	20422,5	2,635
III	2614,5187	25264,6	42149	43009	50599,6	33,99
IV	1316,0378	8793,76	14670	14970	22015	6,109
V	78,329637	120,784	201,5	205,61	241,905	0,021

- Nansha – Shekou

  This route is divided into 12 parts, with the range power of engine between 625 – 30141kW. The total fuel consumption for this route is 22,142 tons. The operational time for this route is 7,35 hours with total fuel consumption per hour around 3 ton/hour. For further information see appendix table 42.

- Shekou – Tj. Pelepas

  This route is divided into 9 parts, with the range power of engine between 2 – 69951kW. The total fuel consumption for this route is 1021,186 tons. The operational time for this route is 83,5 hours with total fuel consumption per hour around 12,23 ton/hour. For further information see appendix table 43.

- Tj. Pelepas – Port Klang
  This route is divided into 7 parts, with the range power of engine between 6,11 – 59060kW. The total fuel consumption for this route is 85,7 tons. The operational time for this route is 11,5 hours with total fuel consumption per hour around 7,45 ton/hour. For further information see appendix table 44.
- Port Klang – Suez
  This route is divided into 12 parts, with the range power of engine between 16 – 63942kW. The total fuel consumption for this route is 2516,55 tons. The operational time for this route is 247,267 hours with total fuel consumption per hour around 10,17 ton/hour. For further information see appendix table 45.
- Suez- Piraeus
  This route is divided into 11 parts, with the range power of engine between 25 – 68421kW. The total fuel consumption for this route is 385,04 tons. The operational time for this route is 41,833 hours with total fuel consumption per hour around 9,2 ton/hour. For further information see appendix table 46.
- Piraeus – Antwerp
  This route is divided into 18 parts, with the range power of engine between 480 – 66008kW. The total fuel consumption for this route is 1575,75 tons. The operational time for this route is 170 hours with total fuel consumption per hour around 9,26 ton/hour. For further information see appendix table 47.
- Antwerp – Hamburg
  This route is divided into 19 parts, with the range power of engine between 23,7 – 57715kW. The total fuel consumption for this route is 160,98 tons. The operational time for this route is 29,3 hours with total fuel consumption per hour around 9,746 ton/hour. For further information see appendix table 48.

After knowing total fuel consumption for each route, now the total fuel consumption for conventional route can be revealed.

Table 10 Total Fuel Consumption Conventional Route

No	Destination	Operational Hour	Total Fuel Consumption (ton)	Total Consumption / hour
1	HK – Nansha	6	42,86839208	7,144732013
2	Nansha - Shekou	7,35	22,14230965	3,012559137
3	Shekou – Tj Pelepas	83,5	1021,186221	12,2297751
4	Tj Pelepas – Port Klang	11,5	85,6897331	7,451281139
5	Port Klang – Piraeus	288,5	2901,600678	10,05754135
6	Piraeus – Antwerp	170	1575,75914	9,269171411
7	Antwerp - Hamburg	29,3	160,9847412	5,494359768
	Total	596,15	5810,231215	9,74625

In the end, the total fuel consumption for conventional route is 5810,231215 tons during 596,15 hours for the operational time of vessel with average consumption per hour is 9,74625 tons.

4.5 Calculating Total Resistance for Northeast Passage

Before calculating total resistance of ship for Ice Route, there are some assumption that need to be made. For Instance, the projection for ship's speed when through the ice and the bunkering plan for the vessel. Bunkering is assumed happened in Hamburg (North Sea), Port in Barents Sea (Western Area of Russian), and Port in Chucki Sea (Eastern Area of Russian). When passing Northeast Passage (NEP), there are 2 types of condition that shall be passed by a ship. An open water condition and ice resistance condition. Ice resistance condition occurs when ship passing through Barents Sea, Kara Sea, Laptev Sea, East Siberian Sea and Chucki Sea. One thing to remember, the assumption for a ship passing through Northeast Passage is just occurred at Summer Weather, so the ice thickness shall not be more than 20 cm.
Route Planning:

Table 11 Route Planning for Northeast Passage

Route	Distance (nm)	Explanation	Temperature	Ice Thickness
North Sea	1976	Open Water Resistance	15 Celsius	
Norwegian Sea			12 Celsius	
Barents Sea	560	Ice Resistance		20 cm
Kara Sea	930	Ice Resistance		15 cm (West) 10 cm (East)
Laptev Sea	660	Ice Resistance		10 cm
East Siberian Sea	650	Ice Resistance		10 cm
Chucki Sea	490	Ice Resistance		10 cm
Bering Sea	4220	Open Water Resistance	13 Celsius	
East China Sea			20 Celsius	

4.5.1 Calculating Open Water Resistance on Ice Route

On Northeast Passage, there is 6196 nautical miles that must be passed on open water resistance condition. North Sea, Norwegian Sea, Bering Sea and East China Sea is the part of open water resistance condition.

To calculate total resistance for this route, the assumption must to be made especially for the velocity and total operational hours for the vessel. The assumption is made by comparing the distance with the conventional route. For instance, the distance for North Sea and Norwegian Sea is 1976 nautical miles, so route from Shekou – Tj Pelepas is compared to get the velocity for vessel when passing through North and Norwegian Sea.

The estimation for vessel when passing through

- North and Norwegian Sea:

Table 12 Estimation Speed and Operational Time for North & Norwegian Sea

Part	Speed (knot)	Time (hour)	Distance (nm)
I	3	0,75	2,25
II	15	2,5	37,5
III	18	4	72
IV	20	50,1	1002
V	18,5	30	555
VI	18	15	270
VII	10	3,5	35

VIII	3	0,75	2,25
Total		106,6	1976

North and Norwegian Sea is still not covered with ice, so the zone still considered as open water resistance with sea margin at 20%. However, there are 2 different temperature zones that may be passed of the ship, 12 – 15°Celsisus. The range of vessel speed is 1,542 – 10,28 m/s. Total ship resistance is around 80 – 3127 kN. For further information see appendix table 49.

- Barents Sea

Table 13 Estimation Speed and Operational Time for Barents Sea

Part	Speed (knot)	Time (hour)	Distance (nm)
I	1	0,5	0,5
II	5	1	5
III	7,5	1	7,5
IV	10,5	2	21
V	14	6,5	91
VI	15	29	435
Total		40	560

At Barents Sea, vessel is projected to operate at 40 hours with 6 steps. Barents Sea is covered by ice, so it is considered as Ice Resistance. However, the total resistance for the ship is a sum from ice resistance and open water resistance. The sea margin for Barents Sea is assumed 15% with resistance at open water around 8,4 – 1486 kN. For further information see appendix table 50.

- Kara Sea
    - West Kara Sea

Table 14 Estimation Speed and Operational Time for West Kara Sea

Part	Speed (knot)	Time (hour)	Distance (nm)
I	15	3	45
II	10	1	10
III	14	10	140
IV	15	18	270
Total		32	465

- East Kara Sea

Table 15 Estimation Speed and Operational Time for East Kara Sea

Part	Speed (knot)	Time (hour)	Distance (nm)
I	15	9	135
II	16,5	20	330
Total		29	465

Kara Sea is separated into West and East part. Western part of Kara Sea is considered as Atlantic Sea zone meanwhile Eastern part of Kara Sea is considered as Siberian Area. Therefore, there are main difference between western and eastern part. Eastern part of Kara Sea is colder than the Eastern part. For passing through western part of Kara Sea, vessel needs 32 hours and for eastern part, it takes 29 hours. On Western Part of Kara Sea, it is divided into 4 parts with variety of speed vessel 5,14 – 7,71 m/s with total resistance for open water 681 – 1486 kN with sea margin of 15%. While Eastern Part of Kara Sea is divided into 2 parts with variety of speed vessel 7,71 – 8,48 m/s. The total resistance on open water is 1486 – 1786 kN and sea margin at 15%. For further information see appendix table 51-52.

- Laptev Sea

Table 16 Estimation Speed and Operational Time for Laptev Sea

Part	Speed (knot)	Time (hour)	Distance (nm)
I	15	2	30
II	16,5	10	165
III	15	20	300
IV	16,5	10	165
Total		42	660

At Laptev Sea, vessel is projected to operate at 42 hours with 4 steps. Laptev Sea is covered by ice, so it is considered as Ice Resistance. However, the total resistance for the ship is a sum from ice resistance and open water resistance. The sea margin for Laptev Sea is assumed 15% with resistance at open water around 1486 – 1786 kN. For further information see appendix table 53.

- East Siberian Sea

Table 17 Estimation Speed and Operational Time for East Siberian Sea

Part	Speed (knot)	Time (hour)	Distance (nm)
I	16,5	10	165
II	14	20	280
III	13	10	130
IV	12	6,25	75
Total		46,25	650

At East Siberian Sea, vessel is projected to operate at 46,25 hours with 4 steps. East Siberian Sea is covered by ice, so it is considered as Ice Resistance. However, the total resistance for the ship is a sum from ice resistance and open water resistance. The sea margin for East Siberian Sea is assumed 20% with resistance at open water around 967 - 1786 kN. For further information see appendix table 54.

- Chucki Sea

Table 18 Estimation Speed and Operational Time for Chucki Sea

Part	Speed (knot)	Time (hour)	Distance (nm)
I	12	20	240
II	12,5	18	225
III	8	3	24
IV	3	0,4	1,2
Total		41,4	490,2

At Chucki Sea, vessel is projected to operate at 41,4 hours with 4 steps. Chucki Sea is covered by ice, so it is considered as Ice Resistance. However, the total resistance for the ship is a sum from ice resistance and open water resistance. The sea margin for Chucki Sea is assumed 20% with resistance at open water around 135 - 1046 kN. For further information see appendix table 55.

- Bering – East China Sea

Table 19 Estimation Speed and Operational Time for Bering - East China Sea

Part	Speed (knot)	Time (hour)	Distance (nm)
I	1,096255165	0,15397875	0,1688
II	11,09958355	0,456233333	5,064
III	18,91601383	66,83818333	1264,312
IV	17,24230179	1,77931	30,6794
V	18,79294569	5,74854	108,032
VI	18,43930816	42,20158333	778,168
VII	18,71032461	59,99468333	1122,52
VIII	18,25624544	31,59872067	576,874

IX	17,68193351	12,64906917	223,66
X	17,15390184	5,018566667	86,088
XI	16,31434852	1,448540833	23,632
XII	4,565475299	0,231082183	1,055
Total		228,1184916	4220,2532

Bering – East China Sea is still not covered with ice, so the zone still considered as open water resistance with sea margin at 15-20%. However, there are 2 different temperature zones that may be passed of the ship, 13 – 20°Celsisus. The range of vessel speed is 0,5– 9,7 m/s. Total ship resistance is around 9,7 – 2269 kN. For further information see appendix table 50.

4.5.2 Calculating Ice Resistance on Ice Route

Calculation Step:

Barents Sea is used to be an example. The table below shows velocity and time operational of vessel.

There are 2 methods that can be used for determined ice resistance of the vessel:

a. Lindqvist Method

Conditions of Barents Sea:

Table 20 Speed and Operational Hour at Barents Sea

Part	Speed (knot)	Time (hour)	Distance (nm)
I	1	0,5	0,5
II	5	1	5
III	7,5	1	7,5
IV	10,5	2	21
V	14	6,5	91
VI	15	29	435
Total		40	560

Temperature: -2 Celsius

Ice Thickness: 20 cm

Flexural Strength: 0,15 N/mm^2 (See Appendix Figure 19)

Elastic Modulus for Ice: 9 kN/mm^2

Ø: 28°

α: 36°

φ: arc tan $\frac{tan Ø}{sin\alpha}$ = 42°

μ : 0,05

Poisson ratio (v): 0,3

Crushing at Stern:

$F_v = 0{,}5.\sigma_b.{h_i}^2$

F_v = 0,5 x (0,15 x 10^6) Pa x $(20/100)^2 m^2$

= 3000

$$R_c = F_v \frac{\tan\emptyset + \mu.\frac{\cos\emptyset}{\cos\varphi}}{1 - \mu.\frac{\sin\emptyset}{\cos\varphi}}$$

$$R_c = 3000 \frac{\tan 28 + 0{,}05.\frac{\cos 28}{\cos 42}}{1 - 0{,}05.\frac{\sin 28}{\cos 42}}$$

R_c = 1831,18817 N

Bending Component:

$$R_b = 27/64\sigma_b B \frac{{h_{ice}}^{1,5}}{\sqrt{\frac{E}{12(1-v^2)g\rho_{water}}}}\left(\frac{\tan\varphi + \mu\cos\emptyset}{(\sin\alpha\cos\varphi)}\right)\left(1+\frac{1}{\cos\varphi}\right)$$

$$R_b = \frac{27}{64}\ x\ (0{,}15 \text{ x } 10^6)\ x\ 51{,}2 \frac{(0{,}2)^{1,5}}{\sqrt{\frac{(9\ x\ 10^9)}{12(1-0{,}3^2)10\ x\ 1025}}}\left(\frac{\tan 42 + 0{,}05\cos 28}{(\sin 36 \cos 42)}\right)\left(1+\frac{1}{\cos 42}\right)$$

R_b = 5131,54941 N

Submersion Component:

$$k = \left\{T.\frac{B+T}{B+2T} + \mu.\left[\left(0{,}7.L - \frac{T}{\tan\emptyset} - \frac{B}{4\tan\alpha}\right) + T\cos\emptyset\cos\varphi\sqrt{\frac{1}{\sin^2\emptyset} + \frac{1}{\tan^2\alpha}}\right]\right\}$$

$$k = \left\{14.\frac{51{,}2+14}{51{,}2+2x14} + 0{,}05.\left[\left(0{,}7.351{,}5 - \frac{14}{\tan 28} - \frac{51{,}2}{4\tan 36}\right) + 14\cos 28\cos 42\sqrt{\frac{1}{\sin^2 28} + \frac{1}{\tan^2 36}}\right]\right\}$$

K = 22,795195

$R_s = (\rho_{water} - \rho_{ice}).g.h\ tot.B.k$

$R_s = (1025 - 920).10.0{,}2.51{,}2.22{,}795195$

R_s = 240192,058 N

Ice Resistance (on Step I)

$$R_{ice} = (R_c + R_b)\left(1 + 1{,}4\frac{v}{\sqrt{gh_{ice}}}\right) + R_s\left(1 + 9{,}4\frac{v}{\sqrt{gL}}\right)$$

$$R_{ice} = (1831{,}18 + 5131{,}54)\left(1 + 1{,}4\frac{(1\ x\ 0{,}514)}{\sqrt{10x\ 0{,}2}}\right) + 240192{,}058\left(1 + 9{,}4\frac{(1\ x\ 0{,}514)}{\sqrt{10\ x\ 351{,}5}}\right)$$

R_{ice} = 270506,7036 N

= 270,506 kN

Total Resistance (on Step I)

$R_{tot} = R_i + R_{ow}$

R_i (gotten from open water resistance formula) = 9,601 kN

R_{tot} = 270,506 kN +9,601 kN

= 280,107 kN

So, the total Ice Resistance according to Lindqvist method is:

- Barents Sea

  At Barents Sea, there 6 parts of different velocity of vessel. By calculating ice resistance with Lindqvist method, the value of ice resistance for Barents Sea is between 270 – 597 kN. The ice resistance value depends on the thickness and speed velocity of the vessel when passing through ice zones.

Table 21 Total Resistance at Barents Sea

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	0,514	8,348877	1,252332	270,5067	280,1079
II	2,57	180,1206	27,01809	363,9143	571,0531
III	3,855	392,0721	58,81082	422,2941	873,1771
IV	5,397	748,4541	112,2681	492,3498	1353,072
V	7,196	1301,888	195,2832	574,0815	2071,253
VI	7,71	1486,869	223,0303	597,4334	2307,332

- Kara Sea

  At Kara Sea, there is a fundamental difference between Western and Eastern Part of Kara Sea. The thickness of ice at Western Part is 15 cm, meanwhile at the Easter Part is just 10 cm. At Western Kara Sea, there 4 parts of different velocity of vessel, while Eastern Kara Sea just 2 parts. By calculating ice resistance with Lindqvist method, the value of ice resistance for West and East Kara Sea is between 286 – 440 kN. The ice resistance value depends on the thickness and speed velocity of the vessel when passing through ice zones. For further information see appendix table 51-52.

- Laptev Sea

  At Laptev Sea, there 4 parts of different velocity of vessel. By calculating ice resistance with Lindqvist method, the value of ice resistance for Laptev Sea is between 286 – 302 kN. The ice resistance value depends on the thickness and speed velocity of the vessel when passing through ice zones. For further information see appendix table 53.

- East Siberian Sea

  At East Siberian Sea, there 4 parts of different velocity of vessel. By calculating ice resistance with Lindqvist method, the value of ice resistance for Laptev Sea is between 253 – 302 kN. The ice resistance value depends on the thickness and speed velocity of the vessel when passing through ice zones. For further information see appendix table 54.

- Chucki Sea

  At Chucki Sea, there 4 parts of different velocity of vessel. By calculating ice resistance with Lindqvist method, the value of ice resistance for Chucki Sea is between 154 – 258 kN. The ice resistance value depends on the thickness and speed velocity of the vessel when passing through ice zones. For further information see appendix table 55.

b. Riska et Al

Using a same example with Lindqvist method, the riska et Al method will show the value of total resistance as below: (see appendix table 82)

$$R_{ice} = C_1 + C_2 v$$

$$C_1 = f_1 \frac{1}{2\frac{T}{B}+1} BL_{par}h_i + (1 + 0{,}0021\emptyset).\left(f_2 B{h_i}^2 + f_3 L_{bow}{h_i}^2 + f_4 BL_{bow}h_i\right)$$

$$C_1 = 0{,}23 \frac{1}{2\frac{14}{51{,}2}+1} 51{,}2x\, 86{,}97\, x\, 0{,}2 + (1 + 0{,}0021(0{,}48\, rad).(4{,}58x51{,}2x(0{,}2)^2 + 1{,}47x18{,}84x(0{,}2)^2 + 0{,}29x51{,}2x18{,}84x0{,}2)$$

C_1 = 198,9281473 kN

$$C_2 = (1 + 0{,}063\emptyset)\left(g_1 {h_1}^{1,5} + g_2 h_1 B\right) + g_3 h_i\left(1 + 1{,}2\frac{T}{B}\right).\frac{B^2}{\sqrt{L}}$$

$$C_2 = (1 + 0{,}063(0{,}488rad))(18{,}9x(0{,}2)^{1,5} + 0{,}67x0{,}2x51{,}2) + 1{,}55x0{,}2\left(1 + 1{,}2\frac{14}{51{,}2}\right).\frac{51{,}2^2}{\sqrt{351{,}5}}$$

C_2 = 68,15447894 kN

$R_{ice} = C_1 + C_2 v$

R_{ice} = 198,9281473 + (68,15447894 x 0,514 m/s)

= **233, 96 kN**

So, the total Ice Resistance according to Riska et Al method is:

- Barents Sea

  At Barents Sea, there 6 parts of different velocity of vessel. By calculating ice resistance with Riska method, the value of ice resistance for Barents Sea is between 233-724kN. The ice resistance value depends on the thickness and speed velocity of the vessel when passing through ice zones.

  Table 22 Total Resistance at Barents Sea According Riska Method

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	0,514	8,348877	1,252332	233,95	243,56
II	2,57	180,1206	27,01809	374,08	581,22
III	3,855	392,0721	58,81082	461,66	912,54
IV	5,397	748,4541	112,2681	566,75	1427,48
V	7,196	1301,888	195,2832	689,36	2186,53
VI	7,71	1486,869	223,0303	724,39	2434,29

- Kara Sea

  At Kara Sea, there is a fundamental difference between Western and Eastern Part of Kara Sea. The thickness of ice at Western Part is 15 cm, meanwhile at the Easter Part is just 10 cm. At Western Kara Sea, there 4 parts of different velocity of vessel, while

Eastern Kara Sea just 2 parts. By calculating ice resistance with Riska method, the value of ice resistance for West and East Kara Sea is between 350 – 529 kN. The ice resistance value depends on the thickness and speed velocity of the vessel when passing through ice zones. For further information see appendix table 56-57.

- Laptev Sea

  At Laptev Sea, there 4 parts of different velocity of vessel. By calculating ice resistance with Riska method, the value of ice resistance for Laptev Sea is between 350 – 376 kN. The ice resistance value depends on the thickness and speed velocity of the vessel when passing through ice zones. For further information see appendix table 58.

- East Siberian Sea

  At East Siberian Sea, there 4 parts of different velocity of vessel. By calculating ice resistance with Riska method, the value of ice resistance for Laptev Sea is between 299 – 376 kN. The ice resistance value depends on the thickness and speed velocity of the vessel when passing through ice zones. For further information see appendix table 59.

- Chucki Sea

  At Chucki Sea, there 4 parts of different velocity of vessel. By calculating ice resistance with Riska method, the value of ice resistance for Chucki Sea is between 147 – 308 kN. The ice resistance value depends on the thickness and speed velocity of the vessel when passing through ice zones. For further information see appendix table 60.

c. Comparing Value of Lindqvist and Riska Method

- Barents Sea

  From Table 52, there are 2 methods to figure out the value of ice resistance for a vessel, Lindqvist and Riska. When passing through the ice with low velocity, Lindqvist method has a higher value than Riska. On the other hand, when a vessel rises their velocity, Riska method has a higher value for the ice resistance. There is a difference of 15% for the ice resistance between Lindqvist and Riska Method.

Table 23 Comparing Resistance at Barents Sea

Step	R Lindqvist (kN)	R Riska (kN)
I	270,5067036	233,9595
II	363,9143373	374,0852
III	422,2941083	461,6637
IV	492,3498336	566,7579
V	574,081513	689,3678
VI	597,4334215	724,3992

- Kara Sea

  From Table 53 - 54, there are 2 methods to figure out the value of ice resistance for a vessel, Lindqvist and Riska. From the value of ice resistance, Riska method has a greater value than the Lindqvist Method. There is a difference of 18% for the ice resistance between Lindqvist and Riska Method.

  - West Kara Sea

Table 24 Comparing Resistance at West Kara Sea

Step	R Lindqvist (kN)	R Riska (kN)
I	440,0365955	529,7322439
II	354,6661908	402,2307042
III	422,9625146	504,2319359
IV	440,0365955	529,7322439

  - East Kara Sea

Table 25 Comparing Resistance at East Kara Sea

Step	R Lindqvist (kN)	R Riska (kN)
I	286,4245395	350,7749877
II	302,905919	376,1685438

- Laptev Sea

  From Table 55, there are 2 methods to figure out the value of ice resistance for a vessel, Lindqvist and Riska. From the value of ice resistance, Riska method has a greater value than the Lindqvist Method. There is a difference of 20% for the ice resistance between Lindqvist and Riska Method.

Table 26 Comparing Resistance at Laptev Sea

Step	R Lindqvist (kN)	R Riska (kN)
I	1996,323514	2060,673962
II	2357,403633	2430,666257
III	1996,323514	2060,673962
IV	2357,403633	2430,666257

- East Siberian Sea

  From Table 56, there are 2 methods to figure out the value of ice resistance for a vessel, Lindqvist and Riska. From the value of ice resistance, Riska method has a greater value than the Lindqvist Method. There is a difference of 18% for the ice resistance between Lindqvist and Riska Method.

Table 27 Comparing Resistance at East Siberian Sea

Step	R Lindqvist (kN)	R Riska (kN)
I	2446,72962	2519,99224
II	1837,702742	1896,11174
III	1619,00461	1671,47216
IV	1414,639031	1461,16513

- Chucki Sea

  From Table 57, there are 2 methods to figure out the value of ice resistance for a vessel, Lindqvist and Riska. When passing through the ice with low velocity, Lindqvist method has a higher value than Riska. On the other hand, when a vessel rises their velocity, Riska method has a higher value for the ice resistance. There is a difference of 11% for the ice resistance between Lindqvist and Riska Method.

Table 28 Comparing Resistance at Chucki Sea

Step	R Lindqvist (kN)	R Riska (kN)
I	1414,63903	1461,165126
II	1515,02586	1564,522685
III	742,078605	764,8388956
IV	235,877272	228,930307

4.6 Calculating Total Fuel Consumption on Ice Route

The step to calculate total fuel consumption on ice route is similar to the step to calculate total fuel consumption on convention route. The total fuel consumption on ice route:

- North – Norwegian Sea

  This route is divided into 8 parts, with the range power of engine between 246 – 64380kW. The total fuel consumption for this route is 1108,66 tons. The operational time for this route is 106,6 hours with total fuel consumption per hour around 10,4 ton/hour. For further information see appendix table 61.
- Barents Sea
  - Lindqvist Method

    This route is divided into 6 parts, based on Lindqvist Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 288 – 35628kW. The total fuel consumption for this route is 244,51 tons. The operational time for this route is 40 hours with total fuel consumption per hour around 6,11 ton/hour. For further information see appendix table 62.
  - Riska Method

    This route is divided into 6 parts, based on Riska Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 250 – 37589kW. The total fuel consumption for this route is 257,94 tons. The operational time for this route is 40 hours with total fuel consumption per hour around 6,44 ton/hour. For further information see appendix table 63.
- West Kara Sea
  - Lindqvist Method

    This route is divided into 4 parts, based on Lindqvist Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 11718 – 33198kW. The total fuel consumption for this route is 190,28 tons. The operational time for this route is 32 hours with total fuel consumption per hour around 5,95 ton/hour. For further information see appendix table 64.
  - Riska Method

    This route is divided into 4 parts, based on Riska Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 12207 –

34583kW. The total fuel consumption for this route is 198,25 tons. The operational time for this route is 32 hours with total fuel consumption per hour around 6,19 ton/hour. For further information see appendix table 65.

- East Kara Sea
  - Lindqvist Method

    This route is divided into 2 parts, based on Lindqvist Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 30826 – 40041kW. The total fuel consumption for this route is 208,16 tons. The operational time for this route is 29 hours with total fuel consumption per hour around 7,17 ton/hour. For further information see appendix table 66.
  - Riska Method

    This route is divided into 2 parts, based on Riska Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 31819 – 41286kW. The total fuel consumption for this route is 214,7 tons. The operational time for this route is 29 hours with total fuel consumption per hour around 7,4 ton/hour. For further information see appendix table 67.
- Laptev Sea
  - Lindqvist Method

    This route is divided into 4 parts, based on Lindqvist Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 30826 – 40041kW. The total fuel consumption for this route is 285,53 tons. The operational time for this route is 42 hours with total fuel consumption per hour around 6,79 ton/hour. For further information see appendix table 68.
  - Riska Method

    This route is divided into 4 parts, based on Riska Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 31819 – 41286kW. The total fuel consumption for this route is 294,54 tons. The operational time for this route is 42 hours with total fuel consumption per hour around 7,01 ton/hour. For further information see appendix table 69.

- East Siberian Sea
    - Lindqvist Method

      This route is divided into 4 parts, based on Lindqvist Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 17475 – 41559kW. The total fuel consumption for this route is 245,58 tons. The operational time for this route is 46,25 hours with total fuel consumption per hour around 5,3 ton/hour. For further information see appendix table 70.
    - Riska Method

      This route is divided into 4 parts, based on Riska Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 18050 – 42803kW. The total fuel consumption for this route is 253,28 tons. The operational time for this route is 46,25 hours with total fuel consumption per hour around 5,47 ton/hour. For further information see appendix table 71.
- Chucki Sea
    - Lindqvist Method

      This route is divided into 4 parts, based on Lindqvist Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 728 – 19495kW. The total fuel consumption for this route is 139,22 tons. The operational time for this route is 41,4 hours with total fuel consumption per hour around 3,36 ton/hour. For further information see appendix table 72.
    - Riska Method

      This route is divided into 4 parts, based on Riska Method to calculate ice resistance which affect the power of engine, the range power of engine on this route between 707 – 20132kW. The total fuel consumption for this route is 143,77 tons. The operational time for this route is 41,4 hours with total fuel consumption per hour around 3,47 ton/hour. For further information see appendix table 73.
- Bering – East China Sea

  This route is divided into 12 parts, with the range power of engine between 12 – 52676kW. The total fuel consumption for this route is 2199,65 tons. The operational time for this route is 228,11 hours with total fuel consumption per hour around 9,64 tons/hour. For further information see appendix table 74.

After knowing total fuel consumption for each route, now the total fuel consumption for ice route can be revealed.

Table 29 Total Fuel Consumption for Ice Route

No	Destination	Total Fuel Consumption (ton)		Hours	Total Consumption / hour	
		Lindqvist	Riska		Lindqvist	Riska
1	North – Norwegian Sea	1108,661		106,6	10,4	
2	Barents Sea	244,511	257,95	40	6,113	6,449
3	Kara Sea	398,440	412,942	61	6,532	6,77
4	Laptev Sea	285,524	294,549	42	6,798	7,013
5	East Siberian Sea	245,580	253,288	46,25	5,310	5,476
6	Chucki Sea	139,218	143,77	41,4	3,363	3,473
7	Bering – East China Sea	2199,653		228,117	9,643	
	Total	4621,586	4670,812	565,367	8,174	8,261
	Conventional Route	5810,231215		596,15		
	Comparison	79,54%	80,39%	94,84%		

When the total fuel consumption of Ice Route is compared with total fuel consumption of Conventional Route, the data said that, Ice Route can save approximately 20% of fuel consumption when a vessel just saving approximately 5% of her operational hours of her voyage from Asia – Europe. For information, the usage of ice route can reduce 17% of distance to reach Hong Kong Port from Hamburg Port.

4.7 Selecting the most efficient speed for Vessel when passing through Ice Route

As already shown on part 4.6, Ice Route can save 20% of fuel consumption when a vessel just only saves her 5% of operational hours. Now, these parts will try to figure out how many percent that can be saved if a vessel wants to save her 10% of the operational hours.

Hereby, the speed of vessel when a vessel wants to save 10% of the operational hours.

- North – Norwegian Sea

  On the section 4.6, a vessel needs 106,6 hours for passing through North-Norwegian Sea with a distance of 1976 nm. On this section, a vessel saves 6,1 hours of her operation to reach 100,5 hours of operation for passing through 1976 nm. However, the total fuel consumption for this route becomes 1219,96 tons for the operation compare with the 106,6 hours of operation that can using a fuel just only 1108,66 tons. By saving 6,1 hours of operation, a vessel needs 111,3 tons more fuel.

Table 30 Efficient Speed at North - Norwegian Sea

Step	Operational Time	Vs (m/s)	R total (kN)	Total Fuel Consumption
I	0,5	1,542	79,892	0,0204164
II	2,5	7,71	1763,443	13,14195798
III	3,5	9,252	2529,074	31,57405834
IV	52	10,537	3279,853	692,8511732
V	35	10,28	3131,582	434,4003637
VI	4,5	9,252	2544,022	40,95183719
VII	2	6,682	1346,369	6,996366036
VIII	0,5	1,542	80,461	0,024190192

- Barents Sea
  - Lindqvist Method

    On the section 4.6, a vessel needs 40 hours for passing through Barents Sea with a distance of 560 nm. On this section, a vessel saves 1,5 hours of her operation to reach 38,5 hours of operation for passing through 560 nm. However, the total fuel consumption for this route becomes 253,12 tons for the operation compare with the 40 hours of operation that can using a fuel just only 244,51 tons. By saving 1,5 hours of operation, a vessel needs 8,61 tons more fuel. For further information, see appendix table 75.
  - Riska Method

    On the section 4.6, a vessel needs 40 hours for passing through Barents Sea with a distance of 560 nm. On this section, a vessel saves 1,5 hours of her operation to reach 38,5 hours of operation for passing through 560 nm. However, the total fuel consumption for this route becomes 266,61 tons for the operation compare with the 40 hours of operation that can using a fuel just only 257,51 tons. By saving 1,5 hours of operation, a vessel needs 9,1 tons more fuel. For further information, see appendix table 75.

- West Kara Sea
  - Lindqvist Method
    On the section 4.6, a vessel needs 32 hours for passing through West Kara Sea with a distance of 465 nm. On this section, a vessel saves 1,3 hours of her operation to reach 30,7 hours of operation for passing through 465 nm. However, the total fuel consumption for this route becomes 203,91 tons for the operation compare with the 32 hours of operation that can using a fuel just only 190,27 tons. By saving 1,3 hours of operation, a vessel needs 13,64 tons more fuel. For further information, see appendix table 76.
  - Riska Method
    On the section 4.6, a vessel needs 32 hours for passing through West Kara Sea with a distance of 465 nm. On this section, a vessel saves 1,3 hours of her operation to reach 30,7 hours of operation for passing through 465 nm. However, the total fuel consumption for this route becomes 212,38 tons for the operation compare with the 32 hours of operation that can using a fuel just only 198,24 tons. By saving 1,3 hours of operation, a vessel needs 14,14 tons more fuel. For further information, see appendix table 76.
- East Kara Sea
  - Lindqvist Method
    On the section 4.6, a vessel needs 29 hours for passing through East Kara Sea with a distance of 465 nm. On this section, a vessel saves 0,5 hours of her operation to reach 28,5 hours of operation for passing through 465 nm. However, the total fuel consumption for this route becomes 214,2 tons for the operation compare with the 29 hours of operation that can using a fuel just only 208,16 tons. By saving 0,5 hours of operation, a vessel needs 6,04 tons more fuel. For further information, see appendix table 77.
  - Riska Method
    On the section 4.6, a vessel needs 29 hours for passing through East Kara Sea with a distance of 465 nm. On this section, a vessel saves 0,5 hours of her operation to reach 28,5 hours of operation for passing through 465 nm. However, the total fuel consumption for this route becomes 220,88 tons for the operation compare with the 29 hours of operation that can using a fuel just only 214,69 tons. By saving 0,5 hours of

operation, a vessel needs 6,19 tons more fuel. For further information, see appendix table 77.

- Laptev Sea
  - Lindqvist Method

    On the section 4.6, a vessel needs 42 hours for passing through Laptev Sea with a distance of 660 nm. On this section, a vessel saves 1,9 hours of her operation to reach 40,1 hours of operation for passing through 465 nm. However, the total fuel consumption for this route becomes 308,19 tons for the operation compare with the 42 hours of operation that can using a fuel just only 285,52 tons. By saving 1,9 hours of operation, a vessel needs 22,67 tons more fuel. For further information, see appendix table 78.
  - Riska Method

    On the section 4.6, a vessel needs 42 hours for passing through Laptev Sea with a distance of 660 nm. On this section, a vessel saves 1,9 hours of her operation to reach 40,1 hours of operation for passing through 465 nm. However, the total fuel consumption for this route becomes 317,78 tons for the operation compare with the 42 hours of operation that can using a fuel just only 294,54 tons. By saving 1,9 hours of operation, a vessel needs 23,24 tons more fuel. For further information, see appendix table 78.
- East Siberian Sea
  - Lindqvist Method

    On the section 4.6, a vessel needs 46,25 hours for passing through East Siberian Sea with a distance of 650 nm. On this section, a vessel saves 3,25 hours of her operation to reach 43 hours of operation for passing through 650 nm. However, the total fuel consumption for this route becomes 276,38 tons for the operation compare with the 46,25 hours of operation that can using a fuel just only 245,58 tons. By saving 3,25 hours of operation, a vessel needs 30,8 tons more fuel. For further information, see appendix table 79.
  - Riska Method

    On the section 4.6, a vessel needs 46,25 hours for passing through East Siberian Sea with a distance of 650 nm. On this section, a vessel saves 3,25 hours of her operation to reach 43 hours of operation for passing through 650 nm. However, the total fuel consumption for this route becomes 284,87 tons for the operation compare with the 46,25 hours of operation that can using a fuel just only 253,28 tons. By saving 3,25 hours of operation, a vessel needs 31,59 tons more fuel. For further information, see appendix table 79.

- Chucki Sea
    - Lindqvist Method

      On the section 4.6, a vessel needs 41,4 hours for passing through Chucki Sea with a distance of 490 nm. On this section, a vessel saves 3 hours of her operation to reach 38,4 hours of operation for passing through 490 nm. However, the total fuel consumption for this route becomes 155,73 tons for the operation compare with the 41,4 hours of operation that can using a fuel just only 139,21 tons. By saving 3 hours of operation, a vessel needs 16,52 tons more fuel. For further information, see appendix table 80.
    - Riska Method

      On the section 4.6, a vessel needs 41,4 hours for passing through Chucki Sea with a distance of 490 nm. On this section, a vessel saves 3 hours of her operation to reach 38,4 hours of operation for passing through 490 nm. However, the total fuel consumption for this route becomes 160,78 tons for the operation compare with the 41,4 hours of operation that can using a fuel just only 143,77 tons. By saving 3 hours of operation, a vessel needs 17,01 tons more fuel. For further information, see appendix table 80.
- Bering – East China Sea

  On the section 4.6, a vessel needs 228,11 hours for passing through Bering – East China Sea with a distance of 4220 nm. On this section, a vessel saves 19,78 hours of her operation to reach 208,33 hours of operation for passing through 4220 nm. However, the total fuel consumption for this route becomes 2639,09 tons for the operation compare with the 228,11 hours of operation that can using a fuel just only 2199,65 tons. By saving 19,78 hours of operation, a vessel needs 439,44 tons more fuel. For further information, see appendix table 81.

In the end, the conclusion is:

Table 31 Total Fuel Consumption for Efficient Speed

No	Destination	Total Fuel Consumption (ton)		Hours	Total Consumption / hour	
		Lindqvist	Riska		Lindqvist	Riska
1	North – Norwegian Sea	1219,960		100,5	12,139	
2	Barents Sea	253,123	266,617	38,5	6,575	6,925
3	Kara Sea	418,121	433,272	59,2	7,063	7,319
4	Laptev Sea	308,198	317,783	40,1	7,686	7,925
5	East Siberian Sea	276,383	284,872	43	6,428	6,625
6	Chucki Sea	155,732	160,780	38,4	4,056	4,187
7	Bering – East China Sea	2639,097		208,333	12,668	
	Total	5270,615	5322,381	528,033	9,982	10,08
	Conventional Route	5810,231215		596,15		
	Comparison	90,71%	91,60%	88,57%		

When the total fuel consumption of Ice Route is compared with total fuel consumption of Conventional Route, the data said that, Ice Route can save approximately 10% of fuel consumption when a vessel just saving approximately 11% of her operational hours of her voyage from Asia – Europe. For information, the usage of ice route can reduce 17% of distance to reach Hong Kong Port from Hamburg Port.

4.8 Cost Analysis for Conventional Route and Ice Route Based on Fuel Consumption of the ship

Like already said in last section of this chapter, Ice Route can reduce fuel consumption of a ship until 20% depends on the ship operation itself. Fuel consumption can charge ship owners until 50% of their operational costs. So, it is very important to know how much money that will spend on bunkering fuels.

For conventional route, bunkering fuel is projected to be carried on Hong Kong Port as the first port of the voyage and the second and third is Port Klang and Piraeus Port respectively. Conventional Route using Suez Canal to be passing through. The usage of Suez Canal charges a ship for 55315,64 USD. The total price for the fuel during the operation at conventional route is 2443981,114 USD. So, the total price that may be needed for conventional route is 2997496,754 USD.

Conventional Route Cost Analysis

Table 32 Total Price for Conventional Route

Bunkering Plan	Metric Ton Fuel	Price / Metric Ton [10]	Total Price (USD)
Hong Kong	1065,351505	463	493257,7468
Port Klang	2637,818798	460	1213396,647
Pireus	1578,858074	467	737326,7204
		Total Price for Fuel	2443981,114
		Suez Canal Costs	55315,64
		Total Price	2997496,754

For the ice route, bunkering fuel is projected to be carried on Hamburg Port and one of the ports in Russian coastline. However, there is a conflict about who own the Northeast Passage. On this thesis, Northeast Passage is considered as open water for international passage. So, the canal toll of Northeast Passage will not exist and is considered to be zero.

Ice Route Cost Analysis for savings 20% Fuel Consumption.

Table 33 Total Price for Ice Route for savings 20% Fuel Consumption

Bunkering Plan	Metric Ton Fuel		Price / Metric Ton [10,13]	Total Price (USD)	
	Lindqvist	Riska		Lindqvist	Riska
Hamburg	2421,93	2471,16	447	1082605	1104608
Russian Port	2199,65	2199,65	400	879861,1	879861,1
			Total Price for Fuel	1962466	1984469
			Total Price	1962466	1984469

On Ice Route, there is no cost for using a canal because of the assumption of the Passage is international water, so fuel cost is the only cost that will be considered. Total price for ice route is 1962466 USD if using Lindqvist method and 1984469 USD if using Riska method. If using Lindqvist method, a ship can save up to 35% of their operational cost of fuel or can save 1035031 USD and if using riska method, a ship can save up to 34% of their operational cost of fuel or can save 1013027 USD.

Ice Route Cost Analysis for savings 12% Fuel Consumption

Table 34 Total Price for Ice for savings 12% Fuel Consumption

Bunkering Plan	Metric Ton Fuel		Price / Metric Ton [10,13]	Total Price (USD)	
	Lindqvist	Riska		Lindqvist	Riska
Hamburg	2631,52	2683,28	447	1176289	1199428
Russian Port	2639,09	2639,09	400	1055639	1055639
Total Price for Fuel				2231928	2255067
Total Price				2231928	2255067

On Ice Route, there is no cost for using a canal because of the assumption of the Passage is international water, so fuel cost is the only cost that will be considered. Total price for ice route is 2231928 USD if using Lindqvist method and 2255067 USD if using Riska method. If using Lindqvist method, a ship can save up to 26% of their operational cost of fuel or can save 765569,2 USD and if using riska method, a ship can save up to 25% of their operational cost of fuel or can save 742429,9 USD.

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CHAPTER V
RESULT & CONCLUSION

5.1 Conclusion

- Total Fuel Consumption for Conventional Route is 5810,231215 tons with operational hours of a vessel is 596,15 hours. So, the total fuel consumption per hour is 9,74625 tons / hour.
- By using Northeast Passage, a vessel needs 9486 to be traveled from Hong Kong Port to Hamburg Port or vice versa. It saves 17% of distance or ±1900 nautical miles.
- There are 2 methods for calculating Ice Route, Lindqvist and Riska method.
- On the first calculation, a vessel can save 5% of their operational hour by using ice route if compare to the conventional route. But, it saves 20% of fuel consumption. Using Northeast Passage, a vessel just need 565,367 hours with total fuel consumption 4621,58 tons with Lindqvist Method and 4670,82 tons with Riska method.
- On the second calculation, a vessel tries to speed up her speed and save 11% of their operational hour by using ice route if compare to the conventional route. But, it saves only 9% of fuel consumption. Using Northeast Passage, a vessel just need 528,03 hours with total fuel consumption 5270,615 tons with Lindqvist Method and 5322,3813 tons with Riska method.
- Bunkering plan in conventional route is occurred in Hongkong Port, Port Klang and Piraeus Port with a price 463 USD, 460 USD, 467 USD respectively. Suez Canal is controlled by a country so if a vessel wants to pass Suez Canal, a vessel will pay some money to the authority. Total Price of this vessel for passing Suez Canal is 55315,64 USD (using Suez Canal calculator). The total price that needed to be paid for Conventional Route is 2997496,754 USD.
- Northeast Passage is still considered as International water because of there is too much complexity about the declaration. So, there is no taxes for a vessel when passing through the Northeast Passage. Bunkering is occurred at Hamburg and one of port in Russian Coastline with a price of 447 USD at Hamburg and 400 USD at Russian Port. 1962466 USD needs to be paid for a vessel if a vessel wants to deliver cargoes from Hamburg Port to Hongkong Port or vice versa. It saves 35% or equivalent to1035031 USD.

- On the second calculation when a ship wants to save the operational time to 11% compared to the conventional route, ship's owner need to spend 2231928 USD for bunkering fuel. It saves 25% of the operational cost of the ship or equivalent to 765569,2 USD.
- There is no additional fuel treatment equipment for a vessel because, Northeast Passage is just projected for a shipping company to operate their vessel on summer condition. And the environmental condition of Northeast Passage on summer is not so far away from the condition on winter at conventional route.

5.2 Suggestion

Determining the speed of a vessel when it operates becomes fundamental for saving fuel of the vessel. However, it can't be done easily because there is a time contract that must be obeyed. Northeast Passage can be a solution for shipping companies especially a shipping company that has based on East Asia and European Countries. The next study of this bachelor thesis may be determining the number of cargo lost when a ship does not pass through the existing port on the general track. By using Northeast Passage, a ship will not pass countries like Singapore and Malaysia that may have a lot of cargoes that needs to be delivered. By knowing how many cargoes that may be lost by shorten the distance from European Countries to Hong Kong Port, it will provide a great input to the ship owner for choosing the line of the ve

Bibliography

[1] American Bureau of Shipping. (2014). *Navigating the Northern Sea Route.* Houston: American Bureau of Shipping.

[2] Cho, Y. (2011). *The Melting Arctic Changin the World : New Sea Route.* Seoul: Korea Maritme Institute.

[3] Drewery Shipping Consultants Ltd. (2012). *Operating Costs of Container Ships.*

[4] Harvald, S. A. (1983). *Components of Ship Resistance.* Lyngby: Technical University of Denmark.

[5] Korea Maritime Institute. (2013). An Economical Analysis of Container Shipping through Northwest Passage. 8-10.

[6] Lindqvist, G. (1989). *A Straightforward Method for Calculating of Ice Resistance of Ships.* Finland: Wartsilla Marine Industries.

[7] MAN Diesel & Turbo. (2010). *Project Guide MAN B&W K98MC-C7-TII.* Copenhagen: MAN Diesel & Turbo.

[8] Nimmo, F. (2004). What is the Young's Modulus of Ice? *Europa's Icy Shell*, 2.

[9] Oil Monster. (2018, 5 22). Retrieved from Oil Monster: https://www.oilmonster.com

[10] Ship & Bunker. (2018, 5 22). Retrieved from Ship & Bunker: https://shipandbunker.com

[11] Skar, T. (2011). *Ice Induced Resistance of Ship Hulls.* Norwegian University of Science and Technology.

[12] Thorsen, I. B. (2012). *Estimation and Computation of Ice Resistance for Ship Hulls.* Norwegian University of Science and Technology.

[13] Wilhelmsen. (2018, 5 22). *Suez Toll Calculator*. Retrieved from https://www.wilhelmsen.com/tollcalculators/suez-toll-calculator/

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APPENDIX

Table 35 Total Resistance for Nansha - Shekou

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R total (kN)
I	2,2616	137,4729	20,6209377	158,0938555
II	3,855	383,2282	57,4842292	440,7124242
III	6,425	1025,383	153,807449	1179,190444
IV	8,1212	1611,433	241,714973	1853,148127
V	6,939	1189,485	178,422819	1367,908282
VI	7,5558	1401,915	210,287192	1612,201808
VII	7,967	1552,892	232,933838	1785,826089
VIII	6,682	1105,962	165,894323	1271,85648
IX	5,654	801,381	120,207155	921,5881854
X	5,14	666,9029	100,035442	766,938386
XI	3,855	383,2282	57,4842292	440,7124242
XII	2,1588	125,7271	18,8590712	144,5862126

Table 36 Total Resistance for Shekou - Tj. Pelepas

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R total (kN)
I	0,3084	3,089346	0,30893464	3,398281021
II	7,453	1376,115	137,61147	1513,726123
III	10,3828	2656,081	265,60809	2921,688985
IV	11,2052	3091,265	309,12647	3400,391196
V	11,2052	3063,166	306,3166	3369,48263
VI	10,28	2535,951	253,59505	2789,545554
VII	6,0138	900,987	90,098701	991,0857093
VIII	7,453	1343,024	134,30239	1477,326312
IX	4,369	479,3144	47,931436	527,2457993

Table 37 Total Resistance for Tj. Pelepas - Port Klang

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R total (kN)
I	0,4369	5,82162	1,164323941	6,985943644
II	5,842467	841,7015	168,3402935	1010,041761
III	10,05384	2444,279	488,855749	2933,134494
IV	7,2474	1275,745	255,1490987	1530,894592
V	5,184057	668,3646	133,6729223	802,0375338
VI	2,2359	132,4478	26,48956159	158,9373695
VII	0,445467	6,041087	1,208217331	7,249303986

Table 38 Total Resistance for Port Klang - Suez

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R total (kN)
I	0,6168	11,30470621	1,69570593	13,00041215
II	6,168	938,9269539	140,839043	1079,765997
III	10,537	2737,088561	410,563284	3147,651846
IV	9,252	2092,796814	313,919522	2406,716337
V	10,023	2453,842967	368,076445	2821,919412
VI	10,28	2622,88664	393,432996	3016,319636
VII	10,3828	2673,866199	401,07993	3074,946129
VIII	10,1772	2572,383122	385,857468	2958,240591
IX	9,8688	2433,060479	364,959072	2798,019551
X	9,1492	2083,685949	312,552892	2396,238841
XI	8,995	2016,391728	302,458759	2318,850487
XII	2,57	177,6048404	26,6407261	204,2455665

Table 39 Total Resistance for Suez - Piraeus

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R total (kN)
I	4,112	438,321797	65,7482695	504,0700665
II	7,196	1288,101555	193,215233	1481,316788
III	9,6118	2291,9792	343,79688	2635,77608
IV	10,6912	2778,645592	416,796839	3195,442431
V	9,6632	2235,555948	335,333392	2570,889341
VI	6,168	940,3384651	141,05077	1081,389235
VII	3,855	380,4252029	57,0637804	437,4889833
VIII	2,4158	154,9752365	23,2462855	178,221522
IX	0,8738	22,1081045	3,31621567	25,42432017
X	3,2896	280,4269403	42,064041	322,4909814
XI	0,7196	15,26097245	2,28914587	17,55011832

Table 40 Total Resistance for Piraeus - Antwerp

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R total (kN)
I	1,97024	105,7801503	15,867023	121,6471728
II	4,64656	550,3629654	55,036297	605,399262
III	7,6072	1423,505195	142,35052	1565,855714
IV	8,481	1755,891933	175,58919	1931,481127
V	9,065675	2032,25567	203,22557	2235,481237
VI	8,923831	1971,270607	197,12706	2168,397668
VII	8,906218	1975,099339	197,50993	2172,609272
VIII	10,61745	2821,970089	282,19701	3104,167098
IX	10,3314	2653,941576	265,39416	2919,335734
X	8,6352	1855,262171	185,52622	2040,788388
XI	10,4013	2761,35252	276,13525	3037,487772
XII	9,3805	2214,225632	221,42256	2435,648196
XIII	8,3525	1739,912761	173,99128	1913,904037
XIV	8,25484	1708,442567	170,84426	1879,286824
XV	6,53808	1090,146773	109,01468	1199,161451
XVI	5,46896	773,0165868	77,301659	850,3182455
XVII	10,62695	2902,023255	290,20233	3192,22558
XVIII	7,13432	1289,726291	128,97263	1418,69892

Table 41 Total Resistance for Antwerp - Hamburg

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R total (kN)
I	1,542	67,90093	13,5801868	81,48112109
II	3,56716	339,073	67,814606	406,8876359
III	4,454667	519,7229	103,944573	623,6674365
IV	3,30245	292,3942	58,47884	350,8730401
V	3,21764	278,1441	55,6288109	333,7728652
VI	5,773933	856,1467	171,229345	1027,37607
VII	6,43528	1054,973	210,994671	1265,968026
VIII	6,0395	964,5109	192,902176	1157,413057
IX	5,033246	657,3385	131,467692	788,8061541
X	6,333622	1023,109	204,621834	1227,731006
XI	5,751089	849,6371	169,927428	1019,564571
XII	10,08909	2596,666	259,666609	2856,332699
XIII	8,262897	1707,898	341,579572	2049,47743
XIV	5,928133	900,7134	180,142685	1080,856109
XV	8,9179	1978,567	395,713382	2374,280293
XVI	7,071171	1279,899	255,979725	1535,878353
XVII	6,2194	999,6812	199,936238	1199,617431
XVIII	2,895533	230,1019	46,0203833	276,1222997
XIX	0,68105	14,48061	2,89612127	17,3767276

Table 42 Total Fuel Consumpton Nansha - Shekou

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	158,093855	357,5451	596,499	608,673	716,0861	0,0092
II	440,712424	1698,946	2834,38	2892,23	3402,625	0,0331
III	1179,19044	7576,299	12639,7	12897,6	15173,70	0,3427
IV	1853,14812	15049,79	25107,8	25620,2	30141,49	4,3641
V	1367,90828	9491,916	15835,5	16158,7	19010,27	0,4907
VI	1612,20180	12181,47	20322,6	20737,3	24396,88	7,0848
VII	1785,82608	14227,68	23736,3	24220,7	28494,98	3,8506
VIII	1271,85648	8498,545	14178,3	14467,6	17020,76	1,8175
IX	921,588185	5210,66	8693,05	8870,46	10435,83	1,2156
X	766,938386	3942,063	6576,62	6710,82	7895,108	2,3758
XI	440,71,4242	1698,946	2834,38	2892,23	3402,625	0,4968
XII	144,586212	312,1327	520,737	531,364	625,1349	0,0608

Table 43 Total Fuel Consumption Shekou - Tj. Pelepas

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	3,3982810	1,048029	1,60274	1,63545	1,924064	8,11E-05
II	1513,7261	11281,80	17253,1	17605,2	20712,11	8,553782
III	2921,6889	30335,31	46391,6	47338,3	55692,21	9,13867
IV	3400,391	38102,06	58269,2	59458,4	69951,08	478,282
V	3369,4826	37755,72	57739,6	58917,9	69315,25	473,683
VI	2789,5455	28676,52	43854,8	44749,8	52646,87	29,1353
VII	991,08570	5960,191	9114,88	9300,90	10942,24	0,98859
VIII	1477,3263	11010,51	16838,3	17181,9	20214,06	21,1926
IX	527,24579	2303,536	3522,78	3594,67	4229,033	0,46527

Table 44 Total Fuel Consumption Tj Pelepas - Port Klang

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	6,985943	3,052159	5,09197	5,19589	6,112820	0,000523
II	1010,041	5901,135	9844,98	10045,9	11818,71	0,648296
III	2933,134	29489,26	49197,5	50201,5	59060,68	80,37064
IV	1530,894	11095,01	18510,0	18887,7	22220,91	3,160115
V	802,0375	4157,808	6936,55	7078,12	8327,199	1,484518
VI	158,9373	355,3681	592,867	604,967	711,7261	0,025448
VII	7,249303	3,229323	5,38754	5,49749	6,467642	0,000196

Table 45 Total Fuel Consumption Port Klang - Suez

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	13,0004	8,01865	13,3776	13,6507	16,05964	0,0004
II	1079,76	6659,99	11111	11337,7	13338,54	1,1037
III	3147,65	33166,8	55332,8	56462,1	66426,01	786
IV	2406,71	22266,9	37148,3	37906,5	44595,91	14,107
V	2821,91	28284,1	47186,9	48149,9	56646,99	58,857
VI	3016,31	31007,7	51730,8	52786,6	62101,91	463,69
VII	3074,94	31926,5	53263,7	54350,7	63942,04	680,23
VIII	2958,24	30106,6	50227,4	51252,5	60297,08	337,25
IX	2798,01	27613,1	46067,5	47007,6	55303,11	123,82
X	2396,23	21923,6	36575,7	37322,1	43908,41	40,712
XI	2318,85	20858,0	34797,9	35508,0	41774,22	10,708
XII	204,245	524,911	875,72	893,591	1051,284	0,0434

Table 46 Total Fuel Consumption Suez - Piraeus

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	504,07	2072,73	3457,9	3528,55	4151,24	0,170
II	1481,31	10659,5	17783	18146,4	21348,8	1,167
III	2635,77	25334,5	42266	43128,7	50739,6	30,85
IV	3195,44	34163,1	56995	58158,2	68421,4	325,22
V	2570,88	24843	41446	42291,9	49755,2	23,74
VI	1081,38	6670	11127	11354,8	13358,5	3,407
VII	437,48	1686,52	2813,6	2871,07	3377,73	0,074
VIII	178,22	430,547	718,29	732,95	862,29	0,08
IX	25,42	22,2157	37,063	37,81	44,49	0,0038
X	322,49	1060,86	1769,8	1805,98	2124,68	0,3
XI	17,55	12,6290	21,069	21,49	25,29	0,008

Table 47 Total Fuel Consumption Piraeus - Antwerp

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	121,647	239,67	399,85	408,0136	480,01	0,021807
II	605,4	2813	4693,02	4788,802	5633,88	0,200533
III	1565,855	11911	19872,6	20278,23	23856,7	0,460554
IV	1931,481	16380	27328,5	27886,3	32807,41	2,216715
V	2235,481	20266	33810,4	34500,44	40588,7	61,07423
VI	2168,397	19350	32282,6	32941,52	38754,7	180,9119
VII	2172,609	19349,7	32281,5	32940,36	38753,3	228,4011
VIII	3104,167	32958,3	54985	56107,23	66008,50	662,4394
IX	2919,335	30160,8	50317,9	51344,82	60405,6	94,18755
X	2040,788	17622,6	29400,1	30000,18	35294,3	143,085
XI	3037,487	31593,8	52708,6	53784,33	63275,6	115,9184
XII	2435,648	22847,6	38117,1	38895,02	45758,8	5,578766
XIII	1913,904	15985,8	26669,5	27213,86	32016,3	31,27458
XIV	1879,286	15513,2	25881	26409,2	31069,6	16,79438
XV	1199,161	7840,2	13079,9	13346,93	15702,2	6,637244
XVI	850,318	4650,3	7758,2	7916,618	9313,6	4,400072
XVII	3192,225	33923,6	56595	57750,49	67941,7	14,19983
XVIII	1418,698	10121,4	16885,8	17230,44	20271,1	7,957117

Table 48 Total Fuel Consumption Antwerp - Hamburg

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	81,481	125,6	209,61	213,8921	251,6	0,006533
II	406,887	1451,4	2421,4	2470,874	2906,9	0,056598
III	623,667	2778,2	4634,9	4729,571	5564,2	0,270837
IV	350,873	1158,7	1933,1	1972,603	2320,7	0,030123
V	333,772	1073,9	1791,7	1828,277	2150,91	0,069797
VI	1027,376	5932	9896,4	10098,45	11880,52	1,114859
VII	1265,968	8146,85	13591	13868,95	16316,4	1,583916
VIII	1157,413	6990,19	11661	11899,89	13999,86	1,359037
IX	788,806	3970,25	6623,6	6758,836	7951,57	1,543798
X	1227,731	7775,98	12972	13237,59	15573,63	3,325983
XI	1019,564	5863,6	9782,4	9982,016	11743,54	1,140005
XII	2856,332	28817,7	48077	49058,47	57715,85	22,96129
XIII	2049,477	16934,6	28252	28828,96	33916,42	98,21347
XIV	1080,856	6407,45	10689	10907,85	12832,76	7,142248
XV	2374,280	21173,5	35324	36045,25	42406,17	8,209835
XVI	1535,878	10860,4	18118	18488,5	21751,1	4,842681
XVII	1199,617	7460,90	12447	12701,2	14942,5	8,945068
XVIII	276,122	799,521	1333,8	1361,079	1601,26	0,166276
XIX	17,376	11,8344	19,74	20,14654	23,70	0,002384

Table 49 Total Resistance for North - Norwegian Sea

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R total (kN)
I	1,542	66,576989	13,3153978	79,89
II	7,71	1469,5356	293,907128	1763,44
III	9,252	2107,5615	421,51229	2529,07
IV	10,28	2605,8457	521,169142	3127,01
V	9,509	2244,8694	448,973884	2693,84
VI	9,252	2120,0187	424,003736	2544,02
VII	5,14	676,82772	135,365545	812,19
VIII	1,542	67,050685	13,410137	80,46

Table 50 Total Resistance for Bering - East China Sea

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R total (kN)
I	0,56	9,777656	1,466648	11,2443
II	5,7	825,6843	123,8526	949,5369
III	9,72	2328,611	349,2917	2677,903
IV	8,86	1904,486	380,8971	2285,383
V	9,65	2269,065	453,8131	2722,878
VI	9,47	2187,287	437,4574	2624,744
VII	9,61	2249,829	449,9658	2699,795
VIII	9,38	2145,525	429,105	2574,63
IX	9,08	1999,374	399,8747	2399,248
X	8,81	1885,676	377,1351	2262,811
XI	8,38	1711,543	342,3086	2053,852
XII	2,34	147,3348	29,46696	176,8017

Table 51 Total Resistance at West Kara Sea

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	7,71	1486,86	223,03	440,03	2149,93
II	5,14	681,43	102,21	354,6	1138,31
III	7,196	1301,88	195,28	422,9	1920,13
IV	7,71	1486,86	223,03	440,03	2149,93

Table 52 Total Resistance at East Kara Sea

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	7,71	1486,86	223,03	286,42	1996,32
II	8,481	1786,52	267,97	302,9	2357,4

Table 53 Total Resistance at Laptev Sea

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	7,71	1486,86	223,03	286,42	1996,32
II	8,481	1786,52	267,97	302,9	2357,4
III	7,71	1486,86	223,03	286,42	1996,32
IV	8,481	1786,52	267,98	302,9	2357,4

Table 54 Total Resistance at East Siberian Sea

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	8,481	1786,52	357,3	302,9	2446,73
II	7,196	1301,88	260,37	275,43	1837,7
III	6,682	1128,79	225,76	264,45	1619,00461
IV	6,168	967,64	193,53	253,46	1414,64

Table 55 Total Resistance at Chucki Sea

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	6,168	967,64	193,53	253,46	1414,639
II	6,425	1046,72	209,34	258,95	1515,026
III	4,112	443,8	88,76	209,51	742,0786
IV	1,542	67,75	13,55	154,57	235,8773

Table 56 Total Resistance at West Kara Sea According to Riska Method

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	7,71	1486,86	223,03	529,73	2239,63
II	5,14	681,43	102,21	402,23	1185,87
III	7,196	1301,88	195,28	504,23	2001,4
IV	7,71	1486,86	223,03	529,73	2239,63

Table 57 Total Resistance at East Kara Sea According to Riska Method

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	7,71	1486,86	223,03	350,77	2060,67
II	8,481	1786,52	267,97	376,16	2430,66

Table 58 Total Resistance at Laptev Sea According to Riska Method

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	7,71	1486,86	223,03	350,77	2060,67
II	8,481	1786,52	267,97	376,16	2430,66
III	7,71	1486,86	223,03	350,77	2060,67
IV	8,481	1786,52	267,98	376,16	2430,66

Table 59 Total Resistance at East Siberian Sea According to Riska Method

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	8,481	1786,52	357,3	376,16	2519,99
II	7,196	1301,88	260,37	333,84	1896,11
III	6,682	1128,79	225,76	316,91	1671,47
IV	6,168	967,64	193,53	299,98	1461,16

Table 60 Total Resistance at Chucki Sea According to Riska Method

Step	Vs (m/s)	R (kN)	Sea Margin (kN)	R ice (kN)	R total (kN)
I	6,168	967,64	193,53	299,98	1461,16
II	6,425	1046,72	209,34	308,45	1564,52
III	4,112	443,8	88,76	232,27	764,83
IV	1,542	67,75	13,55	147,62	228,93

Table 61 Total Fuel Consumption for North-Norwegian Sea

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	79,89	123,19	205,52	209,72	246,73	0,0306246
II	1763,44	13596,13	22682,7	23145,63	27230,16	13,14195798
III	2529,07	23398	39037	39833,69	46863,16	36,0846381
IV	3127,01	32145,7	53629	54723,83	64380,97	620,9062491
V	2693,84	25615,7	42735	43607,44	51302,87	296,2740939
VI	2544,02	23537,25	39267	40069,13	47140,16	136,506124
VII	812,19	4174,67	6964	7106,83	8360,976	5,681492745
VIII	80,46	124,0705876	206,9	211,21	248,4868	0,036285287

Table 62 Total Fuel Consumption for Barents Sea (Lindqvist)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	280,1	143,9755	240,197	245,099	288,35	0,02807107
II	571,05	1467,606	2448,437	2498,40	2939,3	0,57228195
III	873,17	3366,098	5615,73	5730,33	6741,57	1,308876334
IV	1353,07	7302,53	12182,96	12431,59	14625,4	5,679044062
V	2071,25	14904,74	24865,877	25373,34	29850,99	37,45777339
VI	2307,33	17789,53	29678,644	30284,33	35628,62	199,465072

Table 63 Total Fuel Consumption for Barents Sea (Riska)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	243560,75	125,19	208,85	213,11	250,72	0,024408489
II	581223,87	1493,74	2492,04	2542,9	2991,65	0,582474658
III	912546,63	3517,86	5868,93	5988,7	7045,53	1,367890572
IV	1427480,06	7704,11	12852,92	13115,2	15429,68	5,99134563
V	2186539,15	15734,34	26249,91	26785,62	31512,5	39,542679
VI	2434298,15	18768,44	31311,77	31950,78	37589,16	210,4410519

Table 64 Total Fuel Consumption for West Kara Sea (Lindqvist)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	2149,94	16576,00	27654,09	28218,46	33198,18	19,23
II	1138,31	5850,92	9761,22	9960,42	11718,15	2,27
III	1920,13	13817,28	23051,66	23522,10	27673,06	53,42
IV	2149,94	16576,00	27654,09	28218,46	33198,18	115,36

Table 65 Total Fuel Consumption for West Kara Sea (Riska)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	2239,63	17267,56	28807,82	29395,74	34583,22	20,03
II	1185,88	6095,41	10169,09	10376,62	12207,79	2,36
III	2001,40	14402,10	24027,32	24517,67	28844,32	55,68
IV	2239,63	17267,56	28807,82	29395,74	34583,22	120,17

Table 66 Total Fuel Consumption for East Kara Sea (Lindqvist)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	1996,32	15391,65	25678,21	26202,26	30826,19	53,56
II	2357,40	19993,14	33354,97	34035,68	40041,98	154,60

Table 67 Total Fuel Consumption for East Kara Sea (Riska)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	2060,67	15887,80	26505,94	27046,88	31819,85	55,29
II	2430,67	20614,48	34391,56	35093,43	41286,39	159,41

Table 68 Total Fuel Consumption for Laptev Sea (Lindqvist)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	1996,32	15391,65	25678,21	26202,26	30826,19	11,90
II	2357,40	19993,14	33354,97	34035,68	40041,98	77,30
III	1996,32	15391,65	25678,21	26202,26	30826,19	119,02
IV	2357,40	19993,14	33354,97	34035,68	40041,98	77,30

Table 69 Total Fuel Consumption for Laptev Sea (Riska)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	2060,67	15887,80	26505,94	27046,88	31819,85	12,29
II	2430,67	20614,48	34391,56	35093,43	41286,39	79,70
III	2060,67	15887,80	26505,94	27046,88	31819,85	122,86
IV	2430,67	20614,48	34391,56	35093,43	41286,39	79,70

Table 70 Total Fuel Consumption for East Siberian Sea (Lindqvist)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	2446,73	20750,71	34618,84	35325,35	41559,24	80,23
II	1837,70	13224,11	22062,05	22512,30	26485,06	102,26
III	1619,00	10818,19	18048,21	18416,54	21666,52	41,95
IV	1414,64	8725,49	14556,92	14854,00	17475,29	21,15

Table 71 Total Fuel Consumption for East Siberian Sea (Riska)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	2519,99	21372,05	35655,44	36383,10	42803,65	82,63
II	1896,11	13644,42	22763,27	23227,82	27326,85	105,51
III	1671,47	11168,78	18633,10	19013,37	22368,67	43,31
IV	1461,17	9012,47	15035,68	15342,53	18050,04	21,84

Table 72 Total Fuel Consumption for Chucki Sea (Lindqvist)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	1414,64	8725,49	14556,92	14854,00	17475,29	67,66
II	1515,03	9734,04	16239,50	16570,92	19495,20	67,94
III	742,08	3051,43	5090,76	5194,65	6111,36	3,56
IV	235,88	363,72	606,81	619,19	728,46	0,06

Table 73 Total Fuel Consumption for Chucki Sea (Riska)

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	1461,17	9012,47	15035,68	15342,53	18050,04	69,89
II	1564,52	10052,06	16770,06	17112,30	20132,12	70,16
III	764,84	3145,02	5246,90	5353,98	6298,80	3,67
IV	228,93	353,01	588,93	600,95	707,00	0,06

Table 74 Total Fuel Consumption for Bering - East China Sea

Step	R total (kN)	EHP (kW)	DHP (kW)	SHP (kW)	BHP mcr(kW)	W_{FO} (ton)
I	11,24	6,34	10,57	10,79	12,69	0,00038
II	949,54	5417,28	9037,77	9222,21	10849,66	0,958
III	2677,90	26036,80	43437,72	44324,21	52146,13	670,930
IV	2285,38	20254,30	33790,67	34480,28	40565,03	13,934
V	2722,88	26301,85	43879,91	44775,42	52676,97	58,292
VI	2624,74	24876,81	41502,50	42349,49	49822,93	404,752
VII	2699,79	25964,22	43316,64	44200,65	52000,77	600,556
VIII	2574,63	24159,58	40305,93	41128,50	48386,47	295,164
IX	2399,25	21805,60	36378,73	37121,16	43671,95	106,643
X	2262,81	19951,44	33285,40	33964,70	39958,47	38,713
XI	2053,85	17222,73	28733,03	29319,42	34493,43	9,673
XII	176,80	414,89	692,17	706,30	830,94	0,037

Table 75 Efficient Speed at Barents Sea

Step	Operational Time	Vs (m/s)	$R_{Lindqvist}$ (kN)	R_{Riska} (kN)	Fuel Consumption Lindqvist (ton)	Fuel Consumption Riska (ton)
I	0,5	0,514	280,11	243,56	0,028	0,024
II	0,5	2,57	571,05	581,22	0,286	0,291
III	0,5	5,14	1264,32	1245,31	1,263	1,244
IV	1	6,168	1640,17	1679,55	3,933	4,028
V	2	7,71	2307,33	2399,27	13,756	14,304
VI	34	7,71	2307,33	2434,30	233,85	246,723

Table 76 Efficient Speed at West Kara Sea

Step	Operational Time	Vs (m/s)	R Lindqvist (kN)	R Riska (kN)	Fuel Consumption Lindqvist (tons)	Fuel Consumption Riska (tons)
I	8	7,71	2149,94	2239,63	51,27	53,41
II	1,2	6,425	1601,09	1669,72	4,78	4,991
III	1,5	7,196	1920,13	2001,40	8,01	8,35
IV	20	7,967	2269,94	2363,85	139,84	145,629

Table 77 Efficient Speed at East Kara Sea

Step	Operational Time	Vs (m/s)	R Lindqvist (kN)	R Riska (kN)	Fuel Consumption Lindqvist (ton)	Fuel Consumption Riska (ton)
I	5	7,967	2113,29	2180,61	32,54	33,58
II	23,5	8,481	2357,40	2430,67	181,65	187,3

Table 78 Efficient Speed at Laptev Sea

Step	Operational Time	Vs (m/s)	R Lindqvist (kN)	R Riska (kN)	Fuel Consumption Lindqvist (tons)	Fuel Consumption Riska (tons)
I	1	7,71	1996,32	2060,67	5,95	6,14
II	12,1	8,481	2357,4	2430,67	93,53	96,44
III	17	8,481	2357,4	2430,67	131,41	135,49
IV	10	8,481	2357,4	2430,67	77,3	79,7

Table 79 Efficient Speed at East Siberian Sea

Step	Operational Time	Vs (m/s)	R Lindqvist (kN)	R Riska (kN)	Fuel Consumption Lindqvist (tons)	Fuel Consumption Riska (tons)
I	20,65	8,481	2446,73	2519,99	165,67	170,63
II	19,35	7,196	1837,70	1896,11	98,93	102,07
III	2	6,682	1619,00	1671,47	8,389	8,66
IV	1	6,168	1414,64	1461,17	3,383	3,49

Table 80 Efficient Speed at Chucki Sea

Step	Operational Time	Vs (m/s)	R Lindqvist (kN)	R Riska (kN)	Fuel Consumption Lindqvist (tons)	Fuel Consumption Riska(tons)
I	2	6,168	1414,64	1461,17	6,76	6,98
II	35	6,682	1619	1671,47	146,81	151,57
III	1	5,14	1049,20	1083,85	2,09	2,16
IV	0,4	1,542	235,88	228,93	0,056	0,055

Table 81 Efficient Speed at Bering - East China Sea

Step	Operational Time	Vs (m/s)	R total (kN)	Total Fuel Consumption
I	0,140625	0,61698276	13,366	0,000452207
II	0,416666667	6,2469504	1130,900	1,141354934
III	61,04166667	10,6461111	3218,652	806,411317
IV	1,625	9,70413022	2747,200	16,74960347
V	5,25	10,5768472	3273,376	70,07719993
VI	38,54166667	10,3778167	3141,507	484,4397281
VII	54,79166667	10,5303473	3239,916	720,7028611
VIII	28,85833333	10,2747873	3081,497	353,2727822
IX	11,55208333	9,9515591	2884,166	128,1964321
X	4,583333333	9,65437789	2720,049	46,53575561
XI	1,322916667	9,18186935	2447,072	11,52524442
XII	0,211041667	2,5694926	210,458	0,044502221

Table 82 Value for Riska number

Name	Value	unit
F1	0,23	KN/m^3
F2	4,58	KN/m^3
F3	1,47	KN/m^3
F4	0,29	KN/m^3
G1	18,9	$KN/ (m/s *m^{1,5})$
G2	0,67	$KN/ (m/s *m^2)$
G3	1,55	$KN/ (m/s *m^{2,5})$

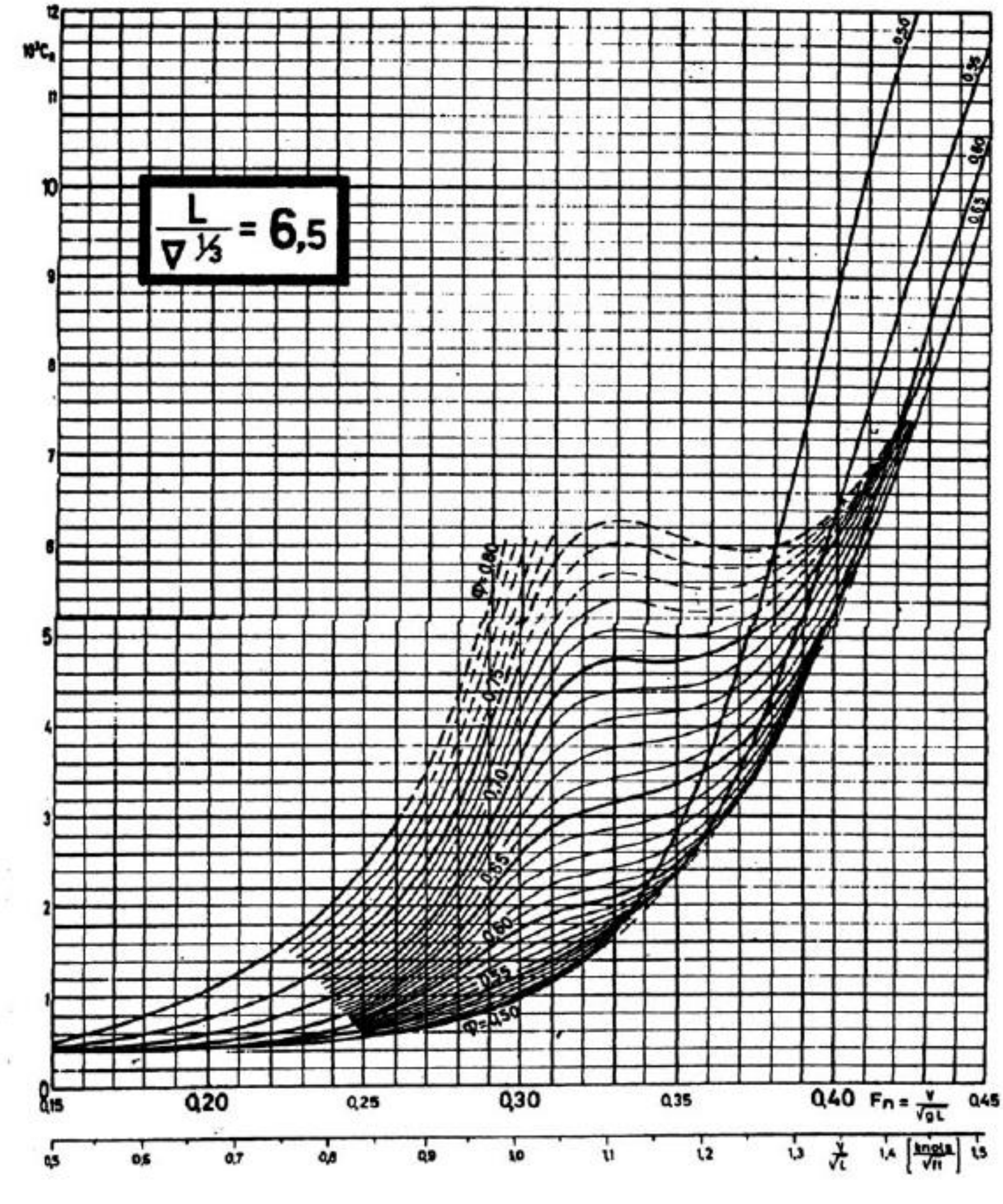

Figure 14 Cr Graphic 6,5

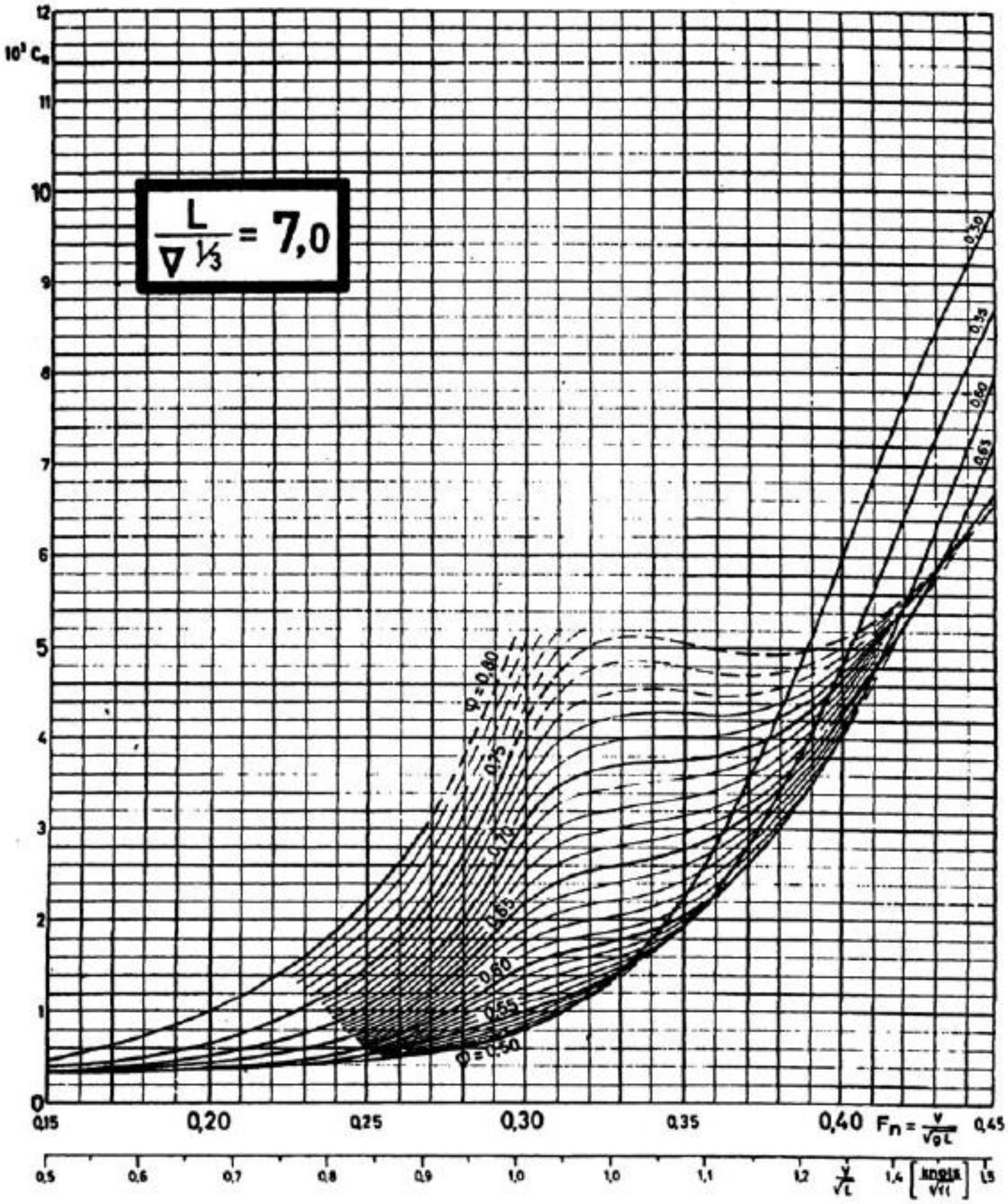

Figure 15 Cr Graphic 7,0

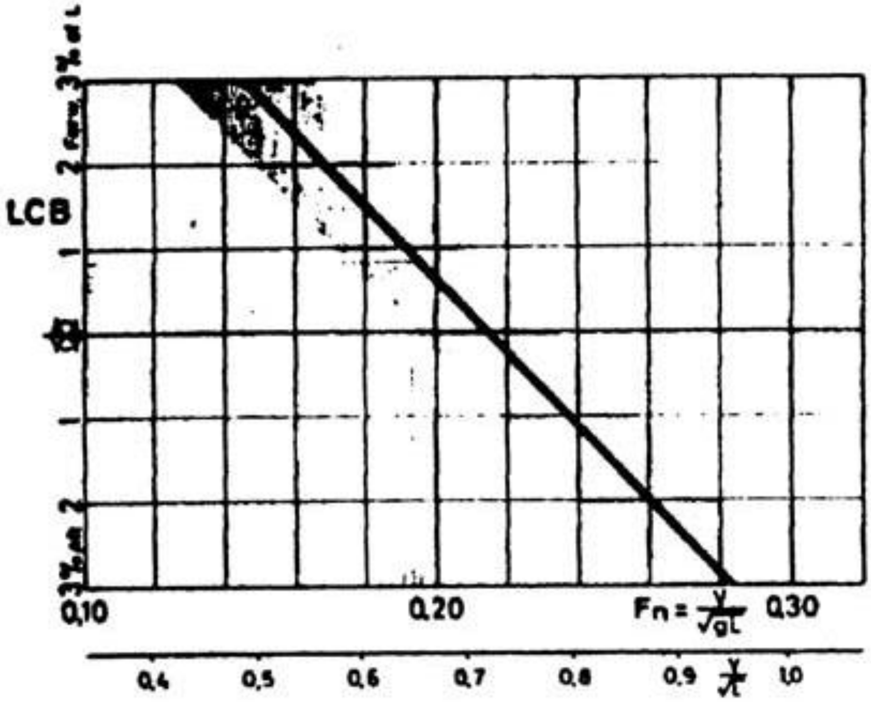

Figure 16 LCB Value

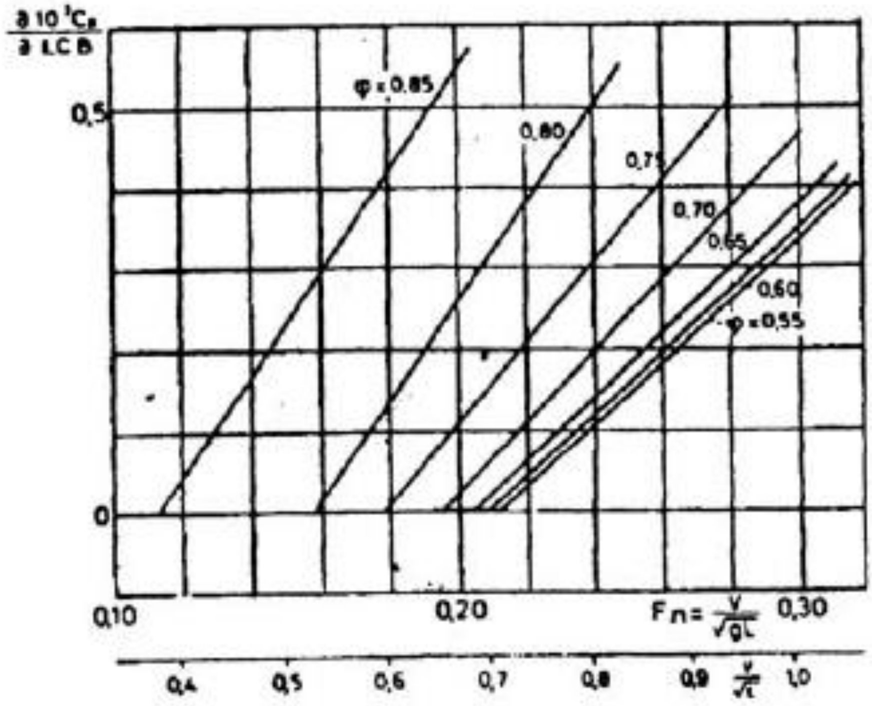

Figure 17 Cr Graphic from LCB

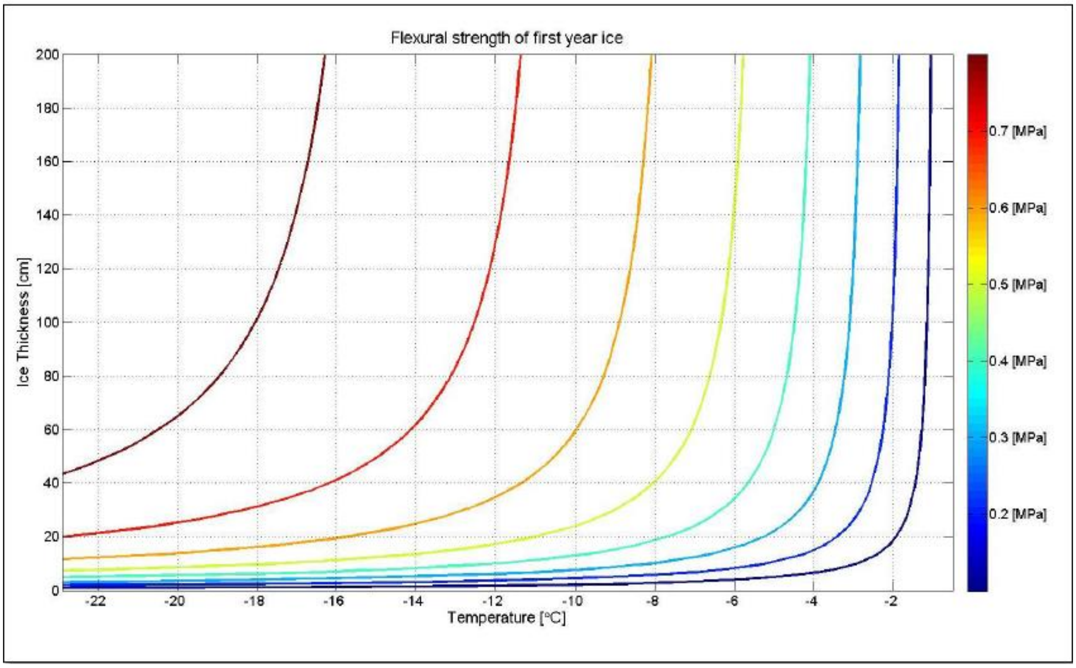

Figure 18 Flexural Strength of Ice

(Source: [12])

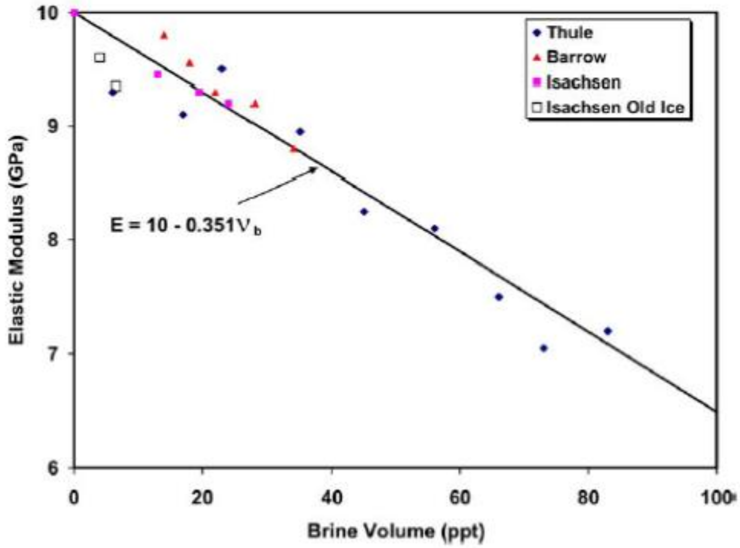

Figure 19 Elastic Modulus as a Function of Brine Volume
(Source: [6].)

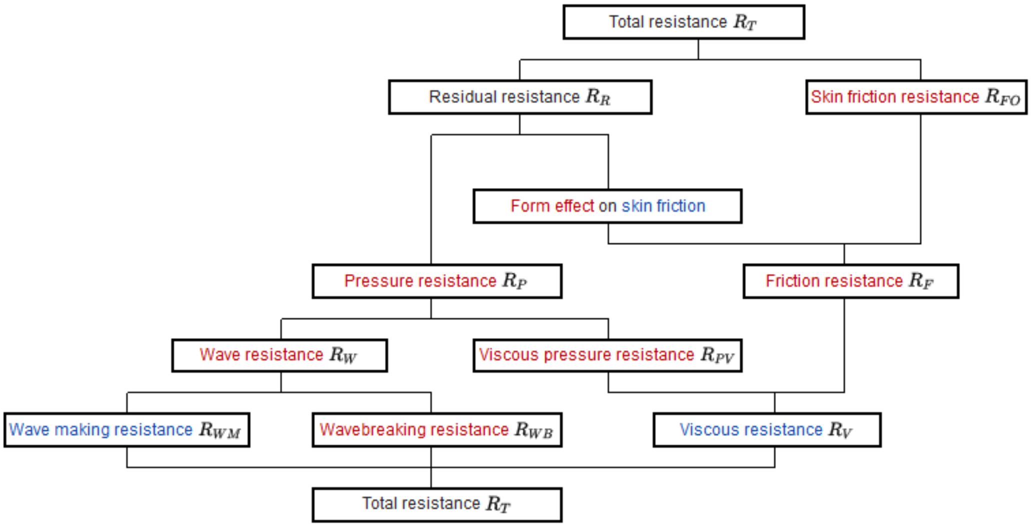

Figure 20 Components of Ship Resistance
(source: [4].)

AUTHOR BIOGRAPHY

The Author was born in Jakarta, August 24th , 1996 as the oldest child from two siblings. He started his formal education at SD Kristen 4 BPK PENABUR JAKARTA, SMP Kristen 5 BPK PENABUR JAKARTA, and SMA Kristen 3 BPK PENABUR JAKARTA. In 2014, author proceed to pursue Bachelor Degree at Department of Marine Engineering (Double Degree Program with Hochschule Wismar), Faculty of Marine Engineering, Institut Teknologi Sepuluh Nopember Surabaya. During the study period, Author did many activities in campus organizations such as: Staff of External Affairs Ministry of BEM ITS (2015-2016) ,General Directors of External Affairs Ministry of BEM ITS (2016-2017), Sponsorship Coordinator of Marine Icon 2016 and Petrolida 2017. Not only active in campus organizations, author also had a working experience as Quality Control Officer at PT. Daya Radar Utama (2016), as Assistant of Technical Superintendant at PT. Samudera Indonesia Ship Management (2017) and also as a part-timer at Cocoyo Drinks (2017).

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