International Journal of Marine Engineering Innovation and Research, Vol. 2(4), Sep. 2018. 242-252
(pISSN: 2541-5972, eISSN: 2548-1479)

Comparing Total Fuel Consumption of A Ship between East Asia and European Countries

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***Abstract*—global warming is the most compelling environmental issues in the world recently. Almost a century, the temperature increased 0,74° C and made the ice in North and South Pole melt in high rate. 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 Arctic Sea, open a new route, called Northeast Passage. Using Northeast Passage will reduce distance and time of the voyage. The big idea of this research 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 research. Results of this research, 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 Hong Kong 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 Hong Kong . The usage of Northeast Passage can saves 35% of expense or equivalent to 1035031 USD.**

Keywords—fuel oil consumption, global warming, ice resistance, ice route, northeast passage.

I. Introduction

Nowadays, the temperature of surfaces around the world increased dramatically. It was happened because of global warming effects. By increasing surfaces temperature, ice melts in very high rate [1-2]. Northeast Passage is a new route for shipping industries, connects European and East Asia Countries, along the Arctic Ocean and shorten the distance between those countries. 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.

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 icebreaker to remove ice from her path. Ice also may be harmful for the durability of ship hull because of their solid form.

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.

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.

II. Method

In this research will compare total fuel consumption of a ship. A ship that will be examined, travels from East Asia Countries to Europe or vice versa. On this thesis, a ship travels from Hong Kong Port to Hamburg Port. There are 2 routes that will be compared, first one is Conventional Route, using Suez Canal and the second one is a new route, North-East Passage. Using Northeast Passage will increase the resistance of the ship because of the ice layer along the route especially in Russian Coastline.

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First step will be taking the vessel's speed when operates in conventional route using Automatic Identification System. After that, calculating total resistance and total fuel consumption is needed, using Harvalrd & Guldhammer method.

Second step of this thesis will be calculating total fuel consumption for a ship when operates on North-East Passage. Before knowing total fuel consumption, total resistance of ship is needed by using Lindqvist and Riska et Al methods. After knowing the total fuel consumption, selecting the most suitable speed for a vessel is needed for a great input for ship owner's to select the best option that he has.

2.1 North-East 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.

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. Hereby the table of distance comparison between Port of Rotterdam and Port in Asia. Can be shown in table 1 and figure 1 [3].

Figure. 1. NEP Route (blue) & Conventional Route (red)

TABLE 1.
DISTANCE FROM ROTTERDAM PORT TO EAST ASIA COUNTRIES

	To Rotterdam, via:				
From	**Cape of God**	**Suez Canal**	**NEP**	**Difference Suez & NEP**	
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
Hong Kong , China	13.014 nm	9701 nm	8594 nm	11%	1107nm

2.2 Physical & Mechanical Ice Properties

There are some points that must be known for physical & mechanical properties of ice [4-7].

1. Ice Thickness
   Ice Thickness can be known from Stefan Equation .

$$h_i = \sqrt{\frac{2K_i}{\rho_{ice}\, L_f}[T_b - T_a]t_{freeze}} \quad (1)$$

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

$$S_i[ppt] = 4{,}606 + \frac{91{,}603}{h_i[cm]} \quad (2)$$

3. 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.

$$v_b = S\,(\frac{49{,}185}{|T|} + 0{,}532) \quad (3)$$

4. Flexural Strength
   The flexural strength is a measure of how a material resists bending before failure.

$$\sigma_b = 1{,}76\ \exp(-5{,}88\,.\sqrt{v_b}) \quad (4)$$

5. Elastic Modulus of 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.

$$E = 10 - 0{,}0351\ V_b \quad (5)$$

2.3 Ice Resistance Calculation Methods

Before calculating ice resistance, there is an important part that must be known first. The angles for the formulas is needed. 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 [4-7]..

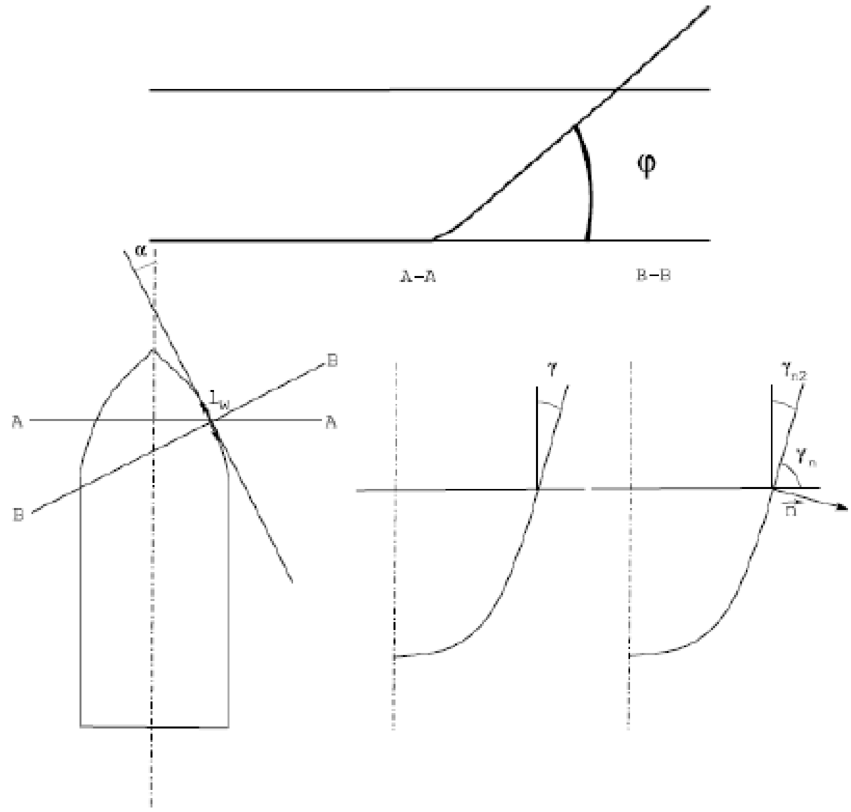

Figure. 2. Ship's Angles

There are 2 methods for calculating ice resistance of ship, using Lindqvist method and Riska method [4-7].

1. **Lindqvist Method**

The model was presented in 1989 and presents a rather simple way of estimating the resistance due to ice. The model gives resistance as a function of main dimensions, hull form, ice thickness, ice strength, and friction.

- 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.

$$R_c = F_v \frac{\tan \emptyset + \mu . \frac{\cos \emptyset}{\cos \cos \varphi}}{1 - \mu . \frac{\sin \emptyset}{\cos \varphi}} \quad (6)$$

Where:

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

Where σ_b is ice strength in bending and h_i is ice thickness.

- 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.

$$R_b = \frac{27}{64} \sigma_b B \frac{h_{ice}^{1,5}}{\sqrt{\frac{E}{12(1-v^2) g \rho_{water}}}} \left(\frac{\tan\varphi + \mu \cos \emptyset}{(\sin \alpha \cos \varphi)}\right)\left(1 + \frac{1}{\cos \varphi}\right) \quad (7)$$

- Submersion

The submersion resistance exists of 2 components, the loss of potential energy and the frictional resistance.

$$R_s = (\rho_{water} - \rho_{ice}) . g . h\, tot . B . k \quad (8)$$

Where:

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

- Speed Dependency

This model assumes that all resistance components increase linearly with speed and uses empirical constants to account.

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

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 were located in the Baltic area. The ice resistance is then expressed as [4-7]

$$R_{ice} = C_1 + C_2 v \quad (10)$$

Where:

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

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

L, B, T are respectively length, breadth, and draught. V is vessel speed, h_i is ice thickness and Ø is the stem angle in degrees. Lpar and Lbow are the length of the parallel side section and length of the bow respectively.

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

$$R_{tot} = R_i + R_{ow} \quad (11)$$

2.4 Open Water Resistance

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 ownership, the greater the resistance, the greater the required engine power, the greater the cost of fuel, vice versa [8].

- Calculating Displacement of ship

$$\nabla = Lwl \times B \times T \times Cb \quad (12)$$

$$\Delta = Lwl \times B \times T \times Cb \times \rho \quad (13)$$

Where:
Lwl is length of waterline, B is breadth, T is draught and Cb is coefficient block.

- Calculating Wetted Surface Area

$$S = 1{,}025 \times Lpp \times (Cp \times B + 1{,}7 \times T) \quad (14)$$

Where:
Cp is Coefficient Prismatic

- Calculating Froude and Reynold Number

$$Fn = \frac{Vs}{\sqrt{gL}} \quad (15)$$

$$Rn = \frac{Vs \times Lwl}{v} \quad (16)$$

- Determining the frictional coefficient

$$Cf = \frac{0{,}075}{(\log Rn - 2)^2} \quad (17)$$

- Determining the frictional Resistance

$$Rf = 0{,}5 \times Cf \times v^2 \times S \quad (18)$$

After getting the value of resistance, the next step is to find power that needed for the ship.

- Effective Horse Power

$$EHP = RT \times Vs \quad (19)$$

- Thrust Horse Power

$$THP = \frac{EHP}{\eta H} \quad (20)$$

- Delivered Horse Power

$$DHP = \frac{EHP}{Pc} \quad (21)$$

Where:

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

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

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

- Shaft Horse Power

$$SHP = \frac{DHP}{\eta s} \quad (22)$$

- Break Horse Power Service Continous Rating

$$BHPscr = \frac{SHP}{\eta g} \quad (23)$$

- Break Horse Power Maximum Continuous Rating

$$BHPmcr = \frac{BHPscr}{0{,}85} \quad (24)$$

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:

$$Fuel\ Oil\ Mass = P \times SFOC \times t \times C \times 10^{-6} \quad (25)$$

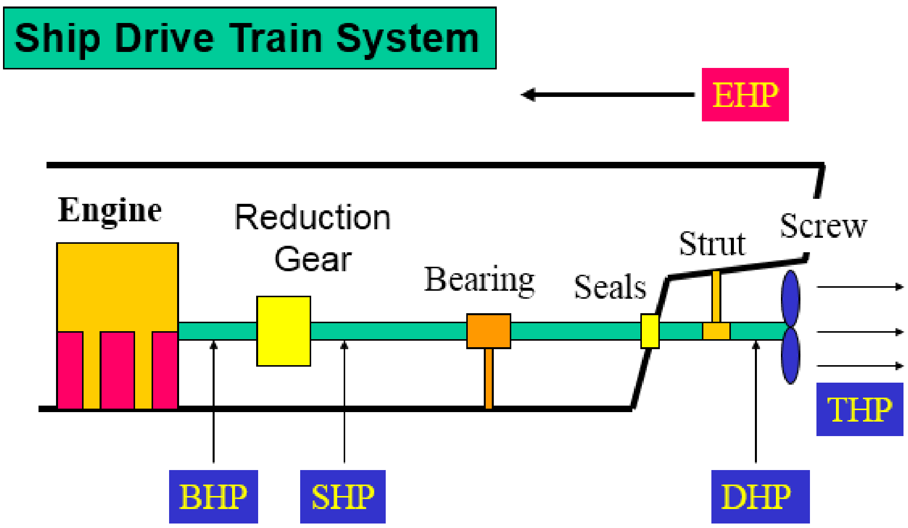

Figure. 3. Schemes for Ship's Power

III. Results and Discussion

3.1 General Data of Ship

Before calculating the resistance of ship, general data of a ship is needed. The data is collected from reliable source. Table 2 is the ship data from reliable source and this is about the principal dimension of ship.

TABLE 2.
SHIP'S GENERAL DATA

Description	Value	Units
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	

3.2 Collecting Data of a Ship

This research is using Automatic Identification System (AIS) that already installed on the ship, collecting the data like draught and velocity from each route. On this research, voyage plan is divided into 8 main routes for the conventional route and 7 main routes for the ice route. Voyage Plan for Conventional Route and voyage plan for ice route can be shown in table 3 and 4 [9-13].

TABLE 3.
VOYAGE PLAN FOR CONVENTIONAL ROUTE

Route No.	Voyage
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

TABLE 4.
VOYAGE PLAN FOR ICE ROUTE

Route No.	Voyage
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

3.3 Calculating Fuel Consumption at Conventional

Before calculating fuel consumption, first of all, the value of total resistance of a ship and engine power is needed. Table 5 is the ship data and the ship speed based on approaching.

TABLE 5.
SHIP'S SPEED DATA

	Time (min)	Design Speed (knot)	Actual Speed (knot)	Average Speed (knot)
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 table 5 is taken from Hong Kong – Nansha route. The vessel was approaching to the Nansha Port. 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. The next step is calculating the total resistance for this part.

Calculation Step:

- $\nabla = Lwl \times B \times T \times Cb$
  = 149733,4 m^3
- $\nabla^{1/3}$ = 53,10143
- L/$\nabla^{1/3}$ = 6,619408
- Fn =0,114
- 10^3Cr = 0,4028
- B/T = 4
- 10^3 Cr B/T Correction = 0,6428
- LCB Standard = -0,1
- LCB = -1,2
- Delta LCB = -1,6
- (d10^3Cr/dLCB) = 0,15
- 10^3 Cr LCB Correction = 0,24
- 10^3 Cr Correction = 1,2856
- Cr Correction = 0,0012856
- Rn $= \frac{v \times L}{kinematic\ viscocity}$
  = 2073012357
- Cf $= \frac{0,075}{(\log Rn - 2)^2}$

= 0,00140101

- Ca = -0,0003
- Caa = 0,00007
- Cas = 0,00004
- C total = 0,00237901
- S =20074,9254 m^2
- R = 1096698,182 N
- Sea Margin = 219339,6 N
- R total = 1316,03782 kN

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.

- $EHP = 10197{,}09\ kW$
- $DHP = \frac{EHP}{Pc}$

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

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

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

$= 0{,}275$

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

$= 0{,}2475$

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

$= 1{,}037931$

$\eta rr = 1{,}05$

$\eta o = 55\%$

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

$= 0{,}599405$

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

$= 17012{,}012\ kW$

- $SHP = 17359{,}2\ kW$
- $BHPscr = 17359{,}2\ kW$
- $BHPmcr = 20422{,}5829\ kW$
- $W\ FO = 2{,}635875\ ton$

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. Detail result in table 6.

TABLE 6.
TOTAL FUEL CONSUMPTION FOR 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

3.4 Calculating Resistance at 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.

TABLE 7.
ENVIRONMENTAL CONDITION AT NEP

Route	Distance (nm)	Explanation	Temperature	Ice Thickness
North Sea Norwegian Sea	1976	Open Water Resistance	15 Celsius 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 East China Sea	4220	Open Water Resistance	13 Celsius 20 Celsius	

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 the sea in some scenario can be shown in table 8 to table 15.

TABLE 8.
TOTAL RESISTANCE AT NORTH-NORWEGIAN SEA

Part	Speed (knot)	Time (hour)	Distance (nm)	R total (kN)
I	3	0,75	2,25	79,89
II	15	2,5	37,5	1763,44
III	18	4	72	2529,07
IV	20	50,1	1002	3127,01
V	18,5	30	555	2693,84
VI	18	15	270	2544,02
VII	10	3,5	35	812,19
VIII	3	0,75	2,25	80,46
	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.

TABLE 9.
TOTAL RESISTANCE AT BARENTS SEA

Part	Speed (knot)	Time (hour)	Distance (nm)	R total I (kN)	R total II (kN)
I	1	0,5	0,5	280,1	243,56
II	5	1	5	571,05	581,22
III	7,5	1	7,5	873,17	912,54
IV	10,5	2	21	1353,07	1427,48
V	14	6,5	91	2071,2	2186,53
VI	15	29	435	2307,3	2434,29
	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 calculating ice route, there are 2 methods, Lindqvist and Riska Method. Environmental condition at Barents Sea is -2 Celsius with ice thickness 20 cm.

I. Lindqvist Method

$$F_v = 0{,}5.\sigma_b.h_i^{\,2} = 3000$$

$$R_c = F_v \frac{\tan\emptyset + \mu.\frac{\cos\emptyset}{\cos\varphi}}{1-\mu.\frac{\sin\emptyset}{\cos\varphi}} = 1831{,}18817 \text{ N}$$

$$R_b = 27/64\,\sigma_b B \frac{h_{ice}^{\,1,5}}{\sqrt{\frac{E}{12(1-v^2)g\rho_{water}}}}\left(\frac{\tan\varphi + \mu\cos\emptyset}{(\sin\alpha\cos\varphi)}\right)\left(1+\frac{1}{\cos\varphi}\right) = 5131{,}54941 \text{ N}$$

K =

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

22,795195

R_s $= (\rho_{water} - \rho_{ice}).g.h\,tot.B.k =$ 240192,058 N

R_{ice} =

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

= 270,506 kN

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

= 280,107 kN

$$C_1 = f_1\frac{1}{2\frac{T}{B}+1}B\,L_{par}h_i + (1+0{,}0021\emptyset).\left(f_2Bh_i^{\,2}+f_3L_{bow}h_i^{\,2}+f_4BL_{bow}h_i\right) = 198{,}9281473\ \text{kN}$$

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

= 68,15447894 kN

$$R_{ice} = C_1 + C_2v$$

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

= 233, 96 kN

R_{to} $_t$= 233,96 kN +9,601 kN

= 243,56 kN

II. Riska Method

TABLE 10.
TOTAL RESISTANCE AT WEST KARA SEA

Part	Speed (knot)	Time (hour)	Distance (nm)	R total I (kN)	R total II (kN)
I	15	3	45	2149,93	2239,63
II	10	1	10	1138,31	1185,87
III	14	10	140	1920,13	2001,4
IV	15	18	270	2149,93	2239,63
	Total	32	465		

TABLE 11.
TOTAL RESISTANCE AT EAST KARA SEA

Part	Speed (knot)	Time (hour)	Distance (nm)	R total (kN)	R total (kN)
I	15	9	135	1996,32	2060,67
II	16,5	20	330	2357,4	2430,66
	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%.

TABLE 12.
TOTAL RESISTANCE AT LAPTEV SEA

Part	Speed (knot)	Time (hour)	Distance (nm)	R total I (kN)	R total II (kN)
I	15	2	30	1996,32	2060,67
II	16,5	10	165	2357,4	2430,66
III	15	20	300	1996,32	2060,67
IV	16,5	10	165	2357,4	2430,66
	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.

TABLE 13.
TOTAL RESISTANCE AT EAST SIBERIAN SEA

Part	Speed (knot)	Time (hour)	Distance (nm)	R total I (kN)	R total II (kN)
I	16,5	10	165	2446,73	2519,99
II	14	20	280	1837,7	1896,11
III	13	10	130	1619	1671,47
IV	12	6,25	75	1414,64	1461,16
	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.

TABLE 14.
TOTAL RESISTANCE AT CHUCKI SEA

Part	Speed (knot)	Time (hour)	Distance (nm)	R total I (kN)	R total II (kN)
I	12	20	240	1414,63	1461,16
II	12,5	18	225	1515,02	1564,52
III	8	3	24	742,07	764,83
IV	3	0,4	1,2	235,87	228,93
	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.

TABLE 15.
TOTAL RESISTANCE AT BERING-EAST CHINA SEA

Part	Speed (knot)	Time (hour)	Distance (nm)	R total (kN)
I	1,096	0,15	0,168	11,244
II	11,099	0,45	5,06	949,53
III	18,91	66,83	1264,3	2677,90
IV	17,24	1,7	30,67	2285,38
V	18,79	5,74	108,03	2722,87
VI	18,43	42,2	778,16	2624,74
VII	18,71	59,9	1122,52	2699,79
VIII	18,25	31,5	576,874	2574,63
IX	17,68	12,64	223,66	2399,24
X	17,15	5,018	86,088	2262,81
XI	16,31	1,44	23,63	2053,85
XII	4,565	0,231	1,055	176,8
	Total	228,11	4220,22	

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.

3.5 Calculating Total Fuel Consumption at Northeast Passage

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. Can be shown in table 16.

TABLE 16.
TOTAL FUEL CONSUMPTION AT NEP

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%		

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 comparison when a vessel wants to save 10% of the operational hours. Can be shown in table 17.

TABLE 17.
TOTAL FUEL CONSUMPTION AT NEP FOR 10% OPERATIONAL HOURS

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	10,080
	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.

3.6 Cost Analysis for Conventional Route and Ice Route Based on Fuel Consumption of 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.

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. Can be shown in table 18 and 19.

TABLE 18.
TOTAL COST AT CONVENTIONAL ROUTE

Bunkering Plan	Metric Ton Fuel	Price / Metric Ton [10]	Total Price (USD)
Hong Kong	1065,35	463	493257,7468
Port Klang	2637,8	460	1213396,647
Pireus	1578,85	467	737326,7204
		Total Price for Fuel	2443981,114
		Suez Canal Costs	553515,64
		Total Price	2997496,754

TABLE 19.
TOTAL COST FOR SAVINGS 20% FUEL CONSUMPTION AT NEP

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

TABLE 20.
TOTAL COST FOR SAVINGS 12% FUEL CONSUMPTIONS AT NEP

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 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. Can be seen in table 20.

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 US.

III. CONCLUSION

Based on calculation and analysis above, can be take some conclusions:

1. 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.
2. There are 2 methods for calculating Ice Route, Lindqvist and Riska method.
3. Hereby, the speed of vessel when a vessel wants to save 10% of the operational hours. 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.
4. 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.
5. Bunkering plan in conventional route is occurred in Hong Kong 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.
6. 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 Hong Kong Port or vice versa. It saves 35% or equivalent to 1035031 USD.
7. 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.
8. 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.

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