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Analysis of Slow Steaming of Ship and Its Impacts

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ABSTRACT

Global trade heavily depends on shipping industry. Growth in seaborne trade causes the increase in fuel consumption and hence higher emissions which are directly related to the issues of global warming. Now, the world is also facing a drastic increase in fuel prices as a consequence of geopolitical conflict between Russia and Ukraine. One of the most effective ways to solve these problems in the maritime industry is to use the slow steaming method which is very cost-effective to implement. Slow steaming involves purposefully lowering ship speed to reduce bunker fuel consumption and also results in lower emissions. Therefore, this method is expected to bring a win-win outcome in the face of environmental damage resulted from GHG emissions and soaring fuel prices. This paper seeks to ascertain whether slow steaming can be used to compensate for the higher expenses associated with using cleaner fuels to comply with the stricter environmental regulations set out by International Maritime Organization. The impacts of using this method were evaluated by three points of view – economic, technical and legal. The results show that slow steaming can reduce the increasing bunker cost for using MGO instead of HFO but still cannot fully compensate for it.

Keywords: Slow Steaming, Operating Costs, Fuel Consumption, Energy Efficiency, Environment

I. INTRODUCTION

The earliest historical evidence of shipping can be traced back to the Babylonian times 5000 years ago. The original shipping routes made advantage of rivers and coastal seaways for trade with adjacent settlements. Until the midst of the 20th century, shipping on a global scale had had very little impact on the world economy. But nowadays the size of the global commercial fleet engaged in international trade has grown enormously because of increased economic globalisation. Globally, the number of commercial fleets increased by 2.95% and amount to 2.2 billion DWT in January 2022 compared to 2021. In 2021, the maritime trade, which accounts for 90% of the global trade, reached up to more than 10000 million tons in terms of trade volume [10].

The main air pollutants contained in the exhaust gas emitted from sea-going vessels are sulphur oxides (SO_X) and carbon dioxide (CO_2). An enormous increase in global commercial fleet together with the rapid expansion of maritime trade consequently leads to higher fuel usage and greater GHG emissions. Costs on fuel fall somewhere between 50% and 70% of total operating costs of a ship. Due to a drastic increase in fuel prices, unpredictability about the future of global maritime industry prevails. As part of the solution in response to these challenges, the practice of slow steaming has received more attention recently [2], [4].

However, bulk shippers hardly ever employ this tactic. Long-distance liner ships on the other hand adopt this energy-saving practice of slow steaming through identifying a slower pace at which the vessel goes. But there are some conflicts of interest because going at a slower speed implies that a greater number of ships are required to consign the same volume of goods to the destination. Nevertheless, slow steaming can be quite appealing in its potential to make a positive contribution towards the reduction of GHG emissions which are proportional to the amount of fuel burned [2].

II. OVERVIEW OF SLOW STEAMING

Slow steaming means that a ship deliberately sails at a slower pace than its designated speed. It was first used as a fuel-saving operative technique to reduce bunker fuel usage during the first oil crisis in 1973 [14]. After then, slow steaming was once more employed to reduce fuel consumption during 2008 financial crisis. In the later part of 2011, MAN Diesel & Turbo conducted a web-based survey in collaboration with more than 200 representatives from the industry-wise enterprises like container, bulk and tanker in order to assess the extent of actual implementation of slow steaming [7]. The survey showed that 149 representatives (84.5%) had implemented that operative procedure. Out of that total percentage, 78.5% represented slow steaming combined with full-load steaming and 6% slow steaming only as shown in Table 1.

TABLE I

COMBINATION OF SLOW STEAMING, AND FULL LOAD STEAMING

Full load steaming	Percentages
All the time (only full load)	21.5
Some of the time	60.4
Hardly at all	12.1
Never (only slow steaming)	6.0

According to a BIMCO survey, the majority of shipping companies indicated that they used slow steaming which varied between 30 and 50% of engine loads in bulk and container shipping enterprises(Table 2).A resounding majority of the 149 respondents who claimed to have used slow steaming in their operations declared that it was the standard.

TABLE II

TYPICAL ENGINE LOAD FOR SLOW STEAMING VESSELS (PERCENTAGES)

Segment	10-30 %	20-40 %	30-50 %
Container	17.8	25.8	56.4
Bulk/Tank/Others	5.9	11.9	82.2

The various tiers of slow steaming are identified depending upon seaways [7]. On an Asia-North America route, a 20% speed reduction might result in a 43% reduction in carbon dioxide emissions. According to a website in [2], slow steaming maintains sustainability while reducing emissions. It has a great potential for offering both market-based and non-market solutions in making attempts to cut GHG emissions [6].The favourable aspect of slow steaming in terms of sustainability is advocated by both economic and environmental perspectives [6], [12].Therefore, slow steaming is a useful technique because its positive effects upon economic sustainability and environmental conservation are already self-evident. Furthermore, another obvious advantage of slow steaming is its practicality for implementation. However, despite all these positive advantages, there was some technical problems regarding implementation in early ships with a design speed of about 27 knots and some engineering solutions were also offered in that study [12].

There are some limitations in reducing fuel consumption by means of slow steaming because it is not all the levels of slow steaming that can decrease fuel consumption. Generally, the level of fuel consumption starts to decrease at a speed below 50% of engine loads[9]. Hence, the speed level that really works and leads to a win-win situation needs to be calibrated. The main goal of the study is to be able to arrive at a realistic solution to what can be the workable level of speed by taking into consideration all the economic, technical and legal standpoints in a comprehensive manner.

III. RESEARCH METHODOLOGY

Most ships are designed to operate at top speeds with an engine load of 85% to 90%.Fuel consumption can be greatly decreased by operating a ship at a speed that is 15% or less below its maximum capabilities [14]. The loss in ship operation speed could be larger with really slow steaming.

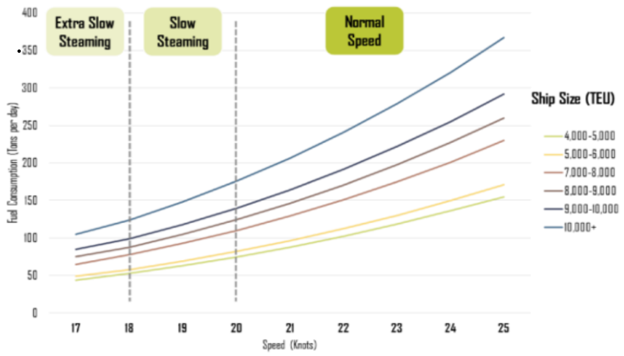

Figure 1: A correlation between fuel consumption and levels of speed across varying ship sizes [3]

A. Establishing Criteria

The basic and secondary criteria for selecting the most efficient ship speed are described in the form of cost-benefit analysis as shown in Table 3 [1]. These criteria and sub-criteria ought to be carefully judged against the costs and benefits associated with them because they can result in different outcomes depending on which criteria are given more priority. Each main criteria has its own corresponding sub-criteria.

TABLE III

THE LIST OF CRITERIA AND SUB-CRITERIA ASSOCIATED WITH THE GOAL

Main Criteria	Sub Criteria	Goal
Technical and Operational Aspect	Engine Efficiency	Benefit
	Auxiliary Consumption	Cost
Financial Aspect	Operational Cost	Cost
	Ship Revenue	Benefit
Environmental Aspect	Carbon Dioxide (CO_2)	Cost
	Nitrogen Oxide (NO_x)	Cost
	Sulfur Dioxide (SO_2)	Cost

The elements and sub-factors that are taken into account when deciding the ship's speed depend on technical and operational aspect, financial aspect, and environmental aspect as described in detail in Table 3. Selecting the most effective ship speed will be made easier by all of the criteria and sub-criteria.

1). Technical and Operational Aspect: The ability of a machine to convert available energy from fuel to mechanical output energy is known as the machine's efficiency. Figure 2 defines efficiency as the ratio of the power generated to the power needed. For instance, not all of the electricity required to turn on the lights is transformed into light energy; some of it is instead converted into heat.

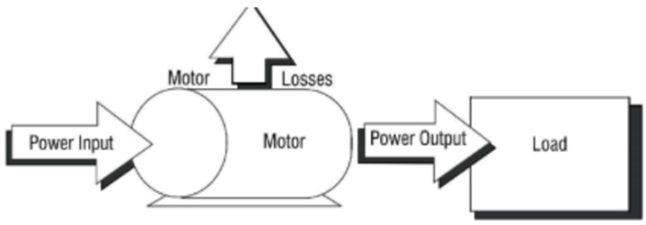

Figure 2: Input power and output power diagram

It is possible to calculate the efficiency value using equation (1),

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \qquad \text{eq (1)}$$

where,
η=Efficiency (%)
Pout =Output power
Pin =Input power

The speed drop will affect how much fuel the auxiliary machinery uses, and the shipment time will increase. Equation(2) is used to determine the total amount of auxiliary engine fuel used for each engine load. The shipping times will also be affected by the speed drop. Auxiliary engine load during sailing conditions is 75%, with a maximum load of 1,000 litres of fuel per vessel.

$$FC = P \times SFOC \times t \qquad \text{eq (2)}$$

where, FC=Fuel consumption
P = Power developed in kilowatt
SFOC= Specific fuel oil consumption (gr/kwh)
t= Auxiliary engine operation time

Equation (3) below can be used to determine the fuel consumption for a certain route once the route's distance has been determined.

$$F = \left(F.C._0 \times \left(\frac{v_1}{v_0}\right)^3\right) \times \frac{d}{v_1} \qquad \text{eq (3)}$$

where, F = Fuel consumed per trip [tonne]
F . C_0 = Fuel consumption @ design speed [ton/h]
v0 = design speed [knots]
v_1 = < design speed [knots]
d = route distance [nautical miles]

Fuel cost is calculated by multiplying the fuel consumption rate by the fuel price (Equation 4). This will provide the price of various types of fuel for a specific route, or mileage. The fuel cost for a specified route, travelling at a specific speed, may be estimated using the Equation 2 result.

$$C_{HFO} = F \times P_{HFO} \qquad \text{eq (4)}$$

where,
C_{HFO} = Cost running on HFO [USD]
F = Fuel consumed [tonne]
P_{HFO} = Price for HFO [USD/TON]

The amount of fuel consumption to fully cover the increased costs when using MGO is determined by taking the fuel cost of a vessel using HFO and equating it to that of a similar vessel using MGO. Then, the corresponding fuel consumption for an MGO engine will be obtained. A vessel's speed must be decreased to fully offset the additional expenses brought on by the pricing differential between MGO and HFO. Equation(5) is used to determine the vessel break-even speed (v1b.e) at which the fuel consumption would be equal to that required to maintain the same fuel cost when operating on MGO.

$$v_{1_{b.e.}} = \sqrt{\frac{F_{MGO} \times v_0^{\,3}}{d \times F.C._0}} \qquad \text{eq (5)}$$

where,
$V_{1b.e.}$ = Break even vessel speed [knots]
However, this is only accurate up to about 50%engine load, and will start to become inaccurate below that level.

2) Financial Aspect: The costs incurred by a ship's operational systems are referred to as operational costs. All the costs related to using fuel and lubricants, and other charges and taxes imposed by ports are all included in the calculation of overall expenditures to run a vessel. Operational costs are comprised of fixed costs such as the charges made by ports and variable

costs, which vary depending on how long the ship will be at sea. The greatest and most significant percentage of the total operational costs is related to fuel usage. Equation(6) is used to determine fuel consumption, and the main variables affecting fuel consumption include ship size, shipping distance, speed, and weather etc.

$$FC = P \times SFOC \times t \qquad \text{eq (6)}$$

where,

FC= Fuel consumption

P = Power developed in kilowatt

SFOC= Specific fuel oil consumption (gr/kwh)

t= Engine operation time

Fuel oil consumption during engine testing can be used to calculate the value of SFOC. It can be multiplied by the 180 cSt fuel oil price, which is Rp. 6.350,00/liter. Super slow steaming can save up to Rp 735.990.000 compared to normal operational load.

Ship revenue is the vessel's total freight service revenue less all the operational expenses. Slow steaming can make a positive contribution towards reducing operational costs to a certain extent but going at a lower speed can have a negative economic impact on shipping revenue because it can decrease the number of round trips a ship can make within a specific timeframe. The amount of cargo that a ship can deliver within a month is referred to as service performance and the calculation of that performance of a ship is necessary to formulate practical measures to make up for potential losses in revenue, which are to be weighted up against the other advantages of slow steaming such as lower operational costs and cutting GHG emissions. Equation (7) is used to calculate service performance:

$$Fs = cap_{eff} \cdot f_T$$
$$Fs = cap_{eff} \cdot TO / (TH + TS) \qquad \text{eq (7)}$$

where,

Fs = Service performance

cap_{eff} = Effective Capacity (ρ = 0,87)

f_T = Maximum number of round trips

TO = Operating time

TH = Harbor Waiting Time

TS = Sea (Shipping) Time

Maximum number of round trips can be determined by dividing the operational time (TO) by the time between the voyage time (TS) and the port time (TH).

The amount of financial profits made by a shipping firm by delivering freight to its customer is known as vessel income. The income of the ship is determined by using equation (8). Full speed generates higher ship revenues than slow, extra-slow, and super-slow steaming. This is due to the poor vessel income that results from sluggish steaming

$$I_V = \sum P_{FR,i} \cdot F_S \qquad \text{eq (8)}$$

where,

I_v= Vessel income

$P_{FR,i}$ = Freights rates

F_s = Service Performance

3) Environmental Aspect: Fuel burning in the ship's engine is what leads to carbon dioxide emissions while at sea. Fossil fuel burning also produces nitrogen oxide compounds and sulphur dioxide molecules. Air pollution caused by nitrogen oxide in the air is unhealthy for plant life as well as for people and other creatures. Acid rain is brought on by high airborne concentrations of sulphur dioxide.

B. **Emissions of Ship**

Slow steaming has the benefit of reducing CO2 emissions, which are directly correlated with the rate of fuel combustion in [2]. The Puget Sound Maritime Air Emission Inventory approach can be used to estimate the ship's emissions. The values required to determine a ship's estimated emissions are energy (kWh), emission factor (g/kWh) and fuel correction factor. Load factor, maximum continuous rated engine power (MCR), and time of ship operation are multiplied to obtain the energy value. To account for differences in fuel properties across various fuel types, fuel correction factors are used.

$$E = \text{Energy} \times EF \times FCF \quad \text{eq (9)}$$

where,

E= Emissions from the engine
Energy = Energy demand (kWh)
EF= Emission factor (g/kWh)
FCF= Fuel Correction Factor

IV. DATA ANALYSIS AND FINDINGS

At the meetings of IMO, slow steaming is still being discussed as a short-term method of reducing greenhouse gas (GHG) emissions. Depending on the starting speed, the different ship types, and even the sizes within the same type, the potential advantages of slow steaming might vary dramatically.

A .Effect of Slow Steaming on Fuel Costs by Two Ships

Curves of fuel usage give a more complete picture of the speed reduction necessary to compensate for more expensive fuel. The cost of gasoline for each route, a two-week itinerary with several port stops, is shown. Through numerous measurements of the actual speed on the internet GPS vessel monitoring service Marine Traffic, each ship's operational speed at sea is calculated.

1) Andromeda J: The 962 TEU Andromeda J is owned and operated by the German shipping company Jüngerhans. According to a time charter agreement, it currently travels between Sweden, Germany, and Great Britain [11]. The two-week sailing schedule for Andromeda J is depicted in Figure 3, and her current schedule is provided below.

	Port	Distance [nm]
Tuesday	Gothenburg	-
Wednesday	-	-
Thursday	Bremerhaven	353
Friday	Hamburg	93
Saturday	Hamburg	-
Sunday	Immingham	379
Monday	Felixstowe	202
Tuesday	Teesports	262
Wednesday	Grangemouth	140
Thursday	Grangemouth	-
Friday	-	-
Saturday	Bremerhaven	452
Sunday	Hamburg	93
Monday	-	-
Tuesday	Gothenburg	395
Sum		2,369

Figure 3: Two-week sailing route for Andromeda J

All of the company's ships are designed to travel at a maximum speed of 18 knots, with a target speed of 17 knots. This is the slowest speed at which the time schedule can be maintained, according to calculations. However, the live ship speed recordings revealed that they were a little slower (Table 4).

TABLEIV

OPERATION SPEED AT SEA FOR ANDROMEDA J

Time	Average speed
2013-05-08 (12.00-13.00)	16.76
2013-05-09 (15.30-16.30)	16.91
2013-05-10 (10.20-11.20)	16.84
2013-05-11 (13.50-14-50)	17.16
2013-05-11 (19.00-20.00)	14.98
Mean	**16.53**
Standard deviation	**0.79**

The bunker prices play an important role in making the required calculations. The global average prices for marine bunker fuels during the last preceding three years are shown in Figure 4. In these studies, 2022 fuel prices will be used for calculations. In Figure 5, the red base line is fixed at the expected fuel cost for sailing at 16.5 knots using HFO. According to 2022 MGO price, the fuel cost is represented by the blue centre line.

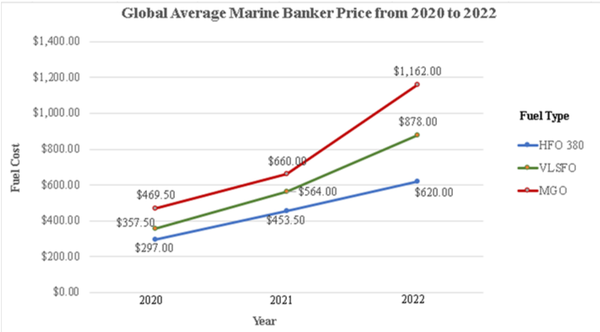

Figure 4: Global Average Marine Bunker Price 2020-2022

(Adapted from [4])

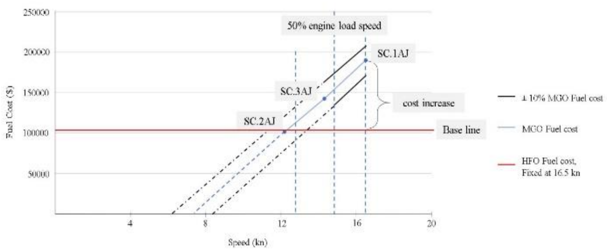

Figure 5: Fuel cost curve Andromeda J(full two-week route)

(Based on 2022 fuel price)

Three hypothetical situations have been developed to illustrate how delayed steaming will impact Andromeda J's fuel costs. The first scenario is that Uni-feeder sticks to the rules and continues to fly Andromeda J at 16.5 knots while utilizing MGO rather than HFO as fuel. When the vessel speed is reduced, the fuel cost will decrease along the fuel cost line until it reaches the base line, or the break-even fuel cost. In Figure 5, Sc.3AJ is the fuel cost at 50% engine load speed (14.3knots) when using MGO. The speeds below 14.3knots can be said to be ineffective because of higher fuel consumptions not in line with the reduced speed. Sc.2AJ is meant to fully offset the higher fuel expenses and the speed at that point is called break-even point speed leading to the balance of fuel costs between HFO and MGO.

TABLE V

FUEL COST SCENARIOS FOR ANDROMEDA J

(FULL TWO-WEEK LOOP)

	Base Line (B.L)	Scenario 1 ($Sc.1_{AJ}$)	ΔSc.1/BL	Scenario 2 ($Sc.2_{AJ}$)	Scenario 3 ($Sc.3_{AJ}$)	ΔSc.3/BL
Fuel	HFO	MGO	-	MGO	MGO	-
Speed [kn]	16.5	16.5	0%	12.2	14.3	-13.4% (-2.2 kn)
Fuel cons [ton]	163.5	163.5	0%	87.24	122.6	-25.0% (-40.9 ton)
Fuel price* [$/ton]	620	1,162	87.4% ($542)	1,162	1,162	87.4% ($542)
Fuel cost [$]	**101,370**	**189,987**	87.4% ($88,617)	**101,370**	**142,461**	40.5% ($41,091)

For the indicated route, the cost of fuel will increase by roughly 40.5%, or $41,091, which is equal to the estimated price difference between Sc.3AJ and the basic line (Table 5). It is not practicable to reduce speed below 14.3 knots under these conditions and assumptions, hence converting to MGO will unavoidably result in a cost rise. The extra cost of gasoline might have been entirely compensated by lowering the speed to 12.2 knots. But as was already said, when the vessel's speed drops below 14.3 knots, fuel consumption starts to increase. Using MGO with no slowing down represents a significant improvement over using HFO at this speed with a cost increase of $88617 (87.4%). Table 6 below describes how the dynamic conditions on fuel price affect the fuel cost trend. The two grey lines in Figure-5 show how the cost curve would vary if the 2022 price estimate were increased or dropped by 10%.

TABLE VI

MGO PRICE'S IMPACT ON SPEED, ANDROMEDA J

Up and Down Condition for MGO Price	At 16.5 knot		At 50% engine Load		Break even speed and fuel consumption at it
	Fuel Cost ($)	Cost Increase with BL	Fuel Cost ($)	Cost Increase with BL	
+10% Price ($1278.2)	208985.7	107615.7 (51.49%)	156707.32	55337.32 (35.3%)	11.4 kn (79.3ton)
-10% Price ($1045.8)	170988.3	69618.3 (40.72%)	128215.08	26845.08 (20.94%)	13 kn (96.93 ton)

The break-even speed for gasoline would be about 13 knots, if the price decreased by 10%. It would be necessary to drop the speed to 11.4 knots if the price increased by 10%. The cost at this 10% increased price would theoretically be 51.49% more than under the baseline scenario. But if gasoline prices continued to rise, there would be considerably more justification for changing the operation speed.

2) Nordic Bremen: A German ship named Nordic Bremen travels from the Baltic Sea to Rotterdam via Sweden, Russia, and the Netherlands. Two ships are operated by Container Express (Contex), a division of SCA Transforest, that perform 14-day loops between the Baltic Sea and Rotterdam, stopping in Sweden and Russia before heading southwest to the Netherlands. Nordic Bremen is a German vessel owned by Nordic Hamburg and sails under the Cypriote flag. It can carry 2036 TEUs and travel at a design speed of 18.5 knots. It has a similar capacity and speed to the Andromeda J, and both ships use the same engine. A mean speed of 16.0 knots and a standard deviation of 0.74 were used to measure the operation speed (Table 7).

TABLE VII

OPERATION SPEED AT SEA FOR NORDIC BREMEN

Time	Average speed
2013-05-10 (07.00-08.00)	15.64
2013-05-11 (16.30-17.30)	14.93
2013-05-12 (03.00-04.00)	15.98
2013-05-15 (14.00-15.00)	16.81
2013-05-15 (18.50-19.50)	16.88
Mean	**16.04**
Standard deviation	**0.74**

Nordic Bremen's two-week trip is slightly longer than Andromeda J's route. The Baltic Sea has all of the ports found in the North Sea, with the exception of Rotterdam. Figure 6 shows Nordic Bremen’s two-week sailing schedule, while the present timetable is given below.

	Port	Distance [nm]
Wednesday	Rotterdam	-
Thursday	-	-
Friday	-	-
Saturday	Stockholm	780
Sunday	-	-
Monday	St. Petersburg	372
Tuesday	St. Petersburg	-
Wednesday	Sundsvall	452
Thursday	Sundsvall	-
Friday	Umeå	123
Saturday	-	-
Sunday	-	-
Monday	-	-
Tuesday	Rotterdam	1028
Sum		**2,755**

Figure 6: Two-week sailing route for Nordic Bremen

The cost curve for Nordic Bremen's whole two-week trip is seen in Figure 7. The blue middle line indicates the fuel cost based on the 2022 MGO rate, and the red base line represents the actual situation. Both are set to operate at a sea speed of 16 knot on HFO. Depending on whether the projected MGO price rose or fell by 10% as shown by the two grey lines in Figure 7, the cost curve would change.

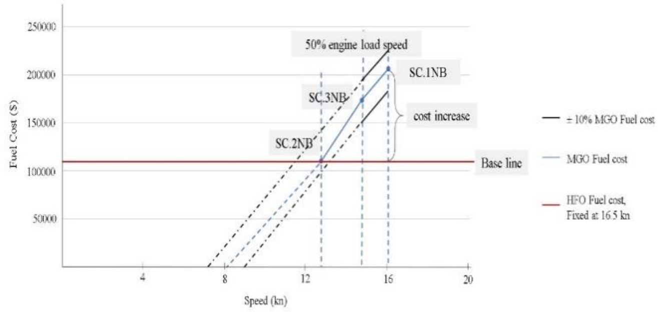

Figure 7: Fuel cost curve Nordic Bremen (full two-week route)

(Based on 2022 fuel price)

Scenario 1(Sc.1NB) is a point that SCA Contex continues to use MGO at Nordic Bremen's existing operating speed of 16 knots. The break-even scenario, Sc.2NB, is reached to the theoretical speed of 12.7 knots, which, like in the case of Andromeda J, is below the minimum. The dotted line in Figure 7 represents 50% engine load speed which is 14.7 knots in this case and symbolized as Sc.3NB. The less distance between Sc.3NB and the base line compared to that between Sc.1NB and the base line indicates that the fuel cost has dropped. Table 8 shows fuel price forecasts for European Bremen (full two-week route). Scenario 2 would have resulted in a fuel cost that was unchanged if the speed were lowered to 12.7 knots. Without any speed reduction as in Scenario 1, the cost of fuel will still rise by almost 87.4%, or $96,150 in this example.

A 1.3 knot speed decrease will reduce the increase in fuel costs to about 30% with 2022 MGO price. A 10% price cut from $1162 to $1045.8 would reduce the cost increase to 18.72%.

TABLE VIII

FUEL COST SCENARIOS NORDIC BREMEN (FULL TWO-WEEK ROUTE)

	Base Line (B.L)	Scenario 1 ($Sc.1_{NB}$)	ΔSc.1/BL	Scenario 2 ($Sc.2_{NB}$)	Scenario 3 ($Sc.3_{NB}$)	ΔSc.3/BL
Fuel	HFO	MGO	-	MGO	MGO	-
Speed [kn]	16	16	0%	12.7	14.7	-8.2% (-1.3 kn)
Fuel cons [ton]	177.4	177.4	0%	94.65	149.4	-15.8% (-28.0ton)
Fuel price* [$/ton]	620	1,162	87.4% ($542)	1,162	1,162	87.4% ($542)
Fuel cost [$]	**109,988**	**206,138.8**	87.4% ($96,150.8)	**109,988**	**173,602.8**	57.84% ($63,614.8)

The two gray lines in Figure 7 depicts how the outcomes would alter if the price changed by 10% in 2022 and Table 9 describes the changes in fuel cost values at SC.1NB, SC.2NB and SC.3NB.

TABLE IX

MGO PRICE'S IMPACT ON SPEED, NORDIC BREMEN

Up and Down Condition for MGO Price	At 16.5 knot		At 50% engine Load		Break even speed and fuel consumption at it
	Fuel Cost ($)	Cost Increase with BL	Fuel Cost ($)	Cost Increase with BL	
+10% Price ($1278.2)	226752.68	116764.68 (106.16%)	190963.08	80975.08(73.62%)	11.8 kn (86.05ton)
-10% Price ($1045.8)	185524.92	75536.92 (68.68%)	156242.52	46254.52(42.05%)	13.3 kn (105.17ton)

The break-even speed for Nordic Bremen in this 10% up and down scenario is lower than the minima of 14.7 knots. The break-even point speed would be 11.8 knots if the price were 10% greater, or $1278.2. It is also not feasible in reality because this position is well below the minimum. A 10% rise in MGO prices would ultimately result in a cost increase of more than 100% compared to the base line. If the price were decreased by 10%, or by $1045.8, the speed to fully compensate for the cost increase compared to the red base line would be 13.3 knots and not practical for the real situation Additionally, a 10% decrease in MGO prices would ultimately result in a cost increase of around 68% when compared to the baseline scenario. Moreover, it can be found that the break-even speed depends on the fluctuations in fuel price. The more fuel price, the less break-even speed.

B. **Findings of Slow Steaming Impact**

Three areas—economic impact, technical impact, and legal impact—will be used to highlight the conclusions of slow steaming impact.

1) Economic impact: According to Alphaliner, carriers are now using 1.2 million TEU of their available container capacity for extra- and super-slow steaming operations. Owners of cargo often suffer from the consequences of longer transit times due to slow steaming. Moreover, shippers can experience more safety stock needs to prevent an out-of-stock condition because of fluctuations in demands.

2) Technical impact: Regarding the technical impacts of slow steaming with modified engines versus those without modified engines, a differentiation must be made. Engine retrofits include things like sliding fuel valves, engine de-rating, flexible turbocharger cut-out systems, and upgraded propellers.

3) Legal impact: The two most important legal ideas related to slow steaming are due dispatch and deviation. One clause applies to time charter parties and another to voyage charter parties. The "Virtual Arrival Clause," which relates to voyage charter parties, allows charterers to request that the owners modify the vessel's speed.

V. CONCLUSIONS

The main research questions, which are framed with broad strategic considerations of how to cut GHG emissions from global shipping industry and how to reduce higher costs on energy while maintaining a high level of energy efficiency during a period of global economic slowdown aggravated by soaring fuel prices, have been handled and slow steaming as a realistic solution to these concerns has been supported by research findings. From the case studies included in the research, we have seen that reducing operational speed from 16.0 – 16.5 knots to 14.3-14.7 knots can offset the increased expenses. The model used to calculate the estimation of fuel consumption is widely accepted in academics and by the shipping industry. It is based on the cubic relationship between fuel consumption and speed.

The research shows that only the levels of speed reduction up to 50% of the engine load at most are considered to be effective. It also has found out that switching from HFO to MGO will raise fuel costs, and slow steaming partially compensates for this increase in fuel costs. The break-even speed even for the same ship can be different from region to region depending on the changes in fuel prices. Therefore, the fuel price is also an important factor to be considered for selecting an optimal slow steaming speed in addition to break-even speed and 50% engine load speed. However, this research has some limitations because we can calculate only for approximation of fuel consumption with the cube law and have a difficulty in practically measuring the exact amount of fuel consumed regarding slow steaming. Moreover, the bunker fuel prices are also assumed to be average for easy calculation in this study. We recommend that the research concerned with slow steaming should be conducted for various types of new ships installed with new engine models and for different trade routes in the future. How and to what extent the market-based measures can affect the sustainability of slow steaming should also be studied.

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