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The Effect of Vessel Speed on Fuel Consumption and Exhaust Gas Emissions

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Abstract: High consumption of fuel and emissions from ships has brought a new perspective tospeed optimization of ship. The reducing in fuel consumption can provide higher savings on the total cost of the vessel. Some regulations on environmental issues have been designated by International Maritime Organization (IMO) and other bodies. This research is based on the development of speed optimization. With case studies of MV. Meratus Mamiri which serving routes of Tj. Priok port-Tj. Perak port, Indonesia. The result of this study expected reduce the fuel consumption and emission of the ship based on speed optimization.

Keywords: Ship Emission, Ship Fuel Consumption, Speed Optimization, Time Window

Introduction

The transportation using ship is one of the main modes of transportation, with a cost effective option for large volume transport in Indonesia. Generally, there are three types of shipping businesses or services on maritime transport, those are linear service, tramper/charter service and industrial shipping.

The difference between the three types of the shipping businesses is not clearly delineated. A ship can change from one kind of type into another type. It depends by whom the vessel is operated. Each type of cruise has an assortment of its own problems in the operation. One of the problems that must be faced by the ship's owner is to determine the amount of the cost of fuel. Valentino *et al*. (2012) has shown that the biggest operational cost in ship is the cost of fuel as shown in Table 1. Due to the costs incurred for fuel, the question arises how to reduce the cost of bunker to the ship so the expenditure for fuel can be reduced.

For such a system, something related to energy use must be environmentally friendly and low maintenance. Similar results were reported recently (Yuan and Bi, 2015). Reducing operating cost still remains a major problem that must be facing by a company. Both shipping companies and other public companies (Bi *et al*., 2015; Yuan *et al*., 2014).

Table 1. Percentage of vessel operating cost

Cost type	Cost (%)
Fuel	47
Insurance etc.	7
Port	46

The reducing of fuel costs can provide higher savings on the total cost of the vessel. Many methods are taken by shipping companies to reduce fuel consumption. One of the alternatives is sailing at low speeds. Due to the non-linear relationship between speed and fuel consumption, it is clear that a ship with running slower would consume less fuel than the ships that run faster. Each ship in the fleet has a service speed which is normally used by shipping companies to planning routes and docking schedules. However, in reality, the ship can sail at a speed of others as well. A ship has a minimum and maximum speed which determines the speed range while sailing.

Semin *et al*. (2008a; 2008b; 2008c; 2008d; 2008e; 2009a; 2009b; 2009c; 2009d; 2010; 20015; Semin, 2012; 2015a; 2005b; Semin and Bakar, 2013; 2014) stated that in recent years, rising fuel prices, declining market conditions and environmental issues in terms of air emissions.Similar results were reported recently (Ismail *et al*., 2008a; 2008b) Environmental issues from ships have brought a new perspective to speed optimization of the ship. Psaraftis and Kontovas (2014)

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reported thatsome regulations on environmental issues has been designated by International Maritime Organization (IMO) and other bodies. The regulation covers the whole range of technical operations up to market and environmental issues of emissions of Green House (GHG) such as carbon dioxide (CO_2), a gas non-greenhouse gases such as sulfur oxides (SOx), nitrogen oxides (NOx), Particulate Matter (PM) and others. For that in addition to being more efficient from an economic perspective, the vessel must also be environmentally friendly in terms of air emissions.

The main purpose of this paper is to clarify that ship speed affect the amount of fuel consumption and exhaust gas emissions.

Relation of Vessel Speed, Fuel Consumption and Emissions

Ships sailing has a distance (s) and a specific time because it will affect to the cost of fuel consumption, where it is highly dependent on the speed. The problem is, sailing ships have a certain time window. Norstad *et al*. (2010) stated that when the ship arrives at the port prior to the schedule it will be fined, as well as if the ship passed through the service schedule will be fined as well. Thus, in cruising mode, ship can be set when running at high speed and when the ship running at low speed. To calculate the fuel consumption of each route with a speed it is used function of engine power, specific fuel consumption and duration of the cruise. To calculate the duration of the journey the vessel can use Equation 1 as below.

$$t = S / v \tag{1}$$

Where:
t = The trip duration of ship (hour)
S = The distance between ports (nm)
v = The speed of the ship (km/h)

Estimation of Fuel Consumption

Fuel is the main energy source of main engine on ship. In the shipping industry, there are several types of fuel include, Heavy Fuel Oil (HFO), Marine Diesel Oil (MDO), Marine Gas Oil (MGO) and biodiesel. The fuel system is a system that is used to supply fuel to the main engine. In general, it consists of three systems that is the transfer system, separating system and the fuel feed system.

The calculation of fuel consumption of engines used formula as in Equation 2.

$$FC = BHPxSFOCxt \tag{2}$$

Where:
FC = Fuel consumption (gr)
BHP = The main engine power (kW)
$SFOC$ = The Specific Fuel Oil Consumption (g/kWh)
t = The time (hours).

Estimation of Ship Exhaust Gas

Fagerholt *et al*. (2010) reported that the beginning of the 21st century has been marked by increasing awareness of the effects of the use of fuel to the operating costs and CO_2 emissions. The main source of emissions from ships is the exhaust gases from the burning of fuel in the ship's engine. After ignition in the engine, air and fuel mixture releases energy to be harnessed mechanical propulsion systems and produces hot flue gases as a byproduct. Lindstad *et al*. (2015) stated that exhaust gasses, carbon dioxide (CO_2) only has the effect of climate, while carbon monoxide (CO), sulfur oxides (SO_X), nitrogen oxides (NO_X), methane (CH_4), carbon black (BC) and organic carbon (OC) has the impact on the climate and the environment both locally and regionally harmful, for example on human health. Similar results were reported recently (Eide *et al*., 2013). The current rules provide for CO_2 emission limits on climate change and NO_X and SO_X to human health and environmental impacts. To that end, significant regulatory activity has occurred within the International Maritime Organization (IMO) and other bodies. Some regulations on environmental issues has been designated the International Maritime Organization (IMO) and other bodies.

Table 2. Emission factor of pollutant (kg per ton fuel) and the type of ship engines

Engine Type	NO_x	CO	CO_2	VOC	PM	SO_x
Steam turb.-BFO	6,98	0,431	3200	0,085	2,5	20s
Steam turb.-MDO	6,25	0,6	3200	0,5	2,08	20s
HS diesel eng.	70	9	3200	3	1,5	20s
Med. speed diesel eng.	57	7,4	3200	2,4	1,2	20s
Slow speed diesel eng.	87	7,4	3200	2,4	1,2	20s
Gas turb.	16	0,5	3200	0,2	1,1	20s
Pleasure-Inboard diesel	48	20	3200	26	Neg.	20s
Pleasure-Inboard gasoline	21,2	201	3000	13,9	Neg.	20s
Outboard gasoline eng.	1,07	540	3000	176	Neg.	20s

Table 3.Principle data of MV. Meratus Mamiri

Ship name/type	MV. Meratus mamiri/container
Dimension (LOA; B; T)	149.58; 23.1; 8.6 m
Vessel Speed (Service)	16 knot
Main engine (Unit, Type, Power, SFOC)	1xMAN B&W 7S50MC, 13610 HP, 170 gr/kWh
Auxiliary engine (Unit, Type, Power, SFOC)	3x Ssangyong-Sulzer 6S20, 1961 HP, 200 gr/kWh
GT	11964 Tones
Routes	Tj. Priok Port Jakarta-Tj. Perak Port Surabaya

Table 4.Ports Distance

Port	Port Area 1 (nm)	Sea Area (nm)	Port Area 2 (nm)
Tj. Priok-Tj. Perak	10	338	25

Emissions are calculated by considering factors such as engine and fuel type of each type of fuel. Pitana *et al.* (2010) has shown that emission rate can be calculated using Equation 3 as below.

$$E = SxtxF \qquad (3)$$

Where:
E = The total emission of pollutants (kg)
S = The fuel consumption (ton/hours)
F = The emission factor (kg/ton of fuel)

Pitana *et al*. (2010) has shownthe emission factor of each pollutant in units of kg per ton fuel and the type of ship engines in Table 2.

Research Methods

The research methods contain of some steps that will be described in the following section as below. The object of this paper is using MV. Meratus Mamiri.

Table 3 Show the principle dimension of MV. Meratus Mamiri and Table 4 show the distance area in Tanjung Perak port and Tanjung priok port.

To calculate the duration of sailing vessel can use Equation 1. The calculation of fuel consumption of engines can use formula as in Equation 2. Emissions are calculated by considering factors such as engine and fuel type of each type of fuel. Emission rate can be calculated using Equation 3.

Result and Discussion

The ship's speed will be varied in order to see the effect of the speed difference on duration of sailing, fuel consumption and exhaust emissions from the ships. Speed variation is based on the area of cruise ships, the speed of the port area 1, the speed of the sea area and the speed of the port area 2. Speed variations can be seen in Table 5.

Table 5. Variations speed of MV. Meratus Mamiri

Speed variation (kn)	Speed variation (kn)
6-18.2-6	7-18.2-7
6-18.7-6	7-18.7-7
6-19.2-6	7-19.2-7
6-19.7-6	7-19.7-7
6-20.2-6	7-20.2-7

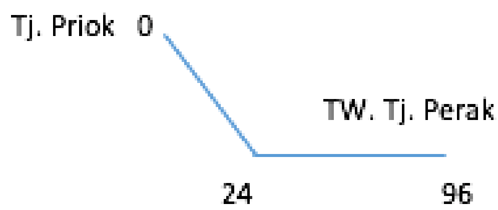

Fig. 1. Time window of Tanjung Perak's port

The case study of MV. Meratus Mamiri operating on the route Tj. Priok-Tj. Perak. At the port that will pass, the vessel has a time windows schedule that must be obeyed. When the ship arrives at the port prior to the schedule will be subject to a charge, as well as if the ship passed through the service schedule will be subject to charge anyway. Thus, in a cruise ship can be set when running at high speed and when the ship running at low speed. Figure 1 shows the time window in the harbor Tj. Perak.

Services time of Tanjung Perak is 72 h, with a demand of port 800 TEUs and queue times (port time) is assumed to harbor idle time is 35 h. Using Equation 4 below, it can be seen that the time of loading and unloading of MV. Meratus Mamiri is 26.6 h:

$$T_{L/U} = (TEUs) / Capacity\ of\ crane\ in\ Portx2 \qquad (4)$$

After knowing all the variables needed, the next step is to calculate the sailing duration of ship, fuel consumption and exhaust gas emissions produced by ship. The calculation of sailing duration of the ship aims to find out how long it takes in one trip. The duration of the ship calculated in accordance with the area and variations in speed that has been modeled in Table 5. Calculation results shown in Table 6. Table 6 it can be seen that the speed of the service vessel, the duration needed for the variation speed of 4-16-4 kn takes sailing for 39.9 h, while for the variation speed of 5-16-5 kn takes sailing for 28.1 h.

After calculating the sailing duration at any speed variation. Next is to analyze the effect of speed changes on fuel consumption on ships. In theory the ship at low speed then produce more fuel consumption slightly. Table 7 shows the results of the calculation of the total fuel consumption on MV Meratus Mamiri at variation of speed that has been previously assumed.

Ship fuel consumption is known, then the amount of exhaust emissions produced ships can also be known. Theoretically the amount of fuel consumption is directly proportional to the amount of emissions produced. If high fuel consumed, the amount of exhaust emissions produced is also high. Table 8 shows the results of the calculation of the amount of emissions released MV. Meratus Mamiri on every variation of speed that has been previously assumed. Emissions that are released in the form of ship NOx, CO, CO_2, VDC, SOx and PM.

Table 7 shown that at a speed of servicing ships varied at 4-16-4 kn 35.7 tons of fuel needed during the trip duration of 29.9 hours, while in the service speed of the ship is varied at 5-16-5 kn 35.8 tons of fuel needed for the duration of the trip 28.1 hours.

Table 8 shown that at a speed of servicing ships varied at 4-16-4 kn with a fuel consumption of 35.7 tons of fuel and trip duration of 29.9 h, the exhaust gases produced is 2036 kg/tonne of fuel NOX, 264 kg/ton of fuel CO, 86 kg/ton of fuel VOC, 114 306 kg/ton of fuel CO_2 and 48 kg/ton of fuel PM. While in the service speed of the ship is varied at 5-16-5 kn with fuel consumption of 35.8 tons and 28.1 h trip duration, the exhaust gases produced is 2039 kg/tonne fuel NOX, 265 kg/ton of fuel CO, 86 kg/ton of fuel VOC, 114 490 kg/ton of fuel CO_2 and 48 kg/ton of fuel PM.

From the above calculation, it was concluded that the speed greatly affect fuel consumption and exhaust. emissions produced. Each ship in the fleet has a service speed which is normally used shipping companies plan routes and schedules to dock. However, in reality, the ship can sail at a speed of others as well sailing.

Table 6. Duration calculation of MV. Meratus Mamiri with variation speed in each area

Speed (kn)	Port area 1st (nm)	Sea area (nm)	Port area 2nd (nm)	Duration (h)			Total (h)
4-15-4	10	338	25	2.5	22.5	6.3	31.3
4-15.5-4	10	338	25	2.5	21.8	6.3	30.6
4-16-4	10	338	25	2.5	21.1	6.3	29.9
4-16.5-4	10	338	25	2.5	20.5	6.3	29.2
4-17-4	10	338	25	2.5	19.9	6.3	28.6
5-15-5	10	338	25	2.0	22.5	5.0	29.5
5-15.5-5	10	338	25	2.0	21.8	5.0	28.8
5-16-5	10	338	25	2.0	21.1	5.0	28.1
5-16.5-5	10	338	25	2.0	20.5	5.0	27.5
5-17-5	10	338	25	2.0	19.9	5.0	26.9

Table 7. Calculation result of fuel consumption MV. Meratus Mamiri

Speed variations (knot)	Duration (hours)	Total of fuel consumption (Ton)
4-15-4	31.3	32.1
4- 15.5-4	30.6	33.9
4-16-4	29.9	35.7
4-16.5-4	29.2	37.6
4-17-4	28.6	39.6
5-15-5	29.5	32.2
5-15.5-5	28.8	33.9
5-16-5	28.1	35.8
5-16.5-5	27.5	37.7
5-17-5	26.9	39.6

Table 8. Emissions calculation results of MV. Meratus Mamiri

Speed Variation (kn)	Duration (h)	Total of fuel Cons. (Ton)	NOx (kg)	CO (kg)	VOC (kg)	CO_2 (kg)	PM (kg)
4-15-4	31.3	32.1	1830	238	77	10275	39
4-15.5-4	30.6	33.9	1931	251	81	10843	45
4-16-4	29.9	35.7	2036	264	86	11430	48
4-16.5-4	29.2	37.6	2144	278	90	12037	50
4-17-4	28.6	39.6	2256	293	95	12664	52
5-15-5	29.5	32.2	1834	238	77	10294	43
5-15.5-5	28.8	33.9	1935	251	81	10861	45
5-16-5	28.1	35.8	2039	265	86	11449	48
5-16.5-5	27.5	37.7	2147	279	90	12055	50
5-17-5	26.9	39.6	2259	293	95	12682	52

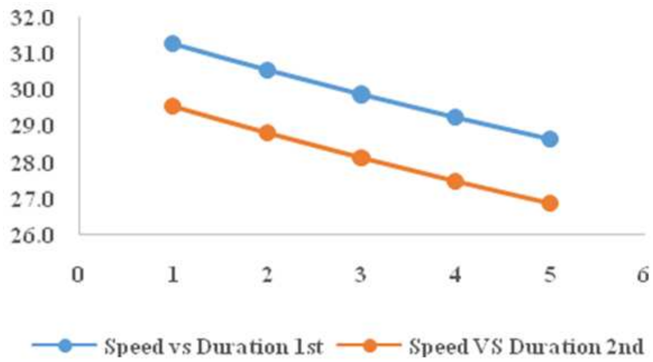

Fig. 2. Relation between speed and duration

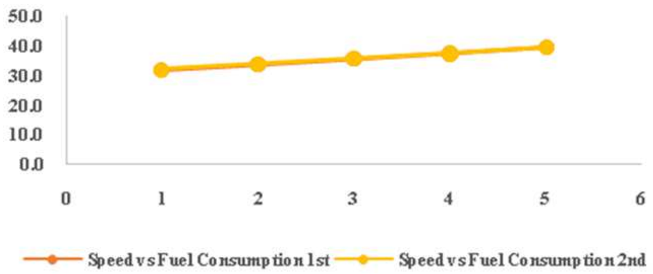

Fig. 3. Relation between Speed and Fuel Consumption

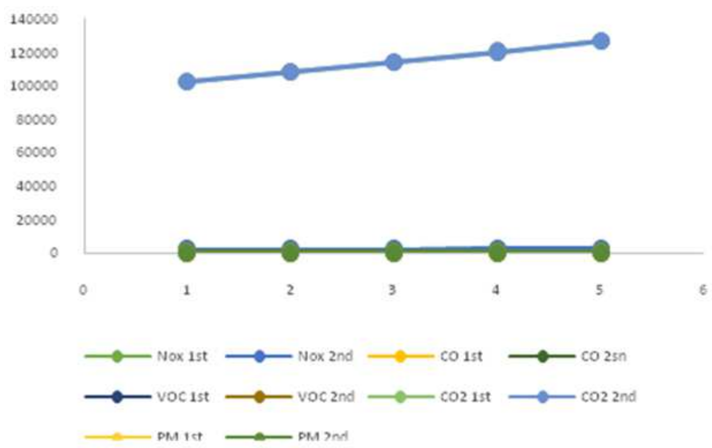

Fig. 4. Relation between Speed and Exhaust Emissions

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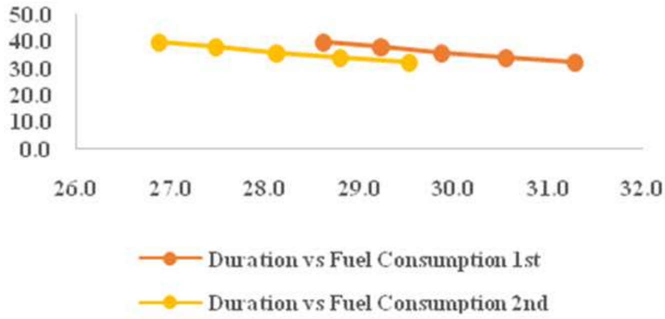

Fig. 5. Relation between duration and fuel consumption

From the above calculation, it was concluded that the speed greatly affects fuel consumption and exhaust emissions produced. Each ship in the fleet has a service speed which is normally used shipping companies plan routes and schedules to dock. However, in reality, the ship can sail at a speed of others as well. Sailing boats at a distance (s) and the particular time because it will affect the cost of fuel consumption is highly dependent on the speed. Here was the influential role of speed optimization. With more optimal speed settings, ships can save fuel consumption and impact on the environment due to exhaust emissions can also be reduced.

Below are some charts that showing the relationship between speed and duration speed and fuel consumption, as well as the speed and exhaust emissions.

Figure 2 shows that the faster the ship, the duration of which will be reached more quickly. The blue line shows the graph for the speed of 4 knots in every area of the port, while the orange line shows the graph to a speed of 5 knots in every area of the port.

Figure 3 shows that the speed is directly proportional to fuel consumption, the faster the boat, the fuel consumption is also higher. Graph velocity variations in the port area at a speed of 4 knots coincide with chart speed of 5 knots. That is because the difference in fuel consumption is not too large.

Figure 4 shows that the exhaust emissions are a function of fuel consumption, the faster the boat, the fuel consumption is also higher, so is the emissions produced.

Figure 5 shows that the faster the duration of the cruise ship, the higher fuel consumption. If the objectives are to reduce fuel consumption and exhaust emissions, keep in mind that each vessel has a specific time window. When the ship arrives at the port prior to the schedule it will be fined, as well as if the ship passed through the service schedule it will be fined as well. Thus, in a cruise ship can be set when running at high speed and when the ship running at low speed.

Conclusion

The reducing in fuel costs can provide big savings on the total cost of the vessel. One of the alternatives is sailing at low speeds. Due to the non-linear relationship between speed and fuel consumption, it is clear that a ship with running slower would consume less fuel than the ships that run faster. This research is the basis of the development of speed optimization to reduce fuel consumption and exhaust emissions for domestic ship in Indonesia. The result of this study shows that ship speed affect the fuel consumption and exhaust gas emissions. By optimizing speed in each port area, ship can reduce the fuel consumption and exhaust emission than sailing in service speed that given by shipping company.

The future research of this study is the use of algorithms for optimizing the speed.

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Author’s Contributions

Ayudhia P. Gusti: Participated in all data analysis and contributed to the writing of the manuscript.

Semin: Contributed in substantial revision and improvement of the draft of the paperand contributed to the writing of the manuscript.

Ethics

Authors have read and approved the publication of this article. There are no ethical issues arising out of the publication of this paper. This work is purely original and no part of it has been published earlier anywhere in any form.

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