Activity-Based Fuel Oil Consumption Estimation for Calculating Energy Efficiency Operational Indicator (EEOI) In an Indonesian Merchant Ship

H Prastowo¹, T Pitana¹, H P Kusama¹
¹Departement of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia.

Email: harrispk25@gmail.com

Abstract. Global shipping accounts for nearly one million tonnes of CO₂ emissions annually during 2013 – 2015 period, and could grow 50%–250% by 2050 if the condition is unchanged. The International Maritime Organization (IMO) as the specialized agency responded to this issue written in MEPC.304(72) about strategy of reducing greenhouse gas (GHG) emissions from ships. Energy Efficiency Operational Indicator (EEOI) is a monitoring tool based on CO₂ emissions proposed by IMO written in MEPC.282(70). The purpose of this research is to evaluate factors influencing the results of EEOI. Estimation of fuel oil consumption using proposed methods by Bialystocki and Konovessis and Moreno-Gutiérrez, et al. are compared with actual fuel oil consumption resulted in average error of 20.44% and 15.45%. The EEOI results is 0.000905 ton CO₂/TEU-nm for MV Meratus Benoa and 0.000509 ton CO₂/TEU-nm for MV Meratus Bontang. Benchmarking process using the same voyage route revealed that MV Meratus Benoa is less efficient than MV Meratus Bontang. MV Meratus Benoa carried less average cargo than MV Meratus Bontang, while having more average fuel oil consumption. Proposed improvement for better EEOI results is improving the cargo management especially for MV Meratus Benoa and evaluation in ship’s operational setting for any specific sea conditions.

1. Introduction
Global warming has been a big issue around the world as a result of excessive greenhouse gas (GHG) emission from many industrial and transportation sectors. The International Council on Clean Transportation (ICCT) reported in 2017 that during 2013 – 2015 period [1], global shipping accounts for 924 million tonnes of CO₂ annually.

Under Paris agreement, parties of United Nations Framework Convention on Climate Change (UNFCCC) reached an agreement to counter climate change and to speed up and intensify any actions needed to support sustainable low carbon future. The aim focusing on strengthen the global response to the treat of climate change by keeping a global temperature rise this century below 2 degrees Celsius above pre-industrial levels and pursue to limit it to further 1.5 degrees Celsius. The agreement entered into force on 4 November 2016 and Indonesia ratified it at 31 October 2016.

As a specialized agency of United Nations for safety navigation shipping and marine pollution, the IMO is forced to take a response regarding the Paris agreement. The Marine Environment Protection Committee (MEPC) of IMO amended MARPOL Annex VI to achieve control over GHG emissions
from ships. This amendment established regulations on energy efficiency of ships, a package of technical measures for new ships and operational reduction measures for all ships.

Energy Efficiency Operational Indicator (EEOI) is a monitoring tool inside the framework of Ship Energy Efficiency Management Plan (SEEMP) developed by The International Maritime Organization (IMO) to achieve a control on GHG emission by ships, particularly in ship’s operational life cycle. IMO voluntarily suggests the use of EEOI as monitoring tool, but any other monitoring tool apart from EEOI could be used.

EEOI utilizes the emission of CO2 as the base to measure the ship’s energy efficiency. EEOI is measured by mass of CO2 emitted by a ship or a fleet compared to the amount of cargo carried and distance sailed. Fuel oil consumption and types of fuel oil used also influence the result of EEOI.

Fuel oil consumption is a big influence in the result of EEOI. Factors attributed inside fuel oil consumption are ship’s speed and engine power. However, during operation of a ship, external factors could also impact the fuel oil consumption. Weather worsening, increasing draft and displacement, and hull and propeller deteriorating could impact in increase of resistance [2], hence contribute to more fuel consumption.

Approaches for operating with less fuel oil consumption have been an interesting topics for ship operators and ship owners. Slow steaming is an application of slowing speed in order to achieve lower fuel consumption as well as carbon emission [3]. Nevertheless, slow steaming still needs more evaluation since it is limited for improvement in safety aspect as engine gradually worn out faster and related to scheduling time of the ship.

Estimation of current ship’s fuel consumption is a big advantage for many ship owners, as data of fuel consumption is more accurate than based on sea trial’s result. This estimation could further be used for assessing the ship’s energy efficiency with more reliable data source.

Amendments to MARPOL Annex VI about data collection system for fuel oil consumption of ships entered into force on 1 March 2018, as adopted by Resolution MEPC.282(70). This amendment requires ships of 5,000 gross tonnage and above to collect consumption data for each of fuel oil they use. Flag states are required to transfer the data into an IMO Ship Fuel Oil Consumption Database, which is a module inside Global Integrated Shipping Information System (GISIS).

This research aims to analyze current energy consumption of the ship and evaluate the factors that influence it. The aim of such analysis could be an accurate estimation of current fuel oil consumption and be a measure of ship’s energy efficiency based on its CO2 emission

2. Method
2.1. Activity-Based Fuel Oil Consumption Estimation.

The object of this method is to estimate the fuel oil consumption on a day-to-day basis. This method needs information regarding the ship’s characteristics during its operational time. In this case of study, noon report is used as the main data source to provide better information about the ship’s activity.

This study compares two methods of fuel oil consumption by [4] which is a statistical analysis and [5] that examine the specific main engine power output and load factor. The method proposed by [4] takes into account 4 parameters:

- Ship’s draft in suggested voyage
- Weather force
- Weather direction
- Date of voyage

These parameters are used for the correction calculation and the results of each parameter will be plotted into a graph.

The calculations is divided into 3 parts that consist of preliminary stages, weather correction stage. Equations used in this method are as follow:

\[
Fuel\ Cons_{\text{corr}} = 24 \times \frac{Fuel\ Cons_{\text{steamed}}}{Steaming\ Time}
\] (1)
These two corrections calculations are used in preliminary stages to plot the initial curves. Second stage is to take into account the weather effect which are the weather force and the weather direction.

\[
Fuel_{\text{Cons}_{\text{LBS}}} = Fuel_{\text{Cons}} \times \frac{Fuel_{\text{cons}_{\text{avg}}}}{Fuel_{\text{cons}_{\text{avg}}}}
\]

(3)

\[
Fuel_{\text{Cons}_{\text{LBS}}^{\text{avg}}} = Fuel_{\text{Cons}} \times \frac{Fuel_{\text{cons}_{\text{avg}}^{\text{beam}}}}{Fuel_{\text{cons}_{\text{avg}}^{\text{beam}}}}
\]

(4)

Estimation of fuel oil consumption then could be obtained with regression formula from the final curve of correction.

The second method for the fuel oil consumption estimation is proposed by [5]. This method is initially intended for calculating emission, but to calculate the emission, the method needs accurately calculate the energy consumption of the ship. This proposed method utilizes [6] for calculating emission factors, adapts calculation by [7] for specific fuel oil consumption, uses [8] model for defining the ship’s power and speed relation, and [2] for calculating actual main engine power.

All variables used in the calculation are taken from the on-board data. Equations used in this method are as follow:

\[
P_{\text{transient}} = \frac{R_i \left( \frac{t_{\text{transient}}}{t_i} \right)^\left(\frac{2}{3}\right) V_{\text{transient}}^n}{\eta_{\text{wet}}/\dot{f}}
\]

(5)

\[
L_{\text{F}} = \frac{P_{\text{transient}}}{P_i}
\]

(6)

\[
SFOC_{\text{refine}} = 0.455L^2 - 0.711L + 1.2\ell
\]

(7)

\[
SFOC = SFOC_{\text{refine}} \times SFOC_{\text{heave}}
\]

(8)

where:

- \(P_{\text{transient}}\): Instantaneous power for calculation
- \(P_i\): Power at 100% MCR from on-board test
- \(t_{\text{transient}}\): Draft at time
- \(t_i\): Draft at 100% MCR from on-board test
- \((2/3)\): Assumption of power is related to displacement (Admiralty formula)
- \(V_{\text{transient}}\): Actual ship speed
- \(V_i\): Draft at 100% MCR from on-board test
- \(n\): Constant ship speed coefficient (Speed and power relationship)
4.00 for large, high-speed ships i.e.: container vessels  
3.50 for medium-sized, medium-speed ships i.e.: feeder container ships, Ro-Ro, etc.  
3.20 for low-speed ships i.e.: tankers and bulk carriers

\[ \eta_w : \text{Modification of propulsion efficiency due to weather} \]
\[ \eta_f : \text{Modification of propulsion efficiency due to fouling} \]

2.2. Energy Efficiency Operational Indicator

The Energy Efficiency Operational Indicator (EEOI) is a monitoring tool for managing ship and fleet efficiency performance over time. EEOI is a tool developed by MEPC as a part of Ship Energy Efficiency Management Plan (SEEMP). Ship Energy Efficiency Management Plan is an operational measure to create a mechanism to improve ship’s energy efficiency. Even though it is voluntarily, the approach of applying SEEMP into a ship or fleet could assist ship owners, ship operators, and other parties which are concerned in evaluation of the performance of their ship or fleet [9].

The EEOI calculation was based on guidelines for voluntary use of the ship’s Energy Efficiency Operational Indicator (EEOI). Detailed from formula given by [10] defined EEOI as the ratio of mass of CO2 emitted per unit of transport work.

The formula of EEOI as follow:

\[
EEOI = \frac{\sum_j FC_{ij} \times C_{Fj}}{m_{cargo} \times D} 
\]

(9)

\[
Average \ EEOI = \frac{\sum_i \left( FC_{ij} \times C_{Fj} \right)}{\sum_i \left( m_{cargo} \times D \right)} 
\]

(10)

where:

\( j \) : Fuel type  
\( i \) : Voyage number  
\( FC_{ij} \) : Mass of consumed fuel \( j \) at voyage \( i \)  
\( C_{Fj} \) : Fuel mass to CO2 conversion factor of fuel \( j \)  
\( m_{cargo} \) : Cargo carried, or work done (tonnes, TEU, passengers) or gross tonnage of passenger ships  
\( D \) : Distance travelled

2.3. Fuel Oil to CO2 Conversion Factor

Calculation of CO2 as a product of fuel combustion is done using an approaching method. However, each type of fuels have their specific carbon chain and other chemical properties. Conversion factor is used to determine the amount of CO2 released from a combustion for a specific volume of fuel oil burned. Fuel mass to CO2 mass conversion factors (CF) is released by IMO in the guidelines of EEOI, with value as follow:

| Type of Fuel | Reference | Carbon content (ton-\(CO_2\)/ton-fuel) |
|--------------|-----------|-------------------------------------|
| Diesel/Gas Oil | ISO 8217 Grades DMX through | 0.875 | 3.206000 |
| Type of Fuel                        | Reference       | Carbon content | $C_F$ (ton-CO$_2$/ton-fuel) |
|------------------------------------|-----------------|---------------|-----------------------------|
| 2. Light Fuel Oil                  | DMC, ISO 8217   | 0.860         | 3.151040                    |
|                                    | RMA Grades      |               |                             |
|                                    | through RMD     |               |                             |
| 3. Heavy Fuel Oil                  | ISO 8217 Grades | 0.850         | 3.114400                    |
|                                    | RME through RMK|               |                             |
| 4. Liquified Petroleum Gas (LPG)   | Propane         | 0.819         | 3.000000                    |
|                                    | Butane          | 0.827         | 3.030000                    |
| 5. Liquified Natural Gas (LNG)     |                 | 0.750         | 2.750000                    |

Effectively started from 1 September 2018, Indonesian government mandatorily enforced the use of B20 program. B20 is a mixture of 20% biodiesel and 80% of diesel fuel. Biodiesel is a biofuel in the form of fatty acid methyl ester (FAME) made from vegetable oil.

3. Result and Discussion

This study was done in two ships named MV Meratus Benoa and MV Meratus Bontang. Both ships are sisters ship which assumed to be identically same. Both ships also serving some of the same voyage routes during this research.

3.1. Fuel Oil Consumption (FOC) Estimation

Ship operators have much information about the ship’s performance and activity from the daily noon report. Therefore, the data could be utilized and updated routinely in a specific time range rather than estimating using sea trials data plus margin. The estimation of FOC is specifically devoted for the consumption by the ship’s main engine for cruising mode.

Estimation method by [4] resulted as follow:

![Figure 1. FOC Estimation of MV Meratus Benoa using method from [4]](image-url)
Figure 2. FOC Estimation of MV Meratus Bontang using method from [4]

Figure 1 and Figure 2 shows the result of estimation using method from [4]. The results of FOC estimation is compared to the actual FOC and expressed in calculation of error. MV Meratus Benoa has average error of 19.96% and MV Meratus Bontang has average error of 20.93%.

While estimation method by [5] resulted as follow:

Figure 3. FOC estimation of MV Meratus Benoa using method from [5]

Figure 4. FOC estimation of MV Meratus Bontang using method from [5]
Figure 3 and Figure 4 shows the result of estimation using method from [5]. The results of FOC estimation compared to actual FOC is 17.55% for MV Meratus Benoa and 13.32% for MV Meratus Bontang.

3.2. Energy Efficiency Operational Indicator (EEOI)

Based on the guidelines stated in [10], data of fuel oil consumption, cargo carried, and distance sailed is calculated using formula (9).

Using formula (10) to measure the average EEOI, MV Meratus Benoa has higher average EEOI with 0.000905 ton CO2/TEU-nm compared to MV Meratus Bontang with 0.000509 ton CO2/TEU-nm.

Analyzed from Figure 5 and Figure 6, the trend line of EEOI shows an increase for MV Meratus Benoa and a decrease for MV Meratus Bontang. Variables influencing the results of EEOI could be traced back to the formula (9). Main variables are fuel oil consumption, amount of cargo, and distance sailed by the ship. These factors will directly influencing the result of EEOI.

The correlation between fuel oil consumption and EEOI could be seen in Figure 7 and Figure 11. Both graphs shows increase of EEOI resulted from increase of fuel oil consumption.
Figure 7. Graph of correlation between EEOI and FOC of MV Meratus Benoa

Figure 8. Graph of correlation between EEOI and Cargo of MV Meratus Benoa

Figure 8 and Figure 12 shows the correlation between the amount of cargo carried and EEOI. The amount of cargo really influences the result of EEOI. This could be seen from both graphs that shows significant decrease in cargo resulted in increase of EEOI.
Another direct variable that influences the result of EEOI is distance sailed by the ship. Trend lines of Figure 9 and Figure 13 prove that as distance sailed by the ship decrease, EEOI increases.

Fuel oil consumption is a function of power, and power is a function of ship’s resistance and ship’s speed. Thus, the higher the speed of ship will result in higher resistance of the ship. Hence, higher speed would result in higher fuel oil consumption and EEOI.

Figure 10. Graph of correlation between EEOI and Speed of MV Meratus Benoa

Although speed affects the fuel oil consumption, both trend lines shown in Figure 10 and Figure 14 revealed that even with the relatively same operational speed could produce higher result of EEOI. Therefore, it could be concluded that speed does not really affect the result of EEOI.

Figure 11. Graph of correlation between EEOI and FOC of MV Meratus Bontang
Figure 12. Graph of correlation between EEOI and Cargo of MV Meratus Bontang

Figure 13. Graph of correlation between EEOI and Distance Sailed of MV Meratus Bontang

Figure 14. Graph of correlation between EEOI and Speed of MV Meratus Bontang

3.3. Benchmarking of EEOI

Energy Efficiency Operational Indicator (EEOI) does not have any limitation that indicates that a ship is not efficient. It is only a tool for monitoring the ship’s efficiency continuously. Therefore, to
assess the current energy efficiency of MV Meratus Benoa and Meratus Bontang, benchmarking should be done. Benchmarking process is based on the same route which its distance is assumed to be relatively same, so the only variables that affects the result of EEOI are cargo carried and fuel oil consumption. In term of cargo carried, it could be seen from Figure 16 that MV Meratus Bontang has a higher average than MV Meratus Benoa. This results in lower average of EEOI for MV Meratus Bontang. For fuel oil consumption, Figure 17 shows that MV Meratus Benoa has higher average of fuel oil consumption than MV Meratus Bontang. This makes MV Meratus Benoa has higher average value of EEOI than MV Meratus Bontang. Based on Figure 18, MV Meratus Bontang operated at higher average speed than MV Meratus Benoa. Although higher speed should result in higher fuel oil consumption, MV Meratus Bontang proved that they could have lower result of EEOI even with higher operational speed. But, it could be seen from the graph, that lower speed tends to result in lower value of EEOI. From the benchmarking result of 4 voyage routes, MV Meratus Bontang has lower average EEOI than MV Meratus Benoa. This assessment could be a base for MV Meratus Benoa to evaluate their operational condition.

![Figure 15. Graph of Average EEOI per Voyage Route](image1)

![Figure 16. Graph of Average EEOI and Average Cargo](image2)
4. Conclusion

The estimation of fuel oil consumption is a quite powerful tool to be utilized rather than relying on sea trial’s data. Based on the results of fuel oil consumption estimation, method by [5] has a lower average value of error compared to method by [4].

From the assessment of overall value of EEOI, MV Meratus Bontang has lower average EEOI than MV Meratus Benoa. Average EEOI of MV Meratus Bontang is 56% lower than MV Meratus Benoa.

Based on the benchmarking result of same voyage routes between the two ships, MV Meratus Bontang carried more cargo while consumed less fuel oil. Higher operational speed does not really affect the EEOI because although MV Meratus Bontang operates at higher speed still results in lower average of EEOI.

Possible improvement that could be proposed for both ships is management of cargo. MV Meratus Benoa should carry more cargo per voyage to decrease the EEOI. Both ships operational condition should also be monitored and evaluated to seek for the best operational setting during specific sea condition.

This is extremely important to recognising correct operational settings and decisions, where cost efficiency and environmental friendliness are the top priorities.
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