Estimation and optimization of the voyage energy efficiency operational indicator (EEOI) on Indonesian sea tollway corridors

M Ichsan\textsuperscript{1}, M F Pradana\textsuperscript{2} and B Noche\textsuperscript{3}

\textsuperscript{1} Institute of Embedded Systems, University of Duisburg-Essen, Forsthausweg 2, 47057 Duisburg, Germany
\textsuperscript{2} Department of Civil Engineering, University of Sultan Ageng Tirtayasa, Jl. Jend Sudirman Km 3 Cilegon 42435, Indonesia
\textsuperscript{3} Institute of Transport Systems and Logistics, University of Duisburg-Essen, Forsthausweg 2, 47057 Duisburg, Germany

*Email: muhammad.ichsan@stud.uni-due.de

Abstract. In this research, the Energy Efficiency Operational Indicator (EEOI) used as emission estimation parameter on three Indonesian’s sea toll way corridors. Operational data of the ships, such as speed, Deadweight Tonnage (DWT), load and load’s utilization are used in this research. Moreover, unavailable operational data are to be assumed with comparable assumptions or suitable calculation. Furthermore, the data are used to calculate the fuel consumption of the voyage, which is the main variable in the emission index calculation. The method, so-called, a ‘slow-steaming’ method is utilized to optimize the emission parameter. The result shows that the slow steaming process is indeed bring more efficient emission result for the sea toll way under consideration. Decreasing the speed to 10\% of current speed is decreasing the Fuel Consumption of the ships around 17\% to 19\% yearly. Decreased it further to 12\%, lowered the fuel consumption around 23\% from current yearly fuel consumption. Moreover, applying slow steaming with 10\% and 12\% rate in each route resulted in a decreasing rate of emission produces of around 19\% and 23\% respectively. These results are encouraging as an initial step to measures the emission level on the Indonesian Sea tollway.

1. Introduction

Indonesian government defined Sea Tollway as a technique to connected trade by sea from west to the east part of Indonesia with a constant frequency and schedule [1]. This idea comes from the concern of the economic condition in the eastern part of Indonesia. The government argued that with increasing the level of transportation and logistics from the west to the east and vice versa, can be a solution in closing the economic gap between the western and eastern part of Indonesia. One way to solve it is with the sea highway program. This program comes with the needed improvement plan in every area of sea transportation and logistics.

At the beginning of the implementation process, the Indonesian Sea Tollway programs face various challenges. The first challenge that arises is the lack of the backload. It is because the industry in Eastern Indonesia has a lower output. In effect the load of returning ships is not optimal. The second challenge is the price disparity in eastern Indonesia, although this program is intended to reduce the level of disparity. The third challenge is the port performance problem. The last challenge is the use of
technology and information that has not been maximized [2]. In the future, it is hoped that the much-needed trade balance and improvement in economic condition between east and west can be achieved. However, until now the government is yet to concern about the emissions side of the program. It is fair to assume with the increasing volume of trade and transportation between ports in the sea highway, the amount of Green House Gas (GHG), especially CO$_2$ and NO$_x$, will also be increased. The emission level from commercial shipping activities, especially CO$_2$ level, is not yet regulated [3]. The UNFCCC (United Nations Framework Convention on Climate Change) is failed to include GHG produce by shipping activities as the target of its global emission reduction on the Kyoto Protocol [3]. It again left out, together with aviation activities, the Paris agreement in 2015. This is happening despite some report shows the significant effect of shipping activities on the level of global GHG. Moreover, the GHG emission, especially CO$_2$ level emission from shipping activities, could be listed bigger than Germany if shipping activities assumed as a country [4]. Furthermore, the emission of GHG from ocean-going vessel emits more CO$_2$ than the equivalent of 205 million cars or around 1.046 billion metric ton of GHG emissions [5]. IMO also predicts that by 2050 the amount of carbon dioxide emission would be increasing around 150%-250% billion metric ton [5]. This can happen if no serious action is taken to challenge this trend. It is, indeed, a steep challenge to cut the needed rate of emissions by 2050 [6]. By their calculation, the world shipping emissions CO$_2$ footprints need to be reduced by a factor of five. In other words, by 2050 the emitted CO$_2$ per ton-nm needs to reduce from 25 g to 4 g per ton-nm [6].

One-way to specify the emission level is through the use of the energy efficiency level of a ship. There are two indicators introduced by IMO regarding the energy efficiency level of the ship [5]. There are Energy Efficiency Design Index (EEDI) and the Energy Efficiency Operational Indicator (EEOI). The main difference between the two indicators is regarding their usage. The EEDI is used to measure energy efficiency level in the design level. IMO suggest that using EEDI as the anchor to achieve new design ships to achieve the minimum level of GHG emission of a new ship. The EEOI serve another purpose altogether. While the usage of EEOI is measuring the Energy Efficiency level of a ship, but unlike EEDI, the EEOI measure efficiency level for the existing ships. The EEOI is used to measure the energy efficiency level in the currently available ships at the operational level.

That is why optimization of EEOI can be used to calculate the desired emission level of the shipping activity. The objective of this research is to optimize the rate of EEOI in the decided route on the Sea Tollway of Indonesia as a prototype to conduct a study of emission on it.

2. Methodology
The research is conducted using the bottom-up approach. It is in line with the method that IMO used in its Greenhouse Gas Study [7]. It noted that uncertainty on some variables with bottom-up approach might underestimate the result of emission calculation [7]. This approach is also known as the operational approach as oppose top-down, or fuel consumed approach. It is because of it a rather hard to obtain good quality data from a still a quite new phase of implementation of the project [8]. It is still paramount for this research to try obtaining high-quality data as much as it’s needed. Unavailable data on some variables are assumed. It is as stated in the bottom-up approach, the non-existing or doubtful accuracy of the data for the variable can be assumed with the upmost care of its accuracy.

In 2009, IMO designs management plans for managing ship efficiency. This plan called the Ship Energy Efficiency Management Plan (SEEMP) [10]. In this plan, IMO formulated an index to calculate the energy efficiency level of the existing ship. The Index used to measure energy efficiency on the operational level. The indicator named as energy Efficiency operational Indicator or EEOI. The result of the index calculation shows the level of CO$_2$ emissions per unit of load weight and transport distance (CO$_2$/TEU.nm or CO$_2$/TEU.Km). Applying the SEEMP, also the EEOI has been mandatory since the start of 2013 [11].

The EEOI not only measure the fuel efficiency of the Ships but also evaluate the influence of change in the operation of the ship on the fuel consumption. The formula of EEOI is as follows:
\[ EEOI = \frac{\sum_i F_{Ci} X C_{\text{carbon}}}{\sum_i m_{\text{cargo},i} X D_i} \] (1)

Where:
- \( F_{Ci} \) = Fuel Consumption (Ton)
- \( C_{\text{carbon}} \) = Constant Carbon Content in Fuel
- \( m_{\text{cargo},i} \) = Mass of the cargo Transported (TEU or Cubic Ton)
- \( D_i \) = Distance Travel (nautical mile or kilometre)

The fuel consumption data is usually hard to determine without the current time record of the fuel meter of the ship. In order to have the fuel meter record, the logbook of the ships needs to be acquired.

In the reality of Indonesia Shipping condition, it is hard to have a personal logbook of the ship. It is mainly because there are no regulations, as the time of the writing, which required the shipping companies to give the logbook to the government. This means that the record will not be available to the public. Thus, fuel consumption in the report used estimation value.

The value estimation of fuel consumption is based on the relationship between speed and fuel consumption. The speed data is more readily available compared to fuel consumption. It is because unlike fuel consumption, the speed variable can be accurately assumed by technical specification and operational activity of a ship. The fuel consumption as a cubic representation of ship speed (v) for most type of ship [12], or:

\[ f(v) = kv^3 \] (2)

While this representation is may be adequate to estimate the ship’s fuel consumption in most cases, it failed to factor the cargo weight. This is because the resistance that comes with different loads of utilization affect differently to fuel consumption. The full ship resistance is clearly different from the empty ship. The weight between full and empty also has a different effect on speed and fuel consumption. The effect of loading condition is more apparent when the voyage has several legs. The different leg can have varies loading condition that affected fuel consumption. Thus, it is very important to model a realistic representation of fuel consumption to reflect all different loading condition. Therefore, there is a more complete formula for fuel consumption [12].
Taking into account the effect of weight, the above equation can be extended further:

\[ f(v, w) = k(p + v^q)(w + A)^{2/3} \]  

with:

- \( k, p, q \): constant as such as \( k > 0, p \geq 0 \) and \( q \geq 3 \).
- \( v \): speed (knots)
- \( w \): weight (TEU or Ton)
- \( A \): lightweight ship

In the application of this formula, the variable \( k, p \) and \( q \) is known constant. Most researcher assumes \( p = 0 \) and \( q = 3 \). Furthermore, it is concluded that \( k \) equal to one over fuel coefficient, \( F_c \), that simplify the above formula [13]:

\[ f(v, w) = k(p + v^q)(w + A)^{2/3} \]  

where:

- \( W \): Ship’s Displacement (Tones or TEU)
- \( V \): Speed (knots)
- \( F_c \): Fuel Coefficient

The Fuel coefficient value is depending on the type of machine that the ship used [13]. The machine is separated into two common categories, Steam Turbine, and Diesel machinery. The \( F_c \) for both categories is as follow: Steam Turbine machinery: \( F_c = 110.000 \) approximately; and Diesel machinery installation: \( F_c = 120.000 \) approximately. Diesel installation is assumed for all the ships in this research.

Furthermore, this research is compared with three different arrangement of the main variable, speed and weight proportion, on the level of CO\(_2\) emission from the ship’s activity [13]. The first part is using the current data to calculate all necessary variables needed in the formula. The second part is using the optimize ship’s speed using slow steaming.

The next step is to calculate the optimal level of emission for the ships. ‘Slow-Steaming’ is one approach used to reduce emission. The nonlinear relationship between speed and fuel consumption can be exploited in order to achieve lower fuel consumption. The main reason, at first, to slow the ships is to reduce cost. Lower speed means lower fuel consumption. Hence, it reduces the operational cost of a ship. This activity is the result of fluctuation in fuel prices and the general economic downturn. In the same time, the interest of ‘slow steaming’ also become one of the main interested in the studies of the relationship between the ship’s fuel efficiency activity to the carbon emission its produce. There are benefits that come from the slow steaming operation of a container ship, mainly regarding the economic and environmental effect [14]. Another research produces a similar conclusion in the operation of the bulk container ship [15]. Moreover, there are a lot of studies that conclude that the ship’s speed has a massive effect on the consumption of fuel for that ship.

Most of these studies argue that the ship’s speed has a third-order function of the main engine power consumption. It is mean, if the ship is triple its speed, the engine consumed eight more times of fuel [16]. In the other hand, dropping the speed by 10% can decrease the fuel consumption by around 17% [17].

However, ‘slow-steaming’ has a disadvantage. The main concern of slow steaming is in the practice, especially regarding the ship operation in ECA (Emission Control Area) area for the Eurozone shipping activity [18]. The slow steaming inevitably increases the number of ships needed to deliver the same amount of load, which may increase the emissions. Moreover, the inventory cost also increasing as the effect of slow steaming. It is because slower speed may increase the amount of inventory stays on the ship due increase in transit time.
Nonetheless, slow steaming here to stay. The economic and environmental benefits of it may trigger more adoption of this activity to the foreseeable future.

3. Result
The data used in this research come from the Indonesian ministry of transportation. There are 3 routes out of 15 routes chose to do the emission study on the Indonesian Sea Tollway. These 3 routes are chosen because these routes have the most complete set of data compare to other routes. These routes also can be considered as the representation of the goal of the Indonesian Sea Tollway. It is because all the chosen routes are logistics routes from the eastern biggest hub (Tanjung Perak port) of Sea Tollway, which connected the western part of Indonesia, to the far east of the archipelago. The 2017 operational data of Indonesian Tollway are used. Total 3 different ships, one for each route, are considered. Those routes have different legs and distances.

3.1. Data
Three routes are picked for the emission study. These routes are Tanjung Perak–Namlea (route 1), Tanjung Perak–Waingapu (Route 3), and Tanjung Perak–Sebatik (route 8). As stated before, most of the data come from the Indonesian ministry of transportation. IMO’s online information system (GISIS) and websites like www.vesselfinder.com are used to complete the missing technical data of the ships. On route 1, a general cargo ship named KM. Nusantara Pelangi 101 is used. For 2017, this route has 15 voyages completed with 4 legs recorded on each journey. However, one voyage is omitted from this study due to the limited data on that journey. A general cargo ship, KM. Caraka Jaya (CJ) NIII-22, was used on route 3 which completed 9 voyages and has 14 legs on each journey. On this particular route, the valid data only available on 6 out of 9 journeys, which resulted in voyage 5 and voyage 6 being omitted by this research. The last route is using KM. EL NO.3, another general cargo ship, is utilized on route 8. This route has 15 completed journeys, on which each voyage has 6 legs. Each Route has different specifications. Table 1 below summarizes these keys specifications used on this research.

| Route | Ship          | Origin        | Destination | Distance (nm) | Leg | Avg Distance /leg (nm) | Voyages: Target (2017) | Voyages: Completed (2017) |
|-------|---------------|---------------|-------------|---------------|-----|------------------------|------------------------|--------------------------|
| 1     | KM. Nusantara Pelangi 101 | Tj.. perak   | Namlea      | 1980          | 4   | 495                    | 21                     | 15                       |
| 2     | KM. Caraka Jaya NII-22   | Tj.. Perak   | Waingapu    | 2150          | 14  | 154                    | 13                     | 9                        |
| 3     | KM. EL No. 3    | Tj.. Perak   | Sebatik     | 1195          | 6   | 199                    | 22                     | 14                       |

Furthermore, Table 2 below summarize the keys operational parameter used on the calculation of EEOI:
Adding together the lightweight of the ship is calculated. For each route on its every leg, the ‘real’ DWT are calculated to better reflect the cargo weight situation. The ‘real’ DWT is assumed to be constant. This variable is calculated using Eq. 4. Hence, the ship’s displacement coefficient of cargo ship (0.60 – 0.75) multiply by the DWT of the ship [13]. Furthermore, the lightweight of the ship is calculated. For each route on its every leg, the ‘real’ DWT and ‘real’ displacement are calculated to better reflect the cargo weight situation. The ‘real’ DWT is assumed by using the proportion of max total cargo and ship’s DWT. Adding together the lightweight and the ‘real’ DWT of the ship on each leg estimate the ‘real’ displacement.

Afterward, the theoretical ‘optimize’ EEOI is calculated. At the maximum, slowing the engine load by 10% is a feasible option to lower the emissions level of the ship [19]. Meanwhile, IMO suggest that the engine may slow down to 12% from the maximum speed to achieve the optimization of EEOI. Both values are applied on each route and compared.

### 4. Discussion

The calculation of this research can be used to simplify the estimation of emission level of the Sea Tollway corridors. The main usage may be on the early prediction process of CO₂ before more complex modelled and simulation is utilized. The effect of slow steaming on the emission level can be clearly seen. First, the effect of slow steaming on fuel consumption is discussed. The finding is somewhat consistent with [20]. Decreasing the speed to 10% of current speed is decreasing the Fuel Consumption of the ships around 17% to 19% yearly. Decreased it further to 12%, lowered the fuel consumption 4% more compared to 10% decreased on speed or around 23% from current yearly fuel consumption. These results are shown on the figure below.

---

**Table 2. Operational parameter.**

| Ship | DWT  | Capacity (Ton) | Max Speed (kn) | Displacement | DWT Coef. | Light-Weight | Engine Type | Fuel Coef. | CO₂ Coef. |
|------|------|----------------|----------------|--------------|-----------|-------------|-------------|------------|-----------|
| 1    | 4407 | 2380           | 11             | 6886         | 0.64      | 2479        | Diesel      | 120000     | 0.31      |
| 2    | 360  | 2916           | 11.9           | 5703         | 0.64      | 2053        | Diesel      | 120000     | 0.31      |
| 3    | 1200 | 400            | 9              | 1714         | 0.7       | 514         | Diesel      | 120000     | 0.31      |

---

**Figure 2. Fuel Consumption Route 1.**

**Figure 3. Fuel Consumption Route 3.**
Moreover, the EEOI calculation resulted in a similar pattern. For Route 1, the current CO₂ emission from the activity on the sea Tollway is 3.996 x 10⁻³ ton. CO₂ /tonnes.nm yearly. Route 3 and Route 8 yield CO₂ level around 9.392 x 10⁻³ ton. CO₂ /tonnes.nm and 3.74 x 10⁻³ ton. CO₂ /tonnes.nm, respectively each year. Applying slow steaming with 10% and 12% rate in each route resulted in decreasing rate of emission produces of around 19% and 23% respectively. It shows in the figures below.

**Figure 4.** Fuel Consumption Route 8.

**Figure 5.** EEOI comparison route 1.  
**Figure 6.** EEOI comparison route 3.

**Figure 7.** EEOI comparison route 8.
Furthermore, one probable disadvantage of slow steaming is on the time constraint for each journey. Based on table 1, every route has its own designated goal of voyages per year. This goal determined by the Indonesian government. The rate of slow steaming, which is 10% and 12% of current speed, produces around 11% to 14% more days in the sea for each route per year. Figure 8, 9 and 10 summarize the effect of slow steaming on days needed to complete journey per year and the average days per leg for each route.

![Figure 8](image1.png)  
**Figure 8.** Number of days per trip Route 1.

![Figure 9](image2.png)  
**Figure 9.** Number of days per trip Route 3.

![Figure 10](image3.png)  
**Figure 10.** Number of days per trip route 8.

Lastly, the economic effect of ‘slow-steaming’ is worth to investigate. At the current rate, for the year 2017, the yearly average fuel consumption/day on the aforementioned routes are 16.8 ton, 21.8 ton and 18.99 ton, for routes 1, 3 and 8 respectively. For the cost calculation, as an example, route 1 is chosen. For the year 2017, the bunker fuel cost is assumed at around $304/ton. Hence, the average fuel cost on route1/voyages is $5128/day. By applying slow steaming of 10% and 12% of the current speed on the voyage, the fuel consumption reduces into 13.67 ton and 13.07 ton successively. Thus, resulted in the fuel cost reduction of around $972/day and $1154.5/day. However, while it looks a quite significant reduction of fuel consumption by this calculation, the other factors of the fuel cost, such as electricity production during the voyage and porting, auxiliary engine performance, etc., need to be considered to have a full picture of the effect of slow steaming on fuel cost. The cost calculation in this research is much simplified. Nonetheless, it shows the potential of slow steaming as a cost saver for the ship's operator.
5. Conclusion, Limitation and Future Research

The main objective of this research is to draw a picture of the emission level and a method to reduce it in some of the sea tollway corridors. This emission study is using the operational data from the year of 2017. The route 1, 3 and 8 of that year are used to calculate the level of CO$_2$ produced in these corridors of sea tollway. Therefore, the Energy Efficient Operational Index (EEOI) is calculated to measure the emission level. The slow steaming method is applied as a way to estimate the optimum level of speed that reduces the level of fuel consumption, which is, in the end, helped to reduce the EEOI. From the number calculation, it is can be concluded that reducing the current speed to 10% and 12 % decreased the fuel consumption 19% and 23%. Thus, bring the level of CO$_2$ down to about 19% to 22% in each corridor. Furthermore, the slow steaming method also can be used to reduce the fuel cost of the ship. The main drawback of slow steaming is in the domain of the time constraint. The operator of the ships needs to decide whether the level of delays is acceptable or not based on their obligations to the shippers.

These results, however, are come from many limitations of this research. Firstly, the limitation comes from the quality of the data. The data is limited only on the operational year of 2017. Thus, it is the accuracy of generalization of the parameter in the calculation becomes limited. Moreover, the lack of any modelling of the parameter may decrease the calculation precisions. Lastly, this research is limited in scope. The 3 routes that are chosen may not representative of the larger dataset of the Sea Tollway.

Thus, further research is needed. The used of more dataset is advised to increase the accuracy of parameter generalization. Furthermore, the modelling that involved non-linearity, such as non-linear regression or Artificial Neural Network, may need to be utilized to model the unknown relationship between the parameter used in the calculation. Hence, increasing the precision of the calculation.

References

[1] Bappenas 2014 Tol Laut! (Jakarta: Ministry of Transportation)
[2] Pradana M F and Noche B 2019 Prospect and Challenges in Developing Indonesia Sea Tollway The 2nd Int. Conf. on Food Security Innovation
[3] Panagakos G 2016 The Policy Context Int. Series. In Ops. Res. & Mngmt. Sci. 1–39
[4] Harrould-Kolieb, E 2008 Shipping Impacts on Climate. Oceana.
[5] Buhaug Ø, Corbett J J, Endresen Ø, Eyring V, Faber J, Hanayama S, Lee D S, Lee D, Lindstad H, Markowska A Z, Mjelde A, Nelissen D, Nilsen J, Pålsson C, Winebrake J J, Wu W and Yoshida K 2009 Second IMO GHG Study 2009 (London: International Maritime Organization (IMO))
[6] Lindstad H, Asbjørnslett B E and Strømman A H 2011 Reductions in Greenhouse Gas Emissions and Cost by Shipping at Lower Speeds. Ener. Pol. 39(6) 3456–3464
[7] Smith T W P, Jalkanen J P, Anderson B A, Corbett J J, Faber J, Hanayama S, O’Keeffe E, Parker S, Johansson L, Aldous L, Raucci C, Traut M, Ettinger S, Nelissen D, Lee D S, Ng S, Agrawal A, Winebrake J J, Hoen M, Chesworth S and Pandey A 2015 Third IMO GHG Study 2014 (London: International Maritime Organization (IMO))
[8] Kontovas C A and Psaraftis H N 2016 Transportation Emissions: Some Basics. Int. S. in Op. Re. & Mngmt. Sci., 41–79.
[9] Psaraftis H N and Kontovas C A 2009 CO2 Emission Statistics for The World Commercial Fleet. WMU J. Maritime Affairs. 8(1), 1–25
[10] MEPC 2009 Guidelines for Voluntary Use of the Ship Energy Efficiency Operational Indicator (EEOI) (MEPC.1/Circ.684)
[11] MEPC Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from Ships, 1973, as Modified by the Protocol of 1978 Relating Thereto, Amendments to MARPOL Annex VI, MEPC, 70, 18.
[12] Psaraftis H N 2016 Green Maritime Transportation: Market Based Measures Int. S. in Op. Re. & Mngmt. Sci. 267–297
[13] Barras C B 2004 *Ship Design and Performance for Masters and Mates* (Elsevier)

[14] Notteboom T E and Vernimmen B 2009 The effect of high fuel costs on liner service configuration in container shipping *J. Transport Geography*. 17(5), 325–337

[15] Corbett J J, Wang H and Winebrake J J 2009 The effectiveness and costs of speed reductions on emissions from international shipping, *Trans. Re. P. D: Trans. and Env*. 14(8), 593–598

[16] Ronen D 1982 The Effect of Oil Price on the Optimal Speed of Ships. *J. Op. Re. Soc.* 33(11), 1035.

[17] Faber J, Nelissen D, Hon G, Wang H and Tsimplis M 2012 Regulated Slow Steaming in Maritime Transport: An Assessment of Options, Costs and Benefits. *CE Delft*.

[18] Psaraftis H N and Kontovas C A 2016 Green Maritime Transportation: Speed and Route Optimization *Int. S. in Op. Re. & Mngmt. Sci.* 299–349.