Fuel Oil Consumption Monitoring and Predicting Gas Emission Based on Ship Performance using Automatic Identification System (AISITS) Data

A T A Wijaya¹, I M Ariana¹, D W Handani¹ and H N Abdillah¹

¹Department of Marine Engineering, Faculty of Marine Technology, ITS Surabaya, East Java, Indonesia
E-mail: adam.wijaya12@gmail.com

Abstract. The increasing number of ships has an impact on increasing the amount of fuel consumption and exhaust emissions produced by ships when operating. Analysis of IEA and ICCT shows the amount of emissions and consumption in 2007 to 2015 relatively increased. Ship exhaust emissions become one of the main sources of pollution of the marine environment. Pollutants originating from emissions of ships that have high CO, NOx, HC, SO₂ and CO₂, even sulphur pollutants can cause the risk of disruption of the human health system. Therefore monitoring technology is used by the user or operator to ensure that the ship operates efficiently. An integrated monitoring system is expected to report information such as fuel consumption, emissions and EEOI generated by the ship. The algorithm developed in this study uses the empirical formulation of the Holtrop Method (for basic resistance calculations) and the Stawave Method (for calculation of wind resistance, waves, draft changes and water properties) written in the PHP script programming. This programming is the basis of development at the interface of a program to bring up fuel monitoring data, EEOI and emissions in real time on each ship.

1. Introduction
Efficiency of ship operation can reduce the operating costs and increasing the advantages. Stakeholders in maritime industry such as ship operators, government and administrator, this can furthermore be confirmed increasing the financial sectors, such as Fuel Oil Consumption (FOC) for the operating cost. Accordingly, Ronen in his research, fuel cost correspond to approximately 75% of the total operating cost. For this reason shipping company focus on monitoring fuel efficiency to decrease operational cost of a ship’s voyage [1]. This research focus to predict the ship performance under varying ship operational environmental conditions, the method could help ship’s owner to monitor performance of the ship.

The increasing number of vessels impacts on increasing the amount of fuel oil consumption and exhaust emissions produced by vessels. The data in Figure 1 shows the amount of emissions and fuel oil consumption in 2007 to 2015 relatively increased according to the IEA and ICCT assessments. Total fuel consumption increased from 291 million tons to 298 million tons (+ 2.4%) in the last 3 years from 2013 to 2015 [2].
Figure 1. Predicting Total Fuel Oil Consumption from IEA, IMO and ICCT [2]

Table 1. shows that total CO$_2$ shipping emissions increased from 910 million tons to 932 million tons (+ 2.4%) in the last 3 years, from 2013 to 2015. International shipping emissions increased by 1.4%; domestic shipping emissions increased by 6.8%; and fisheries emissions increased by 17%. In 2015, total shipping emissions were responsible for 2.6% of global CO$_2$ emissions which produced by fossil fuels and industrial processes. International shipping representing around 87% of total CO$_2$ emissions from ships each year [2].

Exhaust gas emissions became a serious threat to the people who live around the coastal area. Pollutants from ship emissions that contain high SO$_2$ content and other pollutants [3]. Ship emissions become one of the main fountain of pollution in the marine environment. Sulfur content will increase the risk of human health. The quality of the atmosphere is correlated with human health, this significantly impacts the health risks along areas that have heavy ship traffic [4].

At the same condition, there are new regulations about environmental that implemented throughout the world. Every ship entering the emission control area (ECA) has to contain low sulfur by fuel emissions produced, but starting in 2020, the International Maritime Organization (IMO) will apply to all ships to use low sulfur fuels. This regulation to reduce air pollution by emissions generated by ships when operating [5]. Monitoring technology is used by ship owners to ensure that the ship operates efficiently. However, most ships do not have a monitoring system. On these ships, the only performance information can be manually taped on the report, recording key information once a day such as ship’s location, service speed, weather conditions on the ship’s voyage, and fuel oil consumption.

Table 1. Comparison of Shipping CO$_2$ Emissions vs Global CO$_2$ Emissions [2]

| Item               | Third IMO GHG Study (Million Tonnes) | ICCT (Million Tonnes) |
|--------------------|--------------------------------------|-----------------------|
|                    | 2007  | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  |
| Global CO2 Emissions | 31.95 | 32.13 | 31.82 | 33.66 | 34.72 | 34.96 | 35.67 | 36.08 | 36.06 |
| International Shipping | 881   | 916   | 858   | 773   | 853   | 805   | 801   | 813   | 812   |
| Domestic Shipping  | 133   | 139   | 75    | 83    | 110   | 87    | 73    | 78    | 78    |
| Fishing            | 86    | 80    | 44    | 58    | 58    | 51    | 36    | 39    | 42    |
| Total Shipping     | 1,100 | 1,135 | 977   | 914   | 1,021 | 942   | 910   | 930   | 932   |
| % of Global        | 3.50% | 3.50% | 3.10% | 2.70% | 2.90% | 2.60% | 2.50% | 2.60% | 2.60% |
Vessel with large capacity and all passenger vessels are required to be equipped with an Automatic Identification System (AIS). The AIS system automatically declares main information including position of the ships, service speed and other data. AIS data is automatically transmitted from the ship every 30 seconds or 3 minutes, depending on the current ship speed. This study aims to study various ways of AIS data in high frequency which can then be applied in monitoring techniques to improve ship performance analysis, by developing a monitoring analysis model. International economic integration provides considerable opportunities for developing countries to achieve better economic sector through international trade and investment channels.

In this research, there are two approaches focusing on resistance calculation by Holtrop method and added resistance calculation by STAWAVE method. Holtrop method calculate the basic resistance such as wind resistance, hull resistance, friction resistance, and the others. This method is not calculate the effect of environmental changes, so the added resistance such as wind resistance, waves, draft changes and water properties calculate by STAWAVE method. The purpose of this study is to examine the fuel oil consumption algorithms of ship during operation. Several multiple regression algorithms of ship fuel oil consumption forecasting under data sampling. The problem of estimating fuel oil consumption dependent on the input parameters such as weather condition, speed and vessel load. voyage of the ship from Surabaya to Jakarta and Jakarta to Surabaya. It is expected that the methodology developed in this study will be used to make the optimal models to ship fuel oil consumption reduction. This concept help vessel to tracking the performance, shipping operations, estimation of ship emissions and eventually be used as a basis data for route optimisation purposes.

2. Literature Review
This parts shows an overview of literature review. The methodology which relevant to fuel efficiency and FOC modelling are analysed. Report of statistic data based on Roll-on/Roll-off vessel (Ro-Ro) in order to identify the influence of factors such as ship’s draft, displacement, weather velocity and direction, and hull and propeller roughness performed by Bialystocki [6]. The corrections recommended are applied to the obtained data along with relevant filtering, curves for each frequently-observed sea state are fitted. This provides a simple algorithm that approximates FOC. A semi-empirical method has been developed for the prediction of operational performance of ships [7]. This system is based on modelling water and added resistance components. Through that, the ship’s operational performance is modelled, taking into consideration the weather and relevant sea state. This model is then employed to optimise the ship’s route.

Automatic Identification System (AIS) is technology that applicable on Very High Frequency (VHF) radio waves which enable various ship information such as name of the ship, position during ship’s tracking, ship’s type, service speed, type of cargo, destination etc. Automatically exchanged between ships in real time, since being introduced to various shipping industry sectors, the important that AIS as a security, marine search and rescue and environmental protection at sea and onshore. Network of coastal-based AIS stations to capture ship information that is transmitted from AIS equipment on a ship to track and monitor vessels close to the shore, vessel monitoring services for maritime authorities has been applied in many countries [8].

AIS can recognize vessels of more than 300 GT on international travel and ships of more than 500 GT on domestic routes. Static and dynamic data from both types of ships can be obtained. Dynamic information is updated every 2 to 10 seconds depending on the speed of the ship. Static information consists of MMSI (Maritime Mobile Service Identify), IMO number, ship name, call sign, length and beam, type of ship, location of position-fixing antenna on the ship. Dynamic information consists of Coordinated Universal Time (UTC), Course Over Ground (COG), Speed Over Ground (SOG), Heading, Navigation Status. The AIS data used in this study are MMSI number, latitude and longitude, IMO number [9].

3. Methodology
This part shows information about the ship’s parameters of resistance and propulsion. Additional resistance or added resistance using the STAWAVE method, in this method the calculation of changes in
additional resistance to the wave resistance, wind resistance, resistance due to changes in draft / draft and water resistance. This additional resistance value is caused by environmental factors.

The amount of additional resistance depends on ship information, such as length, breadth, and speed, as well as wave parameters, such as significant wave heights, wave periods, and wave directions. Therefore, the magnitude of the added wave resistance will change constantly over the life of the ship. To be able to compare the performance of vessels over time, additional resistance due to waves must be removed from total resistance, depending on the wave conditions experienced at each specific location and time.

\[
R_{AWL} = 2 \int_{0}^{\infty} \frac{R_{\text{wave}}(\omega;STW)}{\zeta^2} S_n(\omega)d\omega
\]

where:
- \(R_{AWL}\): the average resistance of irregular waves in Newton
- \(R_{\text{wave}}\): the average resistance to regular waves in Newton
- \(\zeta\): amplitude of wave in meters
- \(\omega\): circular frequency in rad/s
- \(STW\): ship speed in m/s
- \(S_n\): wave frequency spectrum in m²/s

There is additional resistance due to wind, where the wind flows from backwards the ship, additional resistance can be negative, reducing the total resistance of the ship. Additional wave resistance, additional wind resistance will also continue to transfer, and must be removed from the total resistance experienced at any particular location of the ship and time in order to be able to compare the performance of vessels over time.

\[
R_{\text{wind}} = \frac{1}{2} \rho_{\text{air}} V_{\text{air}}^2 C_x A_F
\]

where:
- \(R_{\text{wind}}\): wind force (Newton)
- \(\rho_{\text{air}}\): density of air at temperatures (kg/m³)
- \(V_{\text{air}}\): wind speed (m/s)
- \(C_x\): wind coefficient for relative wind direction
- \(A_F\): surface area (m²)

The hull resistance changes depending on the loading conditions of the ship. A ship with a larger draft will have greater wave resistance, because the ship must move more water and produce different waves when traveling at forward speeds, as well as greater friction resistance due to a larger hull surface area. The draft operation of the ship is expected to change regularly throughout the life of the ship.

\[
R_{\text{DIS}} = 0.65 R_T (\frac{\Delta_0}{\Delta} - 1)
\]

where:
- \(R_{\text{DIS}}\): additional resistance due to a draft increase in Newton
- \(R_T\): total resistance in design conditions at Newton
- \(\Delta_0\): displacement in design conditions
- \(\Delta\): displacement under analyzed condition

The ship’s resistance depends on the properties of the water in the environment. Hull resistance is equal to the density and viscosity of water. Higher density water and higher viscosity will increase the ship’s resistance. The density and viscosity of seawater depends on the temperature and salinity of the water, which varies depending on the location and time. In order to be able to accurately compare the performance of vessels on various trips, resistance correction must be applied to adjust resistance to normalized water conditions.
\[ R_{AS} = R_T (1 - \frac{P_w}{P_{w0}}) - R_F (1 - \frac{C_f}{C_{f0}}) \]

where:
- \( R_{AS} \): correction of resistance due to changes in the nature of water in Newton
- \( R_T \): total resistance
- \( R_F \): friction resistance in water conditions in Newton
- \( C_{f0} \): coefficient of friction resistance in standard water conditions
- \( C_f \): coefficient of friction resistance in water conditions
- \( P_w \): water density under water conditions in kg/m³
- \( P_{w0} \): water density under standard water conditions in kg/m³

The correction of resistance during each reporting period can be calculated (correction of the distance in each voyage during AIS period) from the total effective work performed by the ship, and then dividing it by the total voyage.

\[ R_{corrected} = \frac{W_E - \sum_{i=1}^{n} R_{AWL} \cdot di - \sum_{i=1}^{n} R_{wind} \cdot di - \sum_{i=1}^{n} R_{ADIS} \cdot di - \sum_{i=1}^{n} R_{AS} \cdot di}{\sum_{i=1}^{n} di} \]

where:
- \( R_{corrected} \): average corrected resistance during the reporting period in Newton
- \( W_E \): effective power carried out by the ship
- \( R_{AWL} \): correction due to wave resistance
- \( R_{wind} \): correction of resistance due to wind
- \( R_{ADIS} \): correction of draft resistance
- \( R_{AS} \): correction of resistance due to the nature of water

Power pass to the propeller can be counted based on the total resistance and other ship parameters. Because the ship’s speed changes several times per day, speed through water and efficiency are taken as averages during the daytime reporting period, as shown in the equation.

\[ P_{D_{Corrective}} = \frac{R_{Corrective} \cdot \sum_{i=1}^{n} STW_i \cdot di}{\sum_{i=1}^{n} \eta_o \cdot \eta_H \cdot \eta_{RR} \cdot \eta_i \cdot di} \]

where:
- \( P_{D_{Corrective}} \): delivery power during a period in Watt
- \( R_{Corrective} \): corrected resistance in Newton
- \( STW_i \): ship speed from AIS data in m/s
- \( \eta_o \): gastric efficiency for each AIS period
- \( \eta_H \): efficiency (open water) propeller for each AIS period
- \( \eta_{RR} \): relative rotation efficiency for each AIS period

Daily fuel oil consumption is directly equal to the power delivered by the ship. This is calculated as shown in the equation.

\[ M_{fc} = \frac{P_{D_{Corrective}} \cdot SFOC_{ME} \cdot 24}{\eta_{trans} \cdot 1000 \cdot 1000} \]

where:
- \( M_{fc} \): mass of fuel burned in tons/day
- \( P_{D_{Corrective}} \): delivered power in Watts
- \( SFOC_{ME} \): main engine specific fuel consumption in kg/kWh
- \( \eta_{trans} \): transmission efficiency
In calculating emissions the method used is based on the characteristics of the ship, such as operating mode, engine power capacity, operating time of the ship from which the data is obtained from AIS data. Mathematical estimates of emissions estimates can be seen in the equation below [10]:

\[ E = P \times F_L \times T \times EF \]

where:
- \( P \): engine power (ME, AE and AB)
- \( F_L \): fraction load of engine
- \( Q \): engine operating time
- \( EF \): engine emission factors (ME, AE and AB)

The Energy Efficiency Operational Index is defined as the ratio of the mass of CO\(_2\) released per unit of transportation. EEOI is a representative value of the energy efficiency of ship operations over a consistent period. Various units for the period in which the EEOI is calculated can be used by calculating the operating patterns of each ship operational, such as daily units, weekly units, monthly units, shipping units from port to port, shipping units to destinations, etc. For periods where EEOI is counted, shipping in both ballast and shipping conditions not intended for cargo transportation, for example shipping for docking must be included.

EEOI determines the number of tons of CO\(_2\) emissions per tonne of nautical miles calculated using actual operational data (fuel consumption, mass of cargo carried, and sailing distance) and the actual energy efficiency of the vessel achieved during operation. EEOI is calculated as follows:

\[ EEOI = \frac{\text{Fuel mass conversion factor to } CO_2 \times \text{Fuel oil consumption}}{\text{actual cargo} \times \text{actual distance}} \]

EEOI calculations for each cruise is calculated by using the following equation:

\[ EEOI = \sum_j FC_j x CF_j / (m_{cargo}) \]

To calculate the average EEOI in the calculation period including several shipping:

\[ EEOI_{avrr.} = \frac{\sum_i \sum_j (FC_j x CF_j)}{\sum_i (m_{cargo} x D_i)} \]

where:
- \( j \): type of fuel oil
- \( i \): number of shipping
- \( FC_{ij} \): mass of fuel oil consumption \( j \) / voyage
- \( CF_j \): conversion factor of CO\(_2\) for fuel \( j \) / voyage
- \( m_{cargo} \): cargo (tons) or number of TEUs or gross tonnes for passenger ships
- \( D \): distance in nautical miles

4. Results and Discussion

This study develops an internet-based fuel monitoring system using the example of a ship operated by a shipping company agency. Data collect from the KM ship. Dorolonda from Surabaya - Jakarta and vice versa Jakarta - Surabaya on the 9 and 12 October 2019. Data collection by sailing is needed to obtain a record of fuel consumption, geographical location of sailing vessel routes and collect data needed to calculate the fuel oil consumption, emissions produced, and EEOI. The main data ship KM. The Dorolonda used as a model or example is shown in Table 2.
Table 2. Principle Dimension of The Ship

| Item               | Information         |
|--------------------|---------------------|
| Name               | KM. Doro Londa      |
| Type               | Passenger Ship      |
| MMSI               | 525005046           |
| LOA                | 146.5 m             |
| Draft              | 5.90 m              |
| Breadth            | 23.4 m              |
| Displacement       | 10534.7             |
| Vt Design          | 23.67               |
| Gross Tonnage      | 14,685              |
| Netto Tonnage      | 4,629               |
| Death Weight Tonnage| 3,175               |
| Main Engine        | 2 Krupp MAK 8M 601 C|
| Aux. Engine        | Daihatsu 6 DL - 24  |

Results of shipping routes and geographical location by KM. Doro Londa was recorded based on the position of latitude and longitude. The position of latitude and longitude were plotted on the google earth application to determine the geographical location of the KM. Doro Londa, the route of the geographical location can be seen in Figure 2. Data of fuel oil consumption KM. Doro Londa was recapitulated every hour and supported by latitude & longitude position data to determine the geographical location traversed by the ship. Shipping environmental conditions are also considered. The data shows that fuel consumption is different from the point to point record because there are changes in wind direction, wind speed, current direction, current speed, wave direction and height of waves that move dynamically.

![Figure 2. Route of KM. Doro Londa (Surabaya-Jakarta)](image_url)

Additional resistance of KM. Doro Londa which operates from Surabaya-Jakarta has different data from one location point to another, although there is the same speed as the speed of 17.3 knots; 18 knots; 18.2 knots and 18.3 knots. At two location points there is a negative wind resistance value at 17.9 knots; 18 knots; and 18.2 knots, this is because the wind direction is parallel to the speed of the ship so that the wind direction and speed factors push the ship in the direction of the ship's movement.
The results of the resistance calculation using the Holtrop method are then added to the calculation of additional resistance by the STAWAVE method so that the total resistance obtained is resistance with accurate environmental conditions with 25 different location points as in Figure 3. Differences in total resistance when the Surabaya-Jakarta route and Jakarta-Surabaya occurs because of different environmental conditions so that the total prisoners that must be resisted by ships also experience differences.

The next step is calculating of fuel oil consumption, where the data needed is operational data and technical data of the ship including the specifications of the main engine and auxiliary engines, fuel consumption, and the main data of the ship. This process also calculate the power (Horse Power) required by the ship when maneuvering in terms of maintaining speed (Vs) that are affected by environmental conditions when the ship is sailing. Calculate fuel requirements according to variations in speed. There are several variations of the same speed but require different power this is due to resistance due to different environments.

The pattern of power calculation results (BHP) that correlates with variations in 25 ship speeds and ship resistance at 25 different location points can be seen in Figure 3 and Figure 4. The difference in total resistance when the Surabaya-Jakarta and Jakarta-Surabaya routes occur because the existence of different environmental conditions so that the power (BHP) required by the ship also differences. The graphic pattern in the power calculation (BHP) is equal to the resistance chart pattern because the resistance value is a multiplier factor in determining the power needed for the ship to operate.

The flow of fuel oil consumption (M/E) in every minute fluctuating because of changes in speed and changes in environmental conditions. Additional resistance conditions are greatly influenced by the
magnitude of the resistance value such as flow and direction of the wind and waves. The value of flow rate is important to be monitored periodically because it can be used as a reference for the user or operator of the ship to monitor the number of total fuel oil consumption (M/E) operational required to take a certain operating route. Data flow rate consumption of fuel oil consumption (M/E) KM. Doro Londa with the Jakarta-Surabaya and Surabaya-Jakarta routes can be seen in Figure 5.

Figure 5. Graph of fuel oil consumption (M/E) flow rate KM. Doro Londa

Algorithm of emission calculation using AIS data by considering the actual shipping conditions based on empirical formulation approach, the steps to do the formulation of the algorithm include transforming the formula into MatLab, then converted into PHP script programming language, the results of the MatLab formulation transformation can be fully seen in the attachment. The basis of the formula used is based on the development of calculation of estimated emissions on ships affected by fuel consumption, emission multiplier factors in each type of pollutant.

Twenty-five operating modes are used in relation to shipping times in certain modes. In addition the emission factor is the influence of the total amount of energy consumption produced by the engine with the exhaust gas (CO, NOx, HC, SO2 and CO2). Emission factors are also based on the type of ship (ocean going vessel, coastal vessel, river vessel), engine type (medium and slow speed diesel engine), and the type of fuel used (residual fuel, marine diesel oil, general diesel oil). Based on the empirical formulation and related calculation factors, the emission value of KM is obtained. Doro Londa Jakarta-Surabaya route as shown in Table 3.

| No. | Vs  | CO  | NOx | HC  | SO2 | CO2 |
|-----|-----|-----|-----|-----|-----|-----|
| 1   | 0.0 | 0.00| 0.00| 0.00| 0.00| 0.00|
| 2   | 12.7| 0.018| 0.004| 0.011| 0.008| 1.288|
| 3   | 15.9| 0.151| 0.038| 0.090| 0.066| 10.958|
| 4   | 16.3| 0.183| 0.046| 0.109| 0.080| 13.218|
| 5   | 16.8| 0.207| 0.052| 0.124| 0.090| 15.004|
| 6   | 16.9| 0.203| 0.051| 0.121| 0.088| 14.671|
| 7   | 16.7| 0.212| 0.054| 0.126| 0.092| 15.325|
| 8   | 17.1| 0.271| 0.068| 0.162| 0.118| 19.615|
| 9   | 17.2| 0.271| 0.068| 0.162| 0.118| 19.615|
| 10  | 17.4| 0.283| 0.071| 0.169| 0.123| 20.468|
| 11  | 17.4| 0.199| 0.050| 0.119| 0.087| 14.378|
| 12  | 17.4| 0.203| 0.051| 0.121| 0.088| 14.668|
Calculating the Efficiency Index (EEOI) based on AISITS data in an empirical formula to be applied to the AISITS application so that the results of this study can be displayed and make it easier for users to make decisions. Based on the empirical formulation and related calculation factors, the EEOI KM value is obtained. The Doro Londa route Surabaya-Jakarta is worth 0.001210827 (t- (CO2 / t) -NM) while the Jakarta-Surabaya route has an EEOI index value of 0.000609429 (t- (CO2 / t) -NM), the difference in the value of EEOI due to the load when departing is different from the boat load when returning to the port of Tanjung Perak.

5. Conclusion
The results of empirical calculations compared to M/E measurements of fuel consumption actually have a difference of 14.2% for the Surabaya-Jakarta route and 16.9% for the Jakarta-Surabaya route. With a constant value of 0.857 the results of empirical fuel calculations have an approach of 0.11% for the Surabaya-Jakarta route, while 2.9% for the Jakarta-Surabaya route. This difference in value is caused by the factors of engine lifetime conditions, fluctuating conditions of load (load) and the conditions of using SFOC that adjusts to engine performance. Based on the results of empirical calculations, the value of EEOI KM. Doro Londa Surabaya-Jakarta route is worth 0.001210827 (t- (CO2 / t) -NM) while the Jakarta-Surabaya route has an EEOI index value of 0.000609429 (t- (CO2 / t) -NM). Emission values on the Surabaya-Jakarta route have values (kg / trip) (CO 4,117; NOx 1,041; HC 2,461; SO2 1,798; CO2 298,158) while emissions values (kg / trip) on the Jakarta-Surabaya route (CO 4,373; NOx 1,106; HC 2,613; SO2 1,910; CO2 316,635).

References

[1] D. Ronen, "The Effect of Oil Price on Containership Speed and Fleet Size," J. Oper. Res. Soc., vol. 62 (1), pp. 211-216, 2011.
[2] N. Olmer, Greenhouse Gas Emissions from Global Shipping, Beijing: ICCT, 2015.
[3] K. Simon, "Police Change Driven by an AIS-assisted Marine Emission Inventory in Hong Kong and the Pearl River Delta," Journal of Atmospheric Environment, vol. 76, pp. 102-112, 2013.
[4] A. Hedley, "Cardiorespiratory & All Cause Mortality after Restrictions on Sulphur Content of Fuel in Hongkong an Interv.," vol. 360, pp. 1646-1652, 2002.
[5] S. G. Platts, "The IMO's 2020 Global Sulfur Cap," IMO, 2016.
[6] N. Bialystocki and D. Konovessis, "On the estimation of ship’s fuel consumption," *Journal of Ocean Engineering Science*, vol. 1 (2), pp. 157-166, 2016.

[7] R. Lu, O. Turan, E. Boulougouris, C. Banks and A. Inececik, "A Semi-empirical Ship Operational Performance Prediction Model for Voyage Optimization towards Energy Efficient Shipping," *oCEAN eNGINEERING*, vol. 110, pp. 18-28, 2015.

[8] Y. Chen, "Satellite Based AIS and Its Comparison with LRT," *The International Journal*, vol. 8, pp. 183-191, 2014.

[9] B. Sitorus, T. I. H. Sitorus and P. Wicardiantoro, "Evaluation of Management of Information Systems and Port Information Technology," *Journal of Transportation Management and Logistic*, 2016.

[10] D. W. Handani, I. M. Ariana, T. F. Nugroho and F. Indrayuni, "AIS Based Spatial Distribution of Ship Emission in Madura Strait Indonesia," *Journal of JIME*, vol. 53, pp. 113-118, 2018.