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Fuel Oil Consumption and Carbon Intensity Indicator (CII) Monitoring of Container Ship Using Automatic Identification System (AIS) Data

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***Abstract*—**The IMO has introduced the Carbon Intensity Indicator (CII) to reduce carbon emissions, and it will be mandatory for ships sailing internationally from 1 January 2023. Implementing CII should be a top priority for reducing greenhouse gas emissions from ships sailing in Indonesia's territorial waters, the world's largest maritime country. This study aims to determine the constant in the empirical formula for monitoring fuel consumption and CII implementation using Automatic Identification System (AIS) data from MV. Meratus Padang. The Holtrop method is used to calculate the ship's basic resistance, and the STAWAVE method is then applied to account for environmental conditions during sailing to obtain more accurate results under actual conditions. The total resistance of the Holtrop and STAWAVE methods can be used to calculate the power supplied to the propeller. Furthermore, the propeller's power can be used to calculate fuel consumption. The fuel consumption calculation showed differences of 0.41% on the Surabaya-Banjarmasin route and -0.35% on the Banjarmasin-Surabaya route, with a propeller efficiency of 0.5 with an engine degradation of 9.5%, as the average CII is "E".

Keywords: Monitoring, Fuel Consumption, CII, Holtrop method, STAWAVE method

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I. Introduction

Ships are a means of transportation considered very effective and efficient in moving goods or humans, which are vital in supporting the global economy [1]. Container ships are one example of ships that are the top choice in the transfer of goods, representing 20% of the world's trade [2]; this container-type ship also has a fixed shipping route to serve the transportation of goods transported until a specific time [3]. With constant speed in shipping at sea, this container ship is still considered more effective than other types of ship designs [4]. MV Meratus Padang is one example of a container-type ship owned by PT. Meratus Line operates in Indonesian waters and has a Surabaya-Banjarmasin shipping route, built in 2008. In operation, it is like MV. Meratus Padang can pay attention to the greenhouse gases (GHG) effects caused by SOx, NOx, and CO_2 from conventional fuel combustion [5].

GHG is a maritime industry issue that requires a solution, as a study covering 2012 to 2018 found that GHG emissions increased by 9.6% [6]. Operational optimisation of MV. Meratus Padang, fuel consumption must undoubtedly be an essential concern, as reduced fuel consumption will reduce GHG emissions [7][8]. The use of other energy sources, such as methanol, ammonia, and hydrogen, as energy sources that reduce greenhouse gas emissions [9] and replace conventional fuels can undoubtedly be an alternative for all ships in the future that cannot be applied to the MV. Meratus Padang. The International Maritime Organization (IMO), an agency of the United Nations (UN), has implemented MARPOL Annex VI to reduce CO2 emissions through the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) since January 1, 2013 [10]. The IMO published new guidelines in 2018 to reduce CO2 emissions per global transport task by at least 40% by 2030, aiming for 70% by 2050, and to reduce total GHG emissions by at least 50% by 2050 compared to 2008 levels [11].

CII, an obligation for international ships, has not been fully implemented by ships that sail only in Indonesia's territorial waters, the largest maritime country, to reduce GHG emissions. MV. Meratus Padang, with a gross tonnage of 5745 and built in 2008, can undoubtedly adopt the IMO CII framework to monitor fuel consumption and reduce GHG emissions. In this research, the authors will focus on developing an empirical formula for monitoring fuel consumption based on actual fuel consumption on board and on calculating CII to monitor CO_2 emissions. To calculate the value of the ship's basic resistance using the Holtrop Method, primary ship data is needed, such as ship type, Length of Water Line (LWL), Breadth at the Water line (BWL), General Arrangement of the ship, and additional data such as ship speed, ship draft, and ship mileage. Furthermore, resistance and power can be used to

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estimate fuel consumption. This fuel consumption can change; this is influenced by several environmental factors, such as wind speed, wave direction, high waves, etc., which move dynamically [12]. This environmental factor can be calculated using the STAWAVE method to improve accuracy under actual sailing conditions. Changes in environmental factors can affect the ship's detention, depending on its position while sailing, which can be monitored from Automatic Identification System (AIS) data.

A. Carbon Intensity Indicator (CII)

Climate change, which continues to be a global concern, makes the maritime industry a crucial topic in efforts to address greenhouse gas emissions [13]. Thus, to improve energy efficiency standards, IMO, through the Marine Environment Protection Committee (MEPC-76), launched the Existing Ship Energy Efficiency Index (EEXI) for existing ship designs and the Carbon Intensity Indicator (CII) in June 2021 as an obligatory provision for carbon emission reduction targets [14][15].

The CII is a rating system developed by the IMO as a mandatory measure under Annex VI of MARPOL for all international trade ships of 5000 tonnage or more, effective from January 2023, with the first ratings to be issued in 2024. These ratings are assigned on a scale of A, B, C, D, and E, with A (major superior), B (minor superior), C (moderate), D (less superior), or E (poor performance level) [16]. Ships rated D for three years or E for one year must update their Ship Energy Efficiency Management Plan (SEEMP Pt. III - Ship Operational Carbon Intensity Plan) as a corrective action before the issuance of the Statement of Compliance (SoC), with the deadline for issuing the SoC remaining the same, namely 31 March each year [17].

TABLE 1.
CII (G1) CALCULATIONS GUIDELINES [18].

The type of ship for which CII is calculated	Calculation Method
Bulk carriers	
Tankers	
Container ships	
LNG carriers	
Ro-ro cargo ships	$\frac{CO_2\ Emission}{DWT\ \times Distance}$
General cargo ships	
Refrigerated cargo carriers	
Combination carriers	
cruise passenger ships	
Ro-ro cargo ships (vehicle carriers)	$\frac{CO_2\ Emission}{GT\ \times Distance}$
Ro-ro passenger ships	

B. Automatic Identification System (AIS)

The Automatic Identification System (AIS) is an automatic tracking device that uses very high frequency (VHF) technology and has been used for shipping safety since the introduction of RADAR. The use of AIS and RADAR as electronic systems on ships capable of transmitting static and dynamic data is expected to increase the maritime awareness of ship operators [19]. Until now, AIS has still been considered one of the best tools for receiving and transmitting data from ship to ship and with shore-based facilities, because it can overcome the lack of ship position data [20]. By monitoring ship position data via AIS, ship operators can navigate safely amid limited-visibility weather conditions, thereby minimizing ship accidents. In recent years, there have been many research trends in the use of AIS, focusing on ship accidents, ship speed control, navigation safety, ship travel routes, and even real-time monitoring of areas to maintain security [21][22][23][24][25][26][27].

Figure 1. AIS of MV. Meratus Padang

The existing AIS system is generally divided into AIS Class A and B. However, an AIS that complies with IMO standards is an AIS Class A [28], namely AIS that uses an access scheme. Its communication uses the SO-TDMA (Self Organized Time Division Multiple Access) system, which is used for ships of 300 GT and above. In contrast, AIS Class B uses the CS-TDMA (Carrier Sense - Time Division Multiple Access) system, which is used for ships that do not comply with IMO standards. In this study, the authors use AIS MV Meratus Padang data to monitor fuel consumption and Carbon Intensity Indicators.

II. METHOD

A. Calculation of Resistance Using the Holtrop Method

Ship resistance is the fluid force towards the rear that works against the ship's movement towards the front due to the thrust obtained from the Main Engine. Furthermore, this resistance is known as the ship's elemental resistance and can be calculated using the Holtrop Method. Resistance using the Holtrop Method is a calculation of Total Resistance (RT) from Friction Resistance (R_F), Additional Resistance (R_{APP}), Wave Resistance (R_W), Bulbous Bow Resistance (R_B), Resistance from Transom (R_{TR}), and Model-Ship Correlation Resistance (R_A). Based on the calculation of total resistance using the Holtrop method, corrections for the roughness resistance of the ship's hull will be applied, taking into account uneven surfaces due to the natural attachment of organisms (biofouling). Biofouling, which colonises the hull surface, requires scheduled maintenance because it increases fuel consumption [29]; hull roughness resistance can be calculated using the formula RΔf.

1) Calculation of Friction Resistance (RF)

Frictional resistance is the resistance that arises when a ship moves through a fluid with viscosity, such as seawater; it causes friction along the hull's surface as it passes through the medium. To calculate the value of this frictional resistance, several coefficients are needed as follows:

$$R_F = (1+k) . Cf . 0{,}5 . \rho . S . V^2$$
(1)

2) Calculation of Additional Prisoners (RAPP)

This resistance includes the resistance to the ship model correlation. This is due to the influence of the ship's surface roughness, bearing in mind that the hull surface will never be as smooth as the model's surface. These additional prisoners can also include those outside the hull, such as the rudder, bilge keel, stabilizer, etc. Using the Holtrop Method, this additional resistance is calculated using the following formula:

$$R_{APP} = 0{,}5 . \rho . V^2 . Cf . S_{APP} . (1+k_2)_{eq}$$
(2)

3) Calculation of Wave Resistance (Rw)

Wave resistance is an obstacle caused by a ship's movement through seawater, whether the water is calm or wavy. In calculating the ship's wave resistance using the Holtrop method, it can be formulated as follows:

$$R_w = C1.C2.C5.\nabla.\rho.\text{g}.exp(m_1 . Fn^d + m_2 . \cos(\lambda.Fn^{-2})) \quad (3)$$

4) Calculation of Resistance of the Bulbous Bow (RB)

In calculating the additional resistance of the Bulbous Bow with the Holtrop Method, several calculation parameters must be considered according to the formula for the additional resistance of the Ship according to Holtrop, with the following formula:

$$\text{R}_\text{B} = \frac{0{,}11\exp(-3P_B{}^{-2})\, F_{ni}{}^3 . A_{BT}{}^{1{,}5} . \rho . g}{(1+F_{ni}{}^2)}$$
(4)

5) Calculation of the Transom Resistance (RTR)

In calculating the additional resistance of the transom with the Holtrop method, several calculation parameters must be considered according to the formula for the additional resistance of the ship J. Holtrop. The following formula can determine the value of the Transom Resistance (RTR):

$$R_{TR} = 0.5 . \rho . A_T . V^2 . C_6$$
(5)

6) Calculation of Resistance Model-Ship Correlation (RA)

Furthermore, in calculating the resistance of the ship correlation model (correction value related to the ship model) using the Holtrop Method, several calculation parameters must be considered according to the following formula:

$$R_A = {}^1\!/_2 . \rho . V^2 . S . C_A$$
(6)

7) Calculation of Hull Roughness Resistance (RΔf)

Hull Roughness Resistance is the resistance due to the roughness of the MV Meratus Padang surface, bearing in mind that the ship's surface will never be as smooth as the model's surface. Roughness resistance is due to roughness caused by water corrosion, ship hull fouling, and biofouling. The hull roughness resistance can be formulated as follows:

$$R\Delta f = {}^1\!/_2 . \Delta C_f . \rho . S . V_s{}^2$$
(7)

B. Calculation of Resistance Using the STAWAVE Method

In this section, the resistance generated by waves, wind, and water properties, as well as by changes in the draft, will be calculated, which, from now on, is referred to as the additional resistance of the ship. This additional calculation value is due to changing environmental factors; the calculation method used is the STAWAVE method with the following empirical formula.

1) Calculation of Wave Resistance (RAWL)

Wave resistance depends on factors such as the ship's properties (length, beam, speed) and wave characteristics (significant height, period, and direction). To compare ship performance temporally, the extra wave resistance needs to be separated from the total resistance based on the specific wave conditions at each location and time, using this empirical formula:

$$R_{AWL} = \int_0^{\infty} \frac{R_{wave}(\omega;STW)}{\zeta A^2} S_{n(\omega)\,d\omega} \quad (8)$$

2) Calculation of Wind Resistance (RWIND)

In tailwind conditions, the additional wind resistance can be negative, reducing the ship's overall resistance [12]. Like additional wave resistance, this wind resistance fluctuates temporally and needs to be subtracted from the total resistance at each location and time to evaluate the ship's performance.

$$R_{WIND} = {}^1/_2\ \rho_{air} \,.\, {V_{air}}^2 \,.\, C_x \,.\, A_F \quad (9)$$

3) Calculation of Resistance due to Changes in Draft (RADIS)

Draft changes for every operation MV. Meratus Padang will undoubtedly affect the ship's hull resistance. The greater the ship's draft, the greater its displacement, which lowers its frictional resistance and allows it to move forward. Resistance caused by changes to the draft can be formulated as follows:

$$R_{ADIS} = 0{,}65 \,.\, R_T \,.\left(\frac{\Delta_0}{\Delta} - 1\right) \quad (10)$$

4) Additional Correction Calculations Due to Water Properties (RAS)

The viscosity of seawater, which varies with temperature and salinity, determines the amount of drag on a ship's hull. High viscosity increases the ship's drag, while low viscosity reduces it. Therefore, resistance corrections must be applied in calculations to standardize water conditions, enabling a precise evaluation of the ship's performance.

$$R_{AS} = R_T\left(1 - \frac{P_W}{P_{W0}}\right) - R_F\left(1 - \frac{C_f}{C_{fo}}\right) \quad (11)$$

C. Calculation of Fuel Consumption

The power supplied to the propeller is calculated from the total resistance and other ship factors. The power delivered to the propeller is determined from the corrected resistance and related ship parameters. Biofouling at sea often increases roughness on the hull and propeller, resulting in a speed reduction at constant power or a power increase at constant speed [30]. Given daily fluctuations in ship speed, speed through water and efficiency are weighted averages over the reporting period, while daily fuel consumption is directly proportional to the ship's delivered power. The calculation formula is as follows:

$$M_{fc=} \frac{P_{D\ Corrective} \cdot SFOC_{ME} \,.\, 24}{\eta_{trans} \,.\, 1000.\ 1000} \quad (12)$$

TABLE 2.
THE ESTIMATED POWER LOSS OF THE DIESEL ENGINE DURING OPERATING TIME [32]

Operation Time (Years)	Estimated Diesel Engine Decrease in Power (%)
5	3
10	5 - 7
15	8 - 10
20	12 - 15
25	15 - 20

The fuel consumption calculation of MV. Meratus Padang must monitor engine degradation closely, considering the age of the vessel which is already 15 years old, built in 2008. The total degradation can be classified as compression pressure, injection time, injection pressure, purge air temperature, and purge air pressure [31]. This engine degradation can result in a decrease in ship speed, an increase in fuel consumption, and an increase in ship operational costs by an average of 15% to 25%, with higher increases in some cases when the environment is adversely affected [32]. Furthermore, engine degradation and propeller efficiency that are not taken into account will be treated as constants at each waypoint when calculating fuel consumption.

III. RESULT AND DISCUSSSION

The ship used in this study is the MV. Meratus Padang is owned by Shipping Company PT. Meratus Line with vessel data as follows table 3:

A direct survey was conducted on the MV. Meratus Padang Ship will obtain actual ship operational data as validation. From the ship's AIS data recording, the ship's Longitude and Latitude positions are obtained during operation, while the ship's mileage can be taken from AIS. At Waypoint A-B is the ship's position when the ship, from the berth position at Berlian Surabaya Harbour, maneuvers up to the Beginning of Sea Voyage (BOSV) with the Surabaya Pilot's Guidance.

Waypoint B-C is the ship's position from BOSV to the End of the Sea Voyage (EOSV), where the ship goes based on the Passage Plan made by the ship's officers. The distance for Waypoint C-D is the distance the vessel travels from the Banjarmasin Pilot Guide to the maneuver until the ship berths at KD Trisakti Port, Banjarmasin. Furthermore, the distance to each waypoint is recorded, which is closer to the distance between the two waypoints. The results of the resistance calculations using the Holtrop Method and the STAWAVE Method for each ship position recording are shown in the table below.

TABLE 3.
MV. MERATUS PADANG DATA

Item	Information
MMSI Number	525125017
LOA	117 M
LBP	110 M
Breadth (Moulded)	19.7 M
Depth (Moulded)	8.5M
Summer/Tropical Draft	6.45 M / 6.58 M
Grosse Tonnage	5745 T
Summer Deadweight	7664.6T / 8109.1T
Service Speed	13.8 Knots
Main Engine	2 x Daihatsu 8 DKM-28L/2500kw each GFU IFO 180 (RME 180)
Auxiliary Engine	3 x Deutz MWM License TBD 24 VB /276kw, GFU GO(DMA)

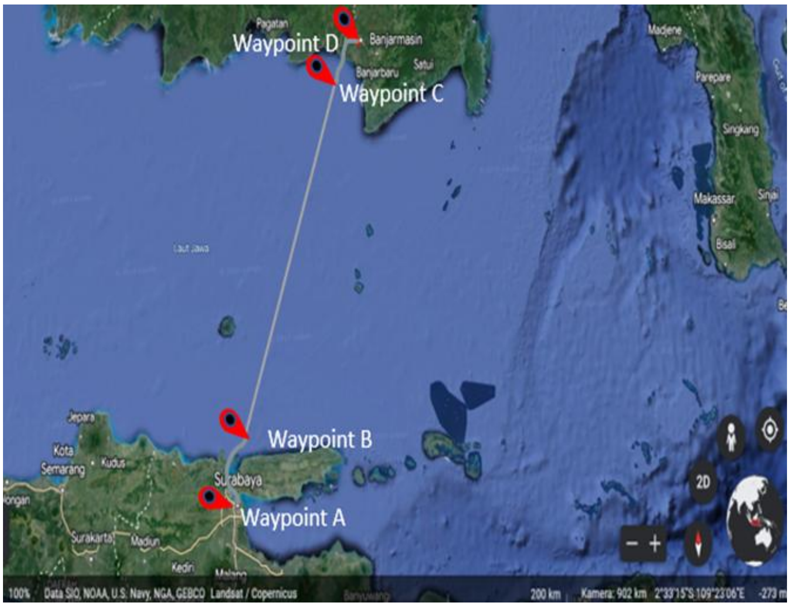

Figure. 2. MV. Meratus Padang route from Surabaya – Banjarmasin and Banjarmasin – Surabaya

TABLE 4.
CALCULATION OF RESISTANCE FOR THE HOLTROP METHOD MV. MERATUS PADANG, SURABAYA – BANJARMASIN ROUTE

Waypoint	Vs Knots	RF (kN)	RAPP (kN)	Rw (kN)	RB (kN)	RTR (kN)	RA (kN)	RΔf (kN)	TOTAL (kN)
				Waypoint A – B					
1	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	5.2	25.41	0.34	0.00	4.79	2.15	3.50	5.70	41.89
3	6.3	36.36	0.49	0.01	7.37	2.80	5.13	8.37	60.53
4	6.8	41.93	0.57	0.04	8.65	3.08	5.98	9.75	69.99
5	8.1	58.16	0.79	0.34	12.16	3.68	8.49	13.83	97.44
-	-	-	-	-	-	-	-	-	-
				Waypoint B – C					
25	11.7	115.75	1.56	16.43	22.07	3.71	17.71	28.86	206.09
26	11.8	117.61	1.59	17.96	22.33	3.66	18.01	29.35	210.52
27	11.8	117.61	1.59	17.96	22.33	3.66	18.01	29.35	210.52
28	11.7	115.75	1.56	16.43	22.07	3.71	17.71	28.86	206.09
29	11.7	115.75	1.56	16.43	22.07	3.71	17.71	28.86	206.09
-	-	-	-	-	-	-	-	-	-
				Waypoint C – D					
44	7.4	49.11	0.66	0.18	10.24	3.38	7.08	11.54	82.21
45	6.8	41.93	0.57	0.04	8.65	3.08	5.98	9.75	69.99
46	6.7	40.79	0.55	0.03	8.39	3.02	5.81	9.46	68.05
47	6.1	34.23	0.46	0.01	6.87	2.68	4.81	7.84	56.92
48	5.4	27.26	0.37	0.00	5.23	2.27	3.77	6.15	45.05

From the calculation data for the Total Resistance of the Holtrop Method and the STAWAVE Method for the Surabaya-Banjarmasin route, the same thing will be done on the Banjarmasin-Surabaya route. The table below shows the calculation data for the Holtrop and STAWAVE methods on the Banjarmasin–Surabaya route.

TABLE 5.
CALCULATION OF THE RESISTANCE FOR THE STAWAVE METHOD MV. MERATUS PADANG, SURABAYA - BANJARMASIN ROUTE

Waypoint	Vs (Knots)	RADIS (N)	RWIND (N)	RAS (N)	RAWL (N)	TOTAL (kN)
			Waypoint A - B			
1	0.0	0	0.00	0	0.00000	0
2	5.2	13,303	1.35	-118.00	0.00019	13.19
3	6.3	13,303	0.31	-165.91	0.00019	13.14
4	6.8	13,303	1.07	-190.08	0.00019	13.11
5	8.1	13,303	0.98	-259.74	0.00019	13.04
-	-	-	-	-	-	-
			Waypoint B – C			
25	11.7	13,303	1.84	-494.82	664.048	12.82
26	11.8	13,303	1.61	-501.75	664.754	12.81
27	11.8	13,303	1.84	-501.75	664.754	12.81
28	11.7	13,303	1.69	-494.82	664.048	12.82
29	11.7	13,303	1.84	-494.82	664.048	12.82
-	-	-	-	-	-	-
			Waypoint C – D			
44	7.4	13,303	4.37	-220.99	0.00333	13.09
45	6.8	13,303	3.45	-190.08	0.00331	13.12
46	6.7	13,303	2.79	-185.13	0.00331	13.12
47	6.1	13,303	0.72	-156.65	0.00329	13.15
48	5.4	13,303	0.67	-126.17	0.00326	13.18

TABLE 6.
CALCULATION OF RESISTANCE FOR THE HOLTROP METHOD MV. MERATUS PADANG, BANJARMASIN – SURABAYA ROUTE

Waypoint	Vs Konts	RF (kN)	RAPP (kN)	Rw (kN)	RB (kN)	RTR (kN)	RA (kN)	RΔf (kN)	TOTAL (kN)
				Waypoint D – C					
1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	5.5	28.21	0.38	0.00	5.46	2.33	3.91	6.38	46.67
3	6.5	38.54	0.52	0.02	7.87	2.91	5.46	8.91	64.24
4	7.6	51.62	0.70	0.20	10.79	3.47	7.47	12.18	86.43
5	7.7	52.90	0.71	0.21	11.06	3.51	7.67	12.50	88.57
-	-	-	-	-	-	-	-	-	-
				Waypoint C - B					
25	11.7	115.75	1.56	16.43	22.07	3.71	17.71	28.86	206.09
26	11.6	113.91	1.54	15.06	21.81	3.75	17.40	28.37	201.83
27	11.7	115.75	1.56	16.43	22.07	3.71	17.71	28.86	206.09
28	11.7	115.75	1.56	16.43	22.07	3.71	17.71	28.86	206.09
29	11.6	113.91	1.54	15.06	21.81	3.75	17.40	28.37	201.83
-	-	-	-	-	-	-	-	-	-
				Waypoint B – A					
42	7.5	50.36	0.68	0.19	10.51	3.42	7.28	11.86	84.31
43	6.8	41.93	0.57	0.04	8.65	3.08	5.98	9.75	69.99
44	6.7	40.79	0.55	0.03	8.39	3.02	5.81	9.46	68.05
45	6.5	38.54	0.52	0.02	7.87	2.91	5.46	8.91	64.24
46	5.3	26.33	0.36	0.00	5.01	2.21	3.63	5.92	43.46

TABLE 7.
CALCULATION METHOD STAWAVE MV. MERATUS PADANG, BANJARMASIN – SURABAYA ROUTE

Waypoint	Vs (Knots)	RADIS (N)	RWIND (N)	RAS (N)	RAWL (N)	TOTAL (kN)
			Waypoint D - C			
1	0.0	0	0.00	0.00	0.00000	0.00
2	5.5	14,458	0.00	-130.34	0.00247	14.33
3	6.5	14,458	0.00	-175.40	0.00250	14.28
4	7.6	14,458	0.00	-231.78	0.00253	14.23
5	7.7	14,458	0.00	-237.26	0.00253	14.22
-	-	-	-	-	-	-
			Waypoint B – C			
25	11.7	14,458	0.00	-494.82	502.618	13.97
26	11.6	14,458	0.00	-487.85	502.084	13.98
27	11.7	14,458	0.00	-494.82	502.618	13.97
28	11.7	14,458	0.00	-494.82	502.618	13.97
29	11.6	14,458	0.00	-487.85	502.084	13.98
-	-	-	-	-	-	-
			Waypoint C – D			
42	7.5	14,458	0.00	-226.35	0.00019	14.23
43	6.8	14,458	0.00	-190.08	0.00019	14.27
44	6.7	14,458	0.00	-185.13	0.00019	14.27
45	6.5	14,458	0.03	-175.40	0.00019	14.28
46	5.3	14,458	0.03	-122.05	0.00019	14.34

Based on the resistance calculation results, the Holtrop and STAWAVE methods are used to calculate fuel consumption and CII. Before calculating fuel consumption, it is necessary to determine the power required to maintain the ship's speed against resistance, which depends on the environmental forces acting on the propeller and is calculated using the total resistance (Holtrop and STAWAVE methods) and other ship parameters.

TABLE 8.
POWER (BHP) OF MV. MERATUS PADANG, SURABAYA – BANJARMASIN ROUTE

Waypoint	Vs Knot	Vs m/s	Holtrop	STAWAVE	R. Total	BHP
			Waypoint A - B			
1	-	0.000	0.00	0.00	0.00	0.00
2	5.2	2.675	41.89	13.19	55.08	327
3	6.3	3.241	60.53	13.14	73.67	530
4	6.8	3.498	69.99	13.11	83.11	645
5	8.1	4.167	97.44	13.04	110.49	1,021
-	-	-	-	-	-	-
			Waypoint B – C			
25	11.7	6.019	206.09	12.82	218.91	2,922
26	11.8	6.070	210.52	12.81	223.33	3,007
27	11.8	6.070	210.52	12.81	223.33	3,007
28	11.7	6.019	206.09	12.82	218.91	2,922
29	11.7	6.019	206.09	12.82	218.91	2,922
-	-	-	-	-	-	-
			Waypoint C – D			
44	7.4	3.807	82.21	13.09	95.29	805
45	6.8	3.498	69.99	13.12	83.11	645
46	6.7	3.447	68.05	13.12	81.17	621
47	6.1	3.138	56.92	13.15	70.07	488
48	5.4	2.778	45.05	13.18	58.23	359

TABLE 9
FUEL OIL CONSUMPTION OF MV. MERATUS PADANG, SURABAYA – BANJARMASIN ROUTE

Waypoint	Vs	Power (BHP)	Engine Load	SFOC	Time	Fuel Oil Consumption
	Knot	(kW)	(%)	(gr/kWh)	(m)	(liter)
			Waypoint A- B			
1	-	0	0	0.0	-	0
2	5.2	327	7	220.5	9	12.583
3	6.3	530	11	220.5	10	22.657
4	6.8	645	13	220.5	13	35.866
5	8.1	1,021	20	220.5	11	48.059
-	-	-	-	-	-	-
			Waypoint B – C			
25	11.7	2,922	58	205,5	38	395.241
26	11.8	3,007	60	204,9	58	618.73
27	11.8	3,007	60	204,9	53	565.392
28	11.7	2,922	58	205,5	55	572.06
29	11.7	2,922	58	205,5	74	769.681
-	-	-	-	-	-	-
			Waypoint C – D			
44	7.4	805	16	220,5	5	17.704
45	6.8	645	13	220,5	9	24.831
46	6.7	621	12	220,5	10	26.124
47	6.1	488	10	220,5	21	43.537
48	5.4	359	7	220,5	22	33.43

TABLE 10
POWER (BHP) OF MV. MERATUS PADANG, BANJARMASIN - SURABAYA ROUTE

Waypoint	Vs Knot	Vs m/s	Holtrop	STAWAVE	R. Total	BHP
			Waypoint D - C			
1	0	0.00	0.00	0.00	0.00	0
2	5.5	2.83	46.67	14.33	61.00	383
3	6.5	3.34	64.24	14.28	78.52	582
4	7.6	3.91	86.43	14.23	100.65	873
5	7.7	3.96	88.57	14.22	102.79	903
-	-	-	-	-	-	-
			Waypoint C - B			
25	11.7	6.02	206.09	13.97	220.06	2,938
26	11.6	5.97	201.83	13.98	215.81	2,856

CONTINUED TABLE 10

POWER (BHP) OF MV. MERATUS PADANG, BANJARMASIN - SURABAYA ROUTE

Waypoint	Vs		Holtrop	STAWAVE	R. Total	BHP
	Knot	m/s				
27	11.7	6.02	206.09	13.97	220.06	2,938
28	11.7	6.02	206.09	13.97	220.06	2,938
29	11.6	5.97	201.83	13.98	215.81	2,856
-	-	-	-	-	-	-
			Waypoint B - A			
42	7.5	3.86	84.31	14.23	98.54	843
43	6.8	3.50	69.99	14.27	84.26	654
44	6.7	3.45	68.05	14.27	82.32	629
45	6.5	3.34	64.24	14.28	78.52	582
46	5.3	2.73	43.46	14.34	57.79	350

TABLE 11

FUEL OIL CONSUMPTION OF MV. MERATUS PADANG, BANJARMASIN - SURABAYA ROUTE

Waypoint	Vs	Power (BHP)	Engine Load	SFOC	Time	Fuel Oil Consumption
	Knot	(kW)	(%)	(gr/kWh)	(m)	(liter)
			Waypoint D - C			
1	0	0	0	0	0	0
2	5.5	383	8	220,5	21	35.019
3	6.5	582	12	220,5	22	53.588
4	7.6	873	17	220,5	10	36.264
5	7.7	903	18	220,5	6	24.087
-	-	-	-	-	-	-
			Waypoint C – B			
25	11.7	2,938	59	205,2	70	730.737
26	11.6	2,856	57	205,9	47	478.573
27	11.7	2,938	59	205,2	71	741.176
28	11.7	2,938	59	205,2	53	553.273
29	11.6	2,856	57	205,9	68	692.404
-	-	-	-	-	-	-
			Waypoint B – A			
42	7.5	843	17	220,5	22	79.373
43	6.8	654	13	220,5	24	67.133
44	6.7	629	13	220,5	23	61.929
45	6.5	582	12	220,5	13	32.391
46	5.3	350	7	220,5	28	41.87

The results of ship resistance calculations using the Holtrop Method and the STAWAVE Method to estimate fuel consumption on the Surabaya-Banjarmasin route, and vice versa, will be validated against actual data recorded by the author during a direct survey on board the MV. Meratus Padang. Empirical factors that the formula does not account for include variations in the main engine load due to rapid maneuvers at each waypoint, engine age, and decreased propeller efficiency. This ship was built in 2008, so it experiences performance degradation compared to new ships. This condition affects the ship's operation: at the same speed, the power generated decreases proportionally, increasing fuel consumption and operational costs by 15%–25% [32]. Therefore, corrections are required for the propeller efficiency (0.5) and the engine degradation (9.5%). Validation of fuel consumption for the Surabaya - Banjarmasin route using the Empirical Formula + Propeller Efficiency and Engine Degradation = 13,319,287 liters, 0.41% different from the fuel consumption recorded on board = 13,373,749 liters.

Meanwhile, on the Banjarmasin-Surabaya route, a difference of -0.35% was found from the empirical formula calculation of 13,117,491 liters with the recorded fuel consumption on board = 13,071,161 liters.

To calculate the CII rating of the MV. Meratus Padang requires ship type, ship DWT, fuel consumption, and ship distance, all of which were obtained in the previous chapter. From the data obtained, CII Rating MV. Meratus Padang on one round-trip route Surabaya - Banjarmasin - Banjarmasin Port - Banjarmasin - Surabaya - Surabaya Port obtained Attained CII / Required CII value of 1.32. Where the Attained CII / Required CII value of MV. Meratus Padang if below 0.83 gets a value of "A", if below 0.94 gets a value of "B", if below 1.06 gets a value of "C", if below 1.19 gets a value of "D", and if above 1.19 gets a value of "E". Therefore, in this one round trip, MV. Meratus Padang gets a CII Rating value of "E". For more details, see the figure of the average CII Rating across one round-trip MV. Meratus Padang is shown in the figure below.

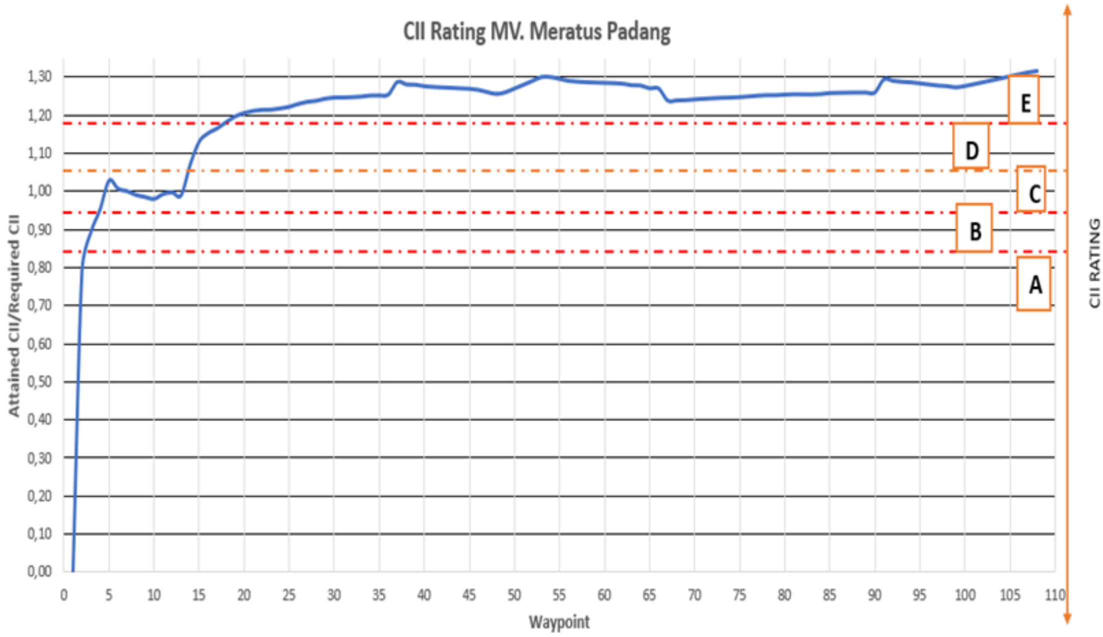

Figure. 3. CII Rating Average Value One Round Trip of MV. Meratus Padang

IV. Conclusion

From the results of calculating fuel consumption using the Holtrop Method and the STAWAVE Method, the value of fuel consumption from Surabaya to Banjarmasin is 13,319.287 Liters, or a difference of 0.41% from the actual fuel consumption, and on the Banjarmasin to Surabaya route, it is obtained 13,117.491 Liters or a difference of -0.35 % from the actual fuel consumption. This calculation, with the addition of constants that cannot be calculated using empirical formulas, such as the load from the main engine, which changes rapidly when maneuvering, the age of the engine, and the efficiency of the propeller, where the ship has been built since 2008, of course, experiences engine degradation and a decrease in propeller efficiency. Where the constant is from the empirical formula of MV. Meratus Padang for propeller efficiency is 0.5, and engine degradation is 9.5%. Corrective actions to reduce CO_2 emissions in MV. Meratus Padang is a critical concern that must be addressed to reduce CO_2 emissions, as the average CII is "E". This highlights the need to accelerate alternative measures that ship managers or ship owners can adopt to operate MV. Meratus Padang, with a minimum target value of "C" at the end of 2026. Continuous monitoring of fuel consumption and CII remains effective and efficient, and it certainly requires a way for ship managers or owners to manage their ships. An online-based system for real-time monitoring could be an option for future monitoring.

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