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Research Article

IMPLEMENTATION OF A SHIP ENERGY EFFICIENCY MANAGEMENT PLAN (SEEMP) ON A FERRY

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ABSTRACT
Energy efficiency is an important focus due to rising fuel costs and greenhouse gas emissions. Although maritime transport is considered as the most environmentally friendly mode of transportation, it contributes significantly to environmental pollution. This study focuses on the Energy Efficiency Operational Index (EEOI) to assess the energy efficiency of the Osmangazi-1 high-speed passenger/vehicle ferry. The analysis reveals that there is a direct relationship between the EEOI values and operational parameters such as cargo weight, speed and sailing distance. The data collected between July and August 2013 shows that the average, minimum and maximum EEOI values are 0.001344, 0.000823 and 0.004322 respectively. Operational measures outlined in the Ship Energy Efficiency Management Plan (SEEMP) aim to reduce emissions and improve fuel efficiency. The findings emphasize that SEEMP should be implemented to reduce CO_2 emissions and promote sustainable maritime practices.

Keywords: *SEEMP, Ferry, Energy Efficiency, EEOI, IMO*

1. INTRODUCTION

The environmental effect of exhaust gas emissions and rising fuel prices have made energy efficiency a top priority in recent years (Leach et al., 2020; Prill & Igielski, 2018). Scientific research on environmental degradation, global warming, and energy-related topics has also increased as a result of this circumstance (Afifa et al., 2024). Although it is considered the most environmentally friendly of the three main modes of transportation: land, sea and air maritime transport has serious negative impacts on environmental pollution (Aminzadegan et al., 2022; Jägerbrand et al., 2019; Jing et al., 2022; Viana et al., 2014; Wu et al., 2011). Most transportation systems, including the maritime, employ internal combustion engines, the most prevalent sources of carbon dioxide and other greenhouse gases (Barreiro et al., 2022; Hüffmeier & Johanson, 2021; Wang et al., 2018). Waste ship-oil sludge (WSOS) (Sasidhar et al., 2023), bilge water (Arslan et al., 2022) and emissions resulting from the use of fuels on ships (Millet et al., 2023) cause environmental pollution. Today, it is known that 90% of international transportation is carried out by maritime transportation (Schnurr & Walker, 2019) and ensuring energy efficiency in ships is possible by reducing fuel costs and waste on ships (Oloruntobi et al., 2023).

The energy required for the propulsion and management of ships is provided by the ship's main engines and auxiliary engines, and the amount of CO_2 gas generated as a result of the combustion of fossil fuels used by these engines depends on the fuel and the amount of carbon in its content (Inal et al., 2022). The increase in the number of ships and thus the increase in the use of fossil fuels also increases the role and share of maritime transportation in emissions (Ayesu, 2023). According to the content of the Second IMO Greenhouse Gas Study in 2009 (Buhaug et al., 2009); it is stated that 1046 million tons of CO_2 emissions were generated as a result of maritime transportation activities in 2007 and this constituted 3.3% of the total CO_2 emissions in the world. It is estimated that if the necessary measures are not taken, this contribution may increase by 150-250% in 2050.

Greenhouse gas emissions from maritime transportation in Turkey constitute 3% of the total emissions, with NO_x, SO_2 and CO_2 from ships in the Marmara Sea constituting 1% of the greenhouse gas emissions from maritime transportation worldwide (Deniz & Durmuşoğlu, 2008). It is predicted that the greenhouse gas emissions from passenger engines operating in the Marmara Sea, the number of which is increasing daily, and ships making international transit are expected to increase continuously (Bayırhan et al., 2019).

To reduce emissions from ships and fuel consumption, the International Maritime Organization (IMO) published the "Ship Energy Efficiency Management Plan" (SEEMP) in March 2012 under circular MEPC.213(63) (IMO, 2013). As of January 1, 2013, all ships exceeding 400 gross tons of international voyages are required to have a SEEMP. The primary objective of SEEMP is to improve the energy efficiency of ship operations for both the company and the vessel. (Beşikçi et al., 2021). Since ships and companies differ, each vessel requires a SEEMP tailored to its specific needs. SEEMP serves as a guiding framework, offering operational and technical recommendations to minimize a ship's energy consumption. It facilitates increased energy efficiency by providing coordination between the company and the ship (Dewan & Godina, 2023; Hansen et al., 2020).

SEEMP should be continuously developed in collaboration with the ship owner, operator, or charter company. Like other management systems, SEEMP aims to enhance energy efficiency through four key phases: planning, implementation, monitoring, and self-assessment and improvement. These stages play a crucial role in each phase of SEEMP.

Energy efficiency measures are classified into two main categories: technical and operational. Technical measures include structural optimization and ship design, improvements to propulsion systems, arrangements for energy systems, use of renewable energy sources and waste heat recovery and exhaust gas cleaning systems. Operational measures include the optimization of time and activities at port, voyage planning and routing according to weather conditions, speed optimization, ship maintenance (such as hull and propeller cleaning) and the use of shore power (Elena, 2012). Operational measures can reduce CO_2 and greenhouse gases by up to 40%. For example, reduction in speed by 10% alone can reduce emissions by 25% (Marin et al., 2010).

In order to increase energy efficiency, Öztürk (2015) concentrated on operational methods. This research examines fuel-efficient activities such weather routing, hull and propeller cleaning, speed optimization, and trip planning and virtual arrival. The study demonstrated how time and speed management are intimately linked to voyage planning and virtual arrival, and it gave instances of how these strategies might cut fuel expenses by as much as 40%.

Musulin et al. (2024) aimed to evaluate how trim optimization of container ships at different speeds can reduce exhaust gas emissions and fuel consumption. They calculated that with the right trim, fuel consumption can be up to 5% lower at constant route and speed. Ship emissions, fuel consumption, and energy efficiency may all be improved by optimizing trim at different speeds and drafts (Riyadi et al., 2022). Trim optimization in ship operations, using operational data and ensemble learning techniques, enhances energy efficiency and reduces emissions, especially for inland sea vessels (J. Gao et al., 2022).

This study differs from the existing literature by focusing on Osmangazi-1, a high-speed passenger/vehicle ferry operating in the Marmara Sea, a region with rapidly increasing maritime traffic. By analyzing Energy Efficiency Operational Index (EEOI) data over a long period of time, this research aims to assess how operational parameters such as trim, average speed, fuel consumption, cargo load and sailing distance affect the energy efficiency of the ferry. Unlike previous studies, which often rely on theoretical or simulation-based models, this study uses actual operational data from the ferry, providing valuable insights into how energy efficiency measures can be implemented in real-world settings.

2. METHODOLOGY

The most important method developed by IMO for controlling the functioning of SEEMPs prepared for ships in service is the EEOI. The information under this section was taken from IMO's circular dated 17.08.2009, numbered MEPC.1/Circ.684. In the formula OF EEOI, it is accepted that the CO_2 emission of a ship is directly related to fuel consumption. In other words, EEOI can be determined as the ratio of the mass of CO_2 produced to the amount of work performed.

For a ship carrying single voyage cargo;

$$EEOI = \frac{\sum_j FC_j \times C_{Fj}}{m_{c\,arg\,o} \times D} \quad (1)$$

For a ship sailing for a certain period of time;

$$\boldsymbol{EEOI_{avarage}} = \frac{\sum_i \sum_j (\boldsymbol{FC_{ij}} \times \boldsymbol{C_{Fj}})}{\sum_i (\boldsymbol{m_{c\,arg\,o,i}} \times \boldsymbol{D_i})} \quad (2)$$

Where j is the fuel type, i is the number of voyages, FC_{ij} is the mass of fuel j consumed in the i-th voyage, C_{Fj} is the conversion factor of fuel mass to CO_2 mass for fuel j, $m_{c\,arg\,o}$ is the mass of the cargo carried (or gross tonnage in passenger ships), D_i is the distance the cargo is carried in nautical miles (Acomi & Acomi, 2014). To apply the formulas above, it is necessary to use Table 1, which lists the carbon content and CO_2 emission data per unit of fuel type.

Table 1. CO_2 conversion per unit of fuel (Kim & Jeon, 2022)

Fuel Type	Reference	Carbon Content	Cf (t-CO_2/t- Oil)
Diesel/Gas Oil	ISO 8217 Grades DMX to DMC	0.875	3.206000
Light Fuel Oil (LFO)	ISO 8217 RMA to RMD class	0.86	3.151040
Heavy-fuel oil (HFO)	ISO 8217 Grades RME to RMK	0.85	3.114400
Liquefied Petroleum Gas	Propane, Butane	0.819 0.827	3.000000 3.030000
Liquefied Natural Gas	-	0.75	2.750000

The voyage EEOI is obtained by multiplying the amount of fuel by the mass amount of CO_2 converted from the fuel and dividing the result by the product of the cargo carried and the nautical miles traveled by the ship. The average EEOI was obtained by dividing the value obtained by multiplying the sum of the individual totals of the fuel types used by the mass amount of CO_2 conversion of the fuels and then summing them by the value obtained by summing the products of the amount of cargo carried at the end of each voyage and the cruising distance. This study aimed to reduce EEOI and average EEOI values using the measures determined in SEEMP.

The data used in this study was collected from the ferry Osmangazi-1 operating in the Turkish Sea of Marmara (Figure 1). Data on the ferry's fuel consumption, speed, and operational conditions were obtained from onboard sensors and operational logs maintained by the ferry's crew and operational team. Osmangazi-1, built in 2007 at Austal Shipyard in Australia with construction number 294, is Turkey's largest vehicle/passenger ferry with a carrying capacity of 1200 passengers and 225 vehicles. The vessel is 88 m long and can reach a maximum speed of 38 knots.

Fig. 1. Osmangazi-1 vessel

Table 2. Properties of the Osmangazi-1 vessel

Property	Value
IMO Number	9372127
Port of Registry	Istanbul
Registry Number	1322
Call Sign	TCCH5
Overall Length	88 m
Registered Length	79.68 m
Beam	24 m
Depth	8.25 m
Gross Tonnage	6133 GT
Net Tonnage	1840 NT
Deadweight Tonnage	520.20 DWT
Keel Laid Date	38742
Delivery Date	39167
Cargo Capacity	225 vehicles and 1200 passengers
Fuel Tank Capacity	(2x50650)+(2x25850)+(3x3500) = 225360 L.
Water Tank Capacity	2x5335 = 10670 L
Engine Power	4x7200 kW–1150 Rpm
Generator Power	4x280 kW, 1500 Rpm

In this study, no specific restrictions were imposed on the engine speeds of the studied ships, and this issue was left entirely to the discretion of the master and chief engineer. It was observed that the vessel prioritized customer satisfaction over energy efficiency and focused more on factors such as speed and voyage time. Table 3 presents the fuel data for Osmangazi-1 for 2013 and shows that there were significant differences in the monthly fuel consumption. The vessel uses diesel fuel, and its characteristics are stated in the supplier's analysis report. The company also performs oil analysis every three months and changes the oil approximately every 1,200 hours of operation depending on usage.

Table 3. Properties of fuel used in the Osmangazi-1 vessel

Property	Unit	Reference Limit	Measurement Uncertainty	Measurement Value	Test Method
Density	kg/m³	Min 820 Max 845	±0.11	829.3	TS EN ISO 12185
Total Contamination	mg/kg	Max 24		<6.0	TS EN 12662
Flash Point	°C	Min 55	±2.42	61	TS EN ISO 2719
Cold Filter Plugging Point	°C	+5 (Summer) -15 (Winter)	±0.91	-7	TS EN 116/AC, Cylindrical Strengthening
250°C Distillation	% (V/V)	Max 65	±0.63	26.1	TS EN ISO 3405
350°C Distillation	% (V/V)	Max 85	±0.54	93.0	TS EN ISO 3405
95% Distillation Temperature	°C	Max 360	±2.75	356.6	TS EN ISO 3405
Water Content	mg/kg	Max 200	±10.60	67	TS EN 6147/EN ISO 12937
Sulfur Content	mg/kg	Max 10	±0.22	5.2	TS EN ISO 20846
Cetane Index	--	Min 46.0	±0.92	57.9	TS EN ISO 4264

While calculating the EEOI, operations carried out for the safety of the ship, lifesaving etc. are excluded and voyages to the shipyard and ballast voyages (voyages without cargo) can be included in the calculations.

The fuel consumption equation represents the amount of fuel consumed by the main engine, auxiliary engines and other equipment at port and underway. The voyage distance refers to the actual distance traveled by the ship in nautical miles. The term "cargo" includes all types of cargo, including general goods, solid, liquid, and gaseous materials, as well as containers, passengers, and vehicles.

While establishing the EEOI monitoring system connected to SEEMP; the calculation period is defined, the sources of information are identified, data is collected, and the information is converted into valid formats. The expected benefits of EEOI are summarized as follows:
- Measurement of energy efficiency at each time step
- Assessment of the structural or operational changes in a ship
- Identification and correction of critical phases of the operational management of a ship
- Performance evaluation of owners and operators
- Continuous monitoring of the ship.

3. RESULTS AND DISCUSSION

Since there are many factors affecting the fuel consumption of a ship, it is only possible to obtain accurate results using methods such as EEOI. Although the values obtained using the EEOI indicate the amount of fuel consumed and CO_2 emissions emitted for the work performed, it should be aimed to keep these values to a minimum. Within the scope of this study, the voyage number, date, port of departure, amount of cargo carried, number of passengers, number of vehicles, trim value, cruising distance, average speed, type of fuel used, voyage EEOI, and average EEOI values were obtained.

The values obtained from the EEOI are used to compare the recorded voyage values. Therefore, it is not expected that the obtained values will be within certain ranges. The EEOI calculated at the end of each voyage indicates the changes in the factors that affect fuel consumption during the voyage. In general, a decrease in the EEOI indicates that energy efficiency measures have been effectively implemented. This also reduces the average EEOI.

Between 01.07.2013 and 15.08.2013, data were collected on the vessel with the current operational status, and the EEOI indicator was calculated and evaluated. According to the results obtained, the average EEOI value was 0.001344, which gives significant results when correlated with other parameters. It was found that the EEOI reached its highest level (0.004322) when the trim and average speeds were high. On the other hand, the EEOI value decreased to its lowest level (0.000823) when trim and average speeds were low.

The average fuel consumption was 6.49 metric tons (MT). The minimum fuel consumption was 5.35 MT, while the maximum fuel consumption was 7.96 MT. The EEOI obtained at the minimum fuel consumption level was 0.001043, which is below the average EEOI. The EEOI obtained at the maximum fuel consumption level is 0.001375, which is very close to the average EEOI. This analysis shows the effect of trim and average rpm on the EEOI. High trim and rpm values decrease energy efficiency and increase fuel consumption, whereas low trim and rpm values indicate more efficient energy use.

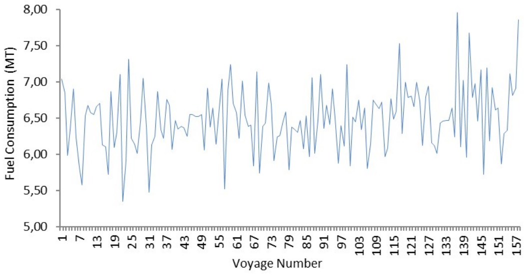

Fig. 2. Fuel Consumption depending on the voyage number

Fig. 3 shows the change in the number of vehicles with the number of voyages. The average number of vehicles was 663. The maximum and minimum number of vehicles carried in this process is 220 and 46, respectively. In terms of the total cargo, the maximum cargo carried by the vessel was 425 tons and the minimum cargo was 88 tons.

When the EEOI values are analyzed, the EEOI values when the number of vehicles is maximum and minimum are 0.000966 and 0.004322, respectively. This shows that the cruise distance plays an important role. It is observed that 57.3472 nautical miles are cruised in the case of maximum cargo transportation, where the EEOI is 0.000966, and 56.71 nautical miles are traveled in the case of minimum cargo transportation. In other words, although less load reduces fuel consumption, the EEOI value is below the average even if the fuel consumption and the amount of load are high for a high cruising distance.

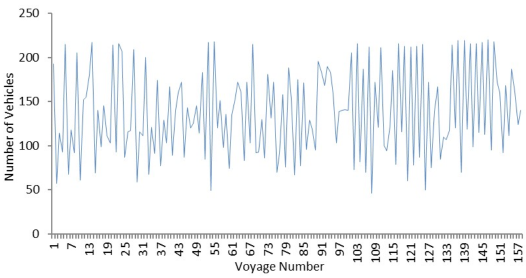

Fig. 3. Number of vehicles depending on the voyage number

According to the graph of vessel speed in relation to the number of voyages shown in Figure 4, the average speed was 34.35 knots. During this period, the maximum recorded speed was 37.5 knots, while the minimum recorded speed was 27.1 knots. At maximum speed, the vessel traveled 61.85 miles, consumed 6.45 tons of fuel, and carried 185 tons of cargo. In contrast, at minimum speed, the vessel cruised 58.73 miles, consumed 6.43 tons of fuel, and transported 247 tons of cargo. The EEOI calculated under the maximum speed conditions (0.001804) was higher than the average EEOI. Notably, although the amount of fuel consumed at the minimum speed was very close to that consumed at the maximum speed, the EEOI value (0.001420) differed and was also above the average EEOI value. This indicates that the load carried is an influential parameter in addition to fuel consumption.

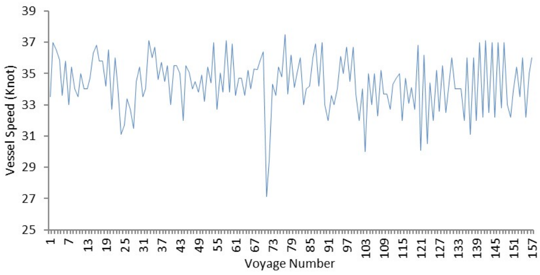

Fig. 4. Vessel speed depending on the voyage number

According to the results obtained, the average cruising distance was 58.7833 nautical miles. During this period, the maximum cruising distance recorded was 69.7334 nautical miles, while the minimum cruising distance was 51.9002 nautical miles (see Figure 5). The EEOI values at the maximum and minimum cruising distances were 0.001603 and 0.001248, respectively.

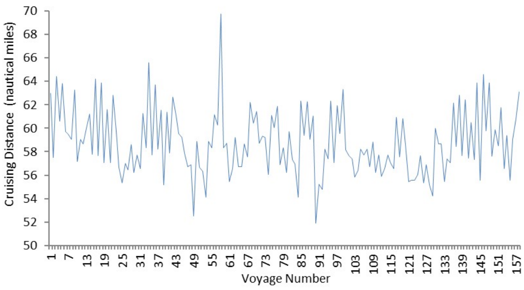

Fig. 5. Cruising distance depending on the voyage number

The number of passengers and vehicles carried on the 21st voyage were 1169 persons and 214 vehicles, respectively, and the ship speed reached 32.7 knots during the voyage, while the number of passengers and vehicles carried on the 53rd voyage were 1182 persons and 217 vehicles, respectively, and the ship speed reached 34.4 knots. If the 21st and 53rd voyages are compared, the EEOI value of 0,000949 for the 21st voyage is higher than the EEOI value of 0,000923 for the 53rd voyage due to the difference between the speeds, although the amount of cargo carried is close to each other. Therefore, it can be concluded that this increase in speed increases fuel consumption and consequently increases CO_2 emissions (Figure 6).

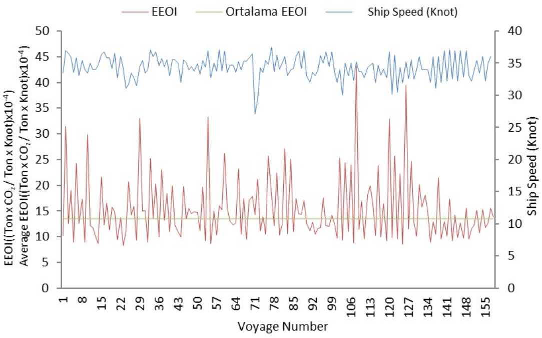

Fig. 6. Relationship between average speed and average EEOI

When the cruising distance between the same ports was maximum, the EEOI value was higher than the average EEOI value by 0.000259, and when the distance was minimum, the EEOI value was lower than the average EEOI value by 0.000096 (Figure 7). However, the cruising distance was extended when necessary due to the importance of ensuring the safety of life and property at sea, depending on the weather conditions. The same ships may take different routes between the same ports depending on weather conditions or other factors. This can lengthen or shorten distances.

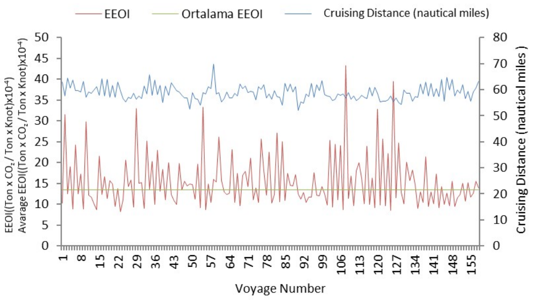

Fig. 7. Relationship between cruising distance EEOI and average EEOI.

For the voyages between the same ports, when the fuel consumption was the maximum, the EEOI value was 0.000301 below the average EEOI, and when the fuel consumption was the minimum, the EEOI value was 0.000328 below the average EEOI (Figure 8). Average EEOI and EEOI are operational indices based on different calculation methods, where fuel consumption is only one factor. These indices are influenced not only by fuel consumption, but also by load, distance and other variables. Therefore, even if the operational index increases, the average index may remain at a lower level.

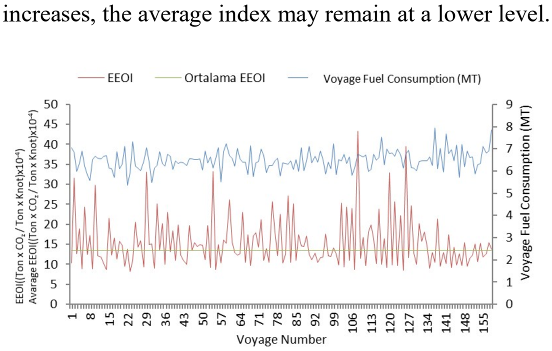

Fig. 8. The relationship between voyage fuel consumption, EEOI and average EEOI

As seen in Figure 9, despite the higher number of passengers and vehicles transported, the increase in ship speed was more important than the increase in the amount of cargo transported on low-speed voyages, and the changes in speed were parallel to the changes in EEOI values. Figure 9 shows that the change in vessel speed has a greater effect on EEOI compared to the cargo carried.

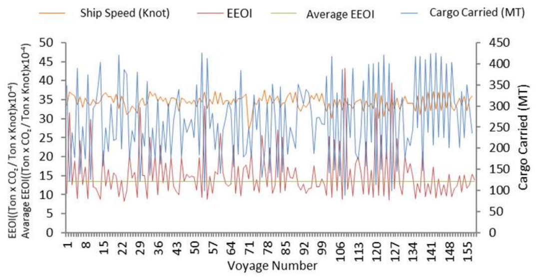

Fig. 9. Relationship between the cargo carried, average speed, and EEOI

As shown in Figure 10, when the average speed was low, a significant reduction in fuel consumption was observed. This reduction also led to a decrease in the EEOI.

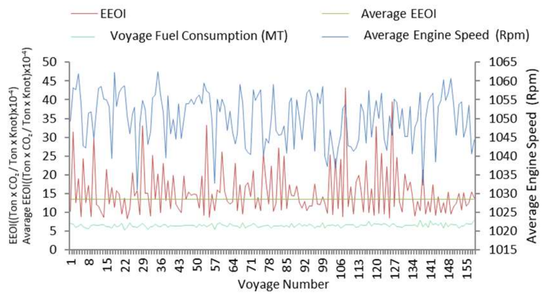

Fig. 10. Relationship between EEOI and average engine speed and fuel consumed

An increase in trim causes an increase in the friction surface of the ship under water and has a negative effect on fuel consumption for voyages with the same amount of cargo. This increased fuel consumption has also negatively affected the EEOI, causing the index to increase (Figure 11). Trim affects the hydrodynamic performance of the vessel, influencing its resistance to motion and, consequently, fuel efficiency. Our analysis found that slight adjustments to the trim could lead to measurable changes in fuel consumption.

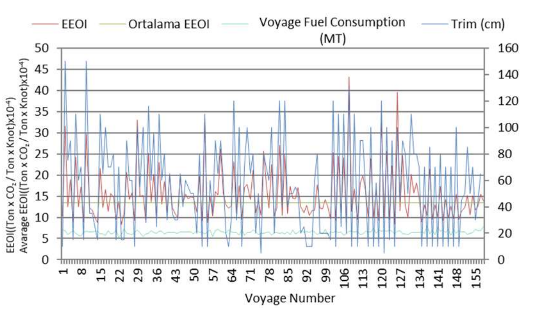

Fig. 11. Relationship between EEOI and trim and fuel consumed

4. CONCLUSION

The increase in marine vessels carrying passengers and vehicles in the Marmara Sea has led to an increase in CO_2 emissions and fuel consumption. The implementation of SEEMP, which is mandatory by IMO for all ships operating internationally over 400 GT, initially in the Marmara Sea and subsequently for all ships operating on the cabotage lines in Turkey will contribute greatly to the realization of energy savings. In conclusion, this study highlights the critical relationship between various operational parameters and fuel consumption in maritime transportation, as assessed using the EEOI. The analysis reveals that multiple factors, including the voyage characteristics, such as cruising distance, trim value, average speed, cargo volume, and the number of passengers, significantly influence fuel consumption and CO_2 emissions. The following conclusions can be drawn from this study:

- It is observed that higher trim and average speed values increase fuel consumption and EEOI.
- Lower trim and speed values improve energy efficiency and reduce fuel consumption.
- When the fuel consumption data of the ship were analyzed, it was determined that the average fuel consumption was 6.49 MT, the minimum consumption was 5.35 MT and the maximum consumption was 7.96 MT.
- At maximum speed (37.5 knots), the vessel consumed 6.45 tons of fuel, while at minimum speed (27.1 knots), 6.43 tons of fuel were consumed. The increase in speed raised the EEOI values: 0.001804 at maximum speed and 0.001420 at minimum speed.
- Increasing the trim value resulted in higher fuel consumption and an increase in the EEOI. High trim values led to an increase in fuel consumption by 0.1-0.2 tons.
- On voyages with maximum cargo (663 vehicles), the EEOI was 0.000966, while for minimum cargo (46 vehicles), the EEOI was 0.004322. The amount of cargo and cruising distance affected the EEOI values.
- Cruising distance plays an important role in determining the EEOI compared to the amount of cargo transported. Lower EEOI values were found at higher cruising distances.
- Vessel speed changes significantly affected fuel consumption and CO_2 emissions, with higher speeds resulting in higher EEOI values.
- The lower speed and fuel consumption reduced the EEOI and improved the energy efficiency.

Overall, this study highlights that ship operators should prioritize energy efficiency in their operations and use tools such as EEOI to monitor performance and identify areas for improvement. Future research should focus on developing more refined strategies to optimize these variables in real-time operational environments to further improve energy efficiency in the maritime sector.

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