Analysis of Fuel Consumption Variation of the 8dkm-28e Main Engine at Stable Performance of 620 RPM in the MV. Tanto Keluarga

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Abstract
This study examines the variation of Heavy Fuel Oil (HFO) fuel consumption of the Daihatsu 8DKM28e Main Engine at a stable performance condition of 620 RPM on the container ship MV. Tanto Keluarga, amidst the pressure of increasing fuel costs and regulations on maritime efficiency and decarbonization. The study uses a descriptive quantitative approach with a population of all main engine operational data during a certain voyage period and a sample of 5 sheets of Noon Report At Sea at a stable voyage condition in the open sea. The main instrument is the daily noon report that records the main engine speed, turbocharger speed, fuel rack, HFO consumption, and weather and sea conditions, plus ship technical documents and academic literature as secondary instruments. The data analysis technique used is descriptive quantitative analysis, with the calculation of averages, ranges, and trends as well as simple correlation examinations between performance parameters. The results show that HFO consumption varies up to approximately 1,005 liters per day at a relatively stable RPM, with a pattern closely related to changes in fuel rack, turbocharger speed, and sea state and weather conditions. The findings support that the main engine performance condition at 620 RPM is in dynamic equilibrium, so that fuel efficiency assessment needs to integrate internal and external factors simultaneously to support operational management, OPEX reduction, and compatibility with IMO EEXI and CII regulations.

Keywords: *Consumption, Efficiency, Fuel, Main Engine and Noon Report..*

I. INTRODUCTION

Maritime transport is the main artery supporting global trade, responsible for the movement of the majority of global cargo volume. Amidst the post-2020 energy transition trend, the maritime industry remains heavily reliant on fossil fuels, particularly Heavy Fuel Oil (HFO), which often accounts for around 50–60% of a ship's total operational expenditure (OPEX) (Han & Wang, 2021; Psaraftis et al., 2022). Globally, increased crude oil price volatility due to geopolitical turmoil and supply chain disruptions since 2022 has exacerbated the financial vulnerability of ship operators. In Indonesia, as the largest archipelagic nation, the national shipping sector faces similar pressures, contributing significantly to gross domestic product through exports and imports (Ministry of Transportation, 2024). The relevance of this topic is not only scientific—in developing ship energy efficiency models—but also practical, as improved fuel efficiency can reduce carbon emissions by around 15–20%, in line with the IMO's decarbonization regulatory direction (Wang et al., 2023).

Furthermore, operational phenomena in the field indicate that the Main Engine, as the primary fuel consumer, often experiences unpredictable consumption variations, even under stable sailing conditions (steady-state at sea). Noon report data from the MV. Tanto Keluarga, for example, revealed that HFO consumption fluctuated even though the main engine (8DKM28e) speed was relatively constant, suspected to be influenced by the dynamics of propeller loads and sea conditions (Pratama et al., 2024). Nationally, reports from ministries and statistical agencies recorded an increase in Indonesian ship fuel consumption in the 2023–2024 period due to the increased frequency of extreme weather in several strategic shipping lanes, which resulted in increased OPEX and decreased energy efficiency (BPS, 2024). This phenomenon creates hidden inefficiencies, where the assumption that stable parameters such as turbocharger RPM and fuel rack will result in stable fuel consumption is often proven to be invalid due to the influence of external factors such as sea state and weather conditions (Abyadha, 2023; Manggombo, 2019).

Previous studies have explored fuel efficiency optimization through analysis of main engine performance parameters. Zhang et al. (2025) found that engine RPM stabilization on certain types of ships can reduce fuel consumption by approximately 10% under long-distance sailing conditions, while Psaraftis et al. (2022) emphasized the role of technical regulations such as the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) in encouraging the adoption of operational efficiency technologies and practices. In the Southeast Asian context, Han & Wang (2021) confirmed the dominance of fuel costs in container ship OPEX, focusing on predictive maintenance based on engine operational data. Several other studies have shown that speed control and route planning can significantly reduce fuel consumption (Wang et al., 2023).

However, the research results show several inconsistencies and limitations. On the one hand, Wang et al. (2023) reported that in calm sea conditions, turbocharger RPM and main engine RPM have a strong correlation with relatively stable fuel consumption. On the other hand, a study by Pratama et al. (2024) actually identified variations in HFO consumption even though engine RPM appeared constant, indicating that internal parameters such as fuel rack and fuel pump position play an important role that is often not reflected in the RPM indicator alone. The main limitation of these studies lies in the approach that focuses too much on internal parameters of the main engine, while external factors such as sea weather conditions, propeller load dynamics, and the influence of deck logs on navigation decisions tend to be ignored, as well as the lack of empirical validation using daily noon report data for diagnostic purposes (Abyadha, 2023; Manggombo, 2019).

This research gap becomes increasingly apparent due to the limited number of studies that specifically integrate internal factors (fuel rack, turbocharger RPM, fuel injection timing) and external factors (weather, sea state, ship speed, and route planning patterns) on medium-sized Indonesian shipping companies, where noon report data is rarely systematically exploited for energy efficiency analysis (Manggombo, 2019). Therefore, the research problem can be formulated sharply as follows: (1) What are the performance characteristics of the 8DKM28e Main Engine including turbocharger RPM, main engine RPM, fuel rack position, HFO consumption, and weather and sea conditions during the voyage? (2) What internal and external factors are correlated with variations in HFO fuel consumption of the Main Engine?

This study aims to systematically describe the performance characteristics of the 8DKM28e Main Engine and identify factors that potentially influence variations in HFO consumption, based on daily noon report data covering 5 operational reports of the MV. Tanto Keluarga during the stable voyage phase (at sea). The urgency of this research is currently reinforced by the IMO CII and EEXI regulations that are mandatory for the Indonesian shipping fleet, so that a more accurate understanding of fuel consumption dynamics is essential for efficiency strategies and emission reductions. The novelty of this research lies in the diagnostic approach that combines daily operational data (engine noon reports) with a concrete voyage context, thus differing from previous studies that tend to focus on engine technical parameters partially. Theoretically, this research contributes to the development of noon report data analysis methodology for ship dynamic energy efficiency models; practically, these findings can be used by shipping companies and ship crews to design more accurate fuel management strategies, reduce OPEX, and support the effective implementation of environmental regulations (Wang et al., 2023).

II. METHODS

This study uses a quantitative approach with a descriptive research design, as formulated in the methodological framework of Sugiyono (2022) and Emzir (2021), which emphasizes that descriptive research aims to describe phenomena, characteristics, or factual conditions of a population without manipulating variables. The quantitative approach was chosen because the study focuses on the collection, processing, and analysis of measurable numerical data, such as main engine speed, turbocharger RPM, fuel rack position, and HFO fuel consumption, taken from ship operational noon reports (Santosa, 2021; Rahman et al., 2022). This descriptive design is relevant to the dynamic nature of the phenomenon of "fuel consumption variation," allowing researchers to describe patterns, trends, and simple correlations between variables in the context of natural shipping operations, as also applied in operational shipping studies based on daily data (Psaraftis et al., 2022).

The research population is all operational data of the Main Engine of DAIHATSU 8DKM28e MV. Tanto Keluarga during a certain voyage period, while the sample used consists of 5 (five) sheets of Noon Report At Sea taken at stable sailing conditions (620 RPM) during several voyages in the fourth quarter of 2024. This sample was selected purposively because it met the inclusion criteria: complete data on engine performance parameters (ME RPM, T/C RPM, fuel rack, HFO consumption), recorded at stable sailing conditions in the open sea, and did not contain report filling anomalies that could potentially bias (Psaraftis et al., 2022; Rahman et al., 2022). The selection of a sample limited to 620 RPM conditions was based on initial analysis showing that the 600 RPM data was not comparable with the main voyage data, so it could not be used as a basis for consistent performance comparison, in line with the principle of measurable and representative data selection in quantitative research (Sugiyono, 2022).

The primary research instrument is the 8DKM28e Main Engine's daily noon report, which serves as both an operational document and a quantitative data collection instrument. This instrument measures engine performance indicators such as main engine speed, turbocharger speed, fuel rack position, HFO consumption per period, and supporting operational conditions such as ship speed, weather conditions, and sea state, in accordance with standard practices for noon reporting on merchant vessels (Psaraftis et al., 2022; Santosa, 2021). In addition to the noon report, secondary instruments include ship technical documents (ship particulars and the 8DKM28e Main Engine manufacturer's manual) and academic literature on fuel efficiency and maritime regulations, which are used to build a theoretical foundation, validate normal parameter value ranges, and provide context for data interpretation (Manggombo, 2019; Zhang et al., 2025). Instrument quality is strengthened through data control procedures that include checking the completeness of entries, unit consistency, and the correspondence between reported values and the physical condition of the engine in the field as visually observed in the Engine Control Room (ECR) and the engine room.

The research procedure was systematically implemented in five main stages. The first stage was planning and permit application, namely obtaining a maritime practice permit and data access from ship management and relevant agencies, which ensured ethical compliance and the legality of operational data use. The second stage was primary data collection through documentation and observation studies: researchers accessed and summarized five 620 RPM noon reports under at-sea conditions, while also conducting direct observations in the ECR and engine room to obtain qualitative data in the form of visual documentation (photos of the instrument panel and the physical condition of engine components) that served as comparisons to validate the accuracy of the recorded values (Santosa, 2021; Rahman et al., 2022). The third stage was data filtration and tabulation, where the numerical data from the five noon reports were summarized in a single integrated table, checked for consistency and entry errors, and formatted according to analysis requirements (Psaraftis et al., 2022). The fourth stage was data analysis, and the final stage was interpretation of the results and writing conclusions, ensuring that each step could be replicated by other researchers (Sugiyono, 2022).

The data analysis technique used is descriptive quantitative analysis, as recommended in research with descriptive design that relies on numerical data to describe the conditions and patterns of operational phenomena (Sugiyono, 2022; Emzir, 2021). The tabulated numerical data were processed to calculate the average value, standard deviation, range of variation, and trend pattern of the main performance parameters (ME RPM, T/C RPM, fuel rack, HFO consumption) during the observation period, so that the performance characteristics of the 8DKM28e Main Engine at 620 RPM can be factually described. The subsequent analysis focused on identifying simple correlations or relationship patterns between variations in HFO fuel consumption and variations in engine performance parameters in the 5 noon report, emphasizing the "how" relationship rather than the experimental cause-and-effect relationship, as also applied in daily data-based maritime operational studies (Psaraftis et al., 2022; Wang et al., 2023). The analysis process can be carried out with the help of numerical data processing software such as SPSS or Excel to ensure the consistency and transparency of the descriptive statistical calculation procedures used.

Ethical considerations for the research were integrated from the planning stage through implementation. The research obtained data access and observation permission from the management of the MV Tanto Keluarga vessel and the relevant agencies overseeing the Marine Practice (PRALA) activities, ensuring that data collection did not disrupt the vessel's operations and safety. All data used is anonymous and does not reveal any personal information of the crew, thus maintaining the privacy of the operators and complying with the principle of data confidentiality (Emzir, 2021; Santosa, 2021). Furthermore, the data was used only for academic purposes and scientific publications, while maintaining the integrity of operational noon reports and technical documentation. Therefore, this research complies with ethical research principles that prioritize preventing harm to third parties and consider aspects of security, privacy, and legality in the use of ship operational data (Psaraftis et al., 2022; Wang et al., 2023).

III. RESULTS AND DISCUSSION

Data Presentation

The primary data used in this study were extracted from five authentic Noon Reports at Sea. These data were collected during sailing conditions where the 8DKM-28e Main Engine operated under operating load. These data were specifically selected for analysis to answer the research problem formulation.

Data Presentation: The primary data used in this study is the result of rigorous filtering of the Noon Report At Sea. This sorting was done to ensure accurate and apple-to-apple fuel consumption calculations. The following data shows observations of engine performance and fuel consumption variations.

Table 1. Main Engine Performance Observation Results Data During the voyage

No.	Report Date	ME (RPM)	TC (RPM)	Avg. Fuel Rack ME	HFO consumption	Weather & Sea Conditions
1	08-09-2024	619	24,800	30	8,275	*Rain-Moderate*
2	09-23-2024	618	24. 841	31	8,375	*Rain-Moderate*
3	09-25-2024	620	24,720	29	8,040	*Cloudy-Slight*
4	10-03-2024	623	24. 641	27	7,370	*Clear-Smooth*
5	10-15-2024	620	24,720	29	8,040	*Cloudy-Slight*

Based on Table 1 above, the engine's mechanical performance parameters are clearly visible. In the five engine performance data samples, the engine performance parameters appear to dynamically adjust to conditions during the voyage, with significant anomalies in fuel consumption (HFO Consumption) recorded. The lowest HFO consumption was recorded at 7,370 liters/24 hours (4th Report), while the highest consumption reached 8,375 liters/24 hours (2nd Report). This difference in consumption of almost 1,005 liters occurred even though the engine was rotated at the same speed, indicating the influence of other engine performance variables beyond the engine speed itself.

Data analysis

Data analysis was carried out in two stages. The first stage focused on validating engine performance parameters. The second stage focused on analyzing anomalies in fuel consumption variations.

1. Main Engine Performance Analysis

Problem Formulation 1 aims to determine the performance characteristics of the 8DKM-28e Main Engine under conditions during the voyage. The data in Table 1 provides a definitive and clear answer. In the five Noon Report observations, the main engine performance parameters were recorded dynamically.

Furthermore, the engine performance parameters also demonstrate dynamic performance. The data in Table 1 demonstrates that the main engine's performance was recorded dynamically at all five data points. Key parameters, such as the fuel rack, validate the study's basic assumptions. This analysis factually establishes that the main engine's mechanical performance baseline was in a dynamic steady-state condition throughout the observation period.

Main Engine RPM, T/C RPM, and Fuel Rack performance are dynamic performance parameters during the voyage. These parameters describe the ship's engine performance when operating dynamically and normally. This identified data demonstrates that there were no issues with the main engine's performance during the voyage.

2. Fuel Consumption Variation Analysis

Problem Formulation 2 aims to identify factors that influence fuel consumption variations while engine performance is dynamic. Data analysis in clearly reveals anomalies or data discrepancies that are the core of this study. Although ME RPM and T/C RPM are proven to be dynamic, the "HFO ME Consumption" data (Liter / 24 Hours) shows very significant fluctuations.

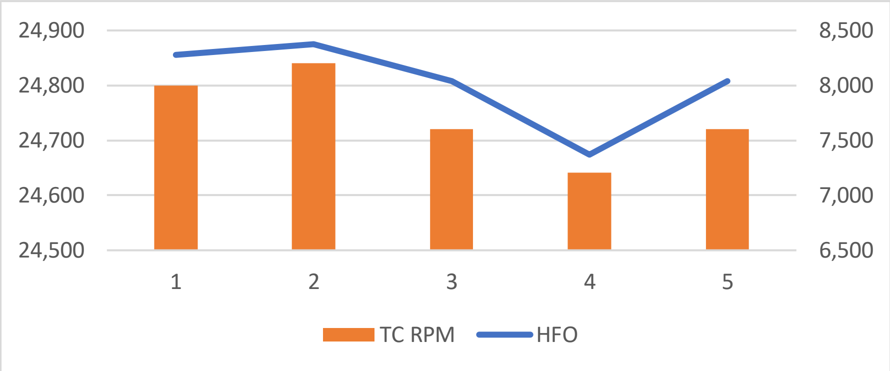

Fig 1. Graph of Variation in HFO ME Consumption

Source: (Researcher Data)

Analysis of Fuel Consumption Variations Based on Figure 1 above, it is clear that there are significant fluctuations in fuel consumption (HFO Consumption) with dynamic engine performance parameters.

Data shows the highest consumption occurred on September 23, 2024, at 8,375 liters per day. Conversely, the lowest consumption was recorded on October 20, 2024, at 7,370 liters per day. There is a consumption gap of 1,005 liters between the two conditions. This variation indicates that the engine is experiencing changes in torque load caused by factors other than RPM adjustment, where the governor increases fuel supply to maintain stable engine speed.

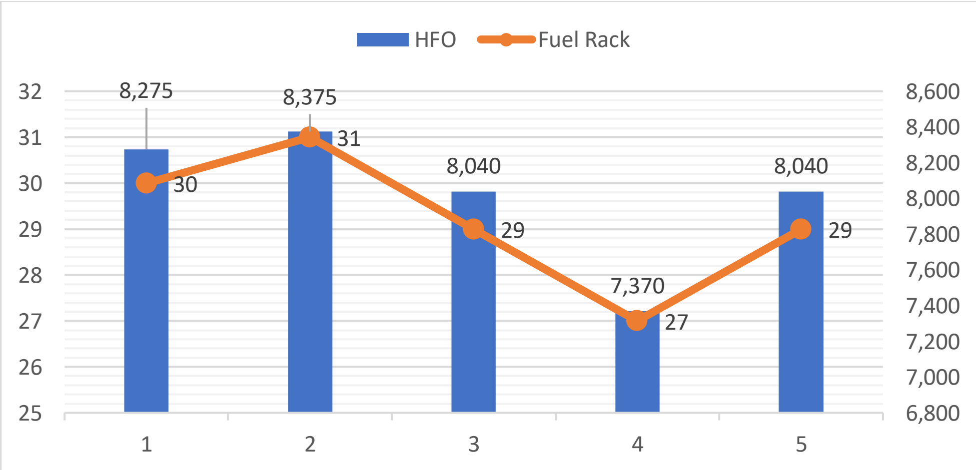

Fig 2. Correlation Analysis of Fuel Rack vs. HFO Consumption

Source: (Researcher Data)

To test the internal factor hypothesis, researchers used a fuel rack correlation analysis to compare fuel consumption with the fuel rack for each noon report. The comparison results are presented in Figure 2.

The fuel rack and HFO consumption showed significant variation. This indicates that variations in HFO consumption are directly influenced by the fuel rack.

This data fact assumes that the increase in fuel consumption in this case was caused by the main engine performance parameters. Therefore, the high fuel rack and HFO consumption on September 23rd indicate significant external resistance. It is known that on that date the ship was experiencing bad sea state (bad weather or currents), so the engine governor automatically increased fuel injection to overcome added resistance and maintain rotation.

Discussion

This discussion section focuses on interpreting the research findings presented in Table 1. The discussion is divided into two main sections based on the problem formulation. The first section discusses the consistency of engine performance, and the second section discusses the anomalies in fuel consumption variation.

Main Engine Performance Validation

The results of the data analysis definitively answer Problem Formulation 1. The data in Table 1 shows that during the five observation periods, the performance parameters of the 8DKM-28e Main Engine were in a changing steady state condition. The engine RPM, turbocharger RPM and fuel rack were recorded dynamically. This condition indicates that although the engine is operationally in a stable working range, there are still small fluctuations that occur in the main parameters of the engine. This phenomenon is common in ship propulsion systems because the engine must continuously adapt to changes in operating conditions such as variations in ship resistance, water conditions, and propeller loads that change in real time during the voyage.

As explained, the turbocharger is a dependent component whose rotation is regulated by the volume and energy of the exhaust gas.(Julianto & Sunaryo, 2020)This dynamic data proves that the main engine's performance parameters are also dynamic. Technically, a small increase or decrease in fuel supply will affect the combustion process in the cylinder, which in turn affects the volume and energy of the exhaust gas that exits the turbocharger. Changes in exhaust gas energy will directly impact the turbocharger's rotational speed (RPM), which then affects the supply of combustion air into the combustion chamber. Thus, the relationship between the fuel rack, Main engine RPM, and turbocharger RPM is an interconnected system in one engine performance control mechanism.

This variation indicates that the engine is experiencing changes in torque load caused by factors other than the RPM setting, where the governor increases the fuel supply to maintain a stable main engine RPM. In principle, the governor in a diesel engine functions as an automatic control system that will adjust the amount of fuel injected when there is a change in the load on the engine shaft. Therefore, although the engine RPM value appears relatively stable, small changes in the fuel rack position and turbocharger rotation are important indicators that the engine is actually responding to the dynamics of operational loads. This strengthens the conclusion that the steady state condition of the main engine in operational practice is not always completely constant, but rather a state of dynamic equilibrium that continuously adjusts to changes in the ship's propulsion system load.

Interpretation of HFO Consumption Variation Anomalies

This discussion focuses on the anomalies found when analyzing Problem Formulation 2. The data in Table 2 shows significant variations in HFO consumption, ranging from 7,370 L/Day to 8,375 L/Day. The initial theoretical hypothesis is based onManggombo (2019) assume that this variation is caused by variations in the fuel rack on the injector to produce optimal combustion.

However, the data analysis findings in Table 4.3 indicate a clear linear correlation. For example, in the report, the main engine parameters for different fuel racks caused changes in HFO consumption. This proves that the fuel rack is an internal factor causing variations in HFO consumption recorded in the Noon Report.

This unexpected finding led to an alternative hypothesis: external factors not recorded in the Noon Report. Industry technical standards, such as ISO 15016:2015, specifically address methodologies for correcting ship performance data for sea state effects. External factors such as weather and sea state significantly influence fuel consumption.(International Organization for Standardization, 2015).

In adverse sea conditions (e.g., high waves), the main engine governor will automatically inject more fuel just to maintain the rotation at 620 RPM. This condition occurs because when the ship faces high waves, strong winds, and unstable sea currents, resistance to the ship's motion will increase significantly. This increased resistance causes the propeller to require greater thrust to maintain its operational performance. When the load on the propeller increases due to heavy sea conditions, the main engine will experience an increased workload. In this situation, the governor system on the main engine functions automatically to maintain stable engine rotation so that it does not decrease or increase from the predetermined value.

The governor system operates on the principle of regulating fuel supply based on changes in engine load. When engine load increases due to unfavorable environmental conditions, the governor detects a tendency for engine speed to decrease. In response, the governor increases the amount of fuel injected into the combustion chamber, increasing combustion energy and generating the additional power needed to maintain engine speed. This way, even if sea conditions increase the mechanical load on the propulsion system, engine speed can still be maintained at the desired value.

Abyadha (2023)supports these findings, stating that weather factors can significantly increase engine loads. The study explains that unstable weather conditions, such as high waves, strong winds, and changing ocean currents, can cause increased ship resistance and load fluctuations on the propulsion system. As a result, the main engine must produce more power to maintain stable ship operations. This increased power requirement directly correlates with increased fuel consumption, as the combustion process must produce more energy to overcome the additional load caused by environmental conditions.

Furthermore, wave-induced ship motions such as pitching, rolling, and heaving can also cause variations in the load on the propeller and main engine. When the propeller is partially out of the water due to pitching or heaving, the load on the engine can change suddenly, then increase again when the propeller is fully submerged again. This dynamic load change forces the governor system to continuously adjust the fuel supply to maintain stable engine speed. This can ultimately lead to higher fuel consumption compared to calm sea conditions.

This phenomenon indicates an alternative hypothesis that external factors such as weather conditions during the voyage can explain the anomaly in the variation of HFO fuel consumption, because changes in the ship's operating environment directly affect the engine's power requirements and the amount of fuel that must be supplied to maintain the desired engine performance. In other words, variations in fuel consumption are not always caused by internal engine factors such as combustion efficiency or engine component conditions, but are also greatly influenced by the ship's operational conditions at sea. Therefore, in analyzing HFO fuel consumption data, weather and sea conditions need to be considered as external variables that have a significant influence on the performance of the main engine and the efficiency of fuel use during cruise operations.

The very high HFO consumption of 8,375 L/day likely occurred due to the internal load on the fuel rack and external factors (bad weather) that increased the propulsion load. Conversely, the low consumption of 7,370 L/day occurred in very calm sea conditions. This finding, correlating performance parameters with the relevance of weather factors, aligns with other studies (e.g.,(Oo et al., 2022) who found that the dynamic response of the governor was greatly influenced by sea conditions.

V. CONCLUSION

This study successfully revealed that under conditions of stable performance of the 8DKM28e Main Engine at 620 RPM, HFO fuel consumption still experienced significant variations due to a combination of internal and external factors. The main findings showed that although ME RPM and T/C RPM operated within a relatively stable range, parameters such as fuel rack, weather conditions, and sea state played an important role in determining fuel consumption patterns, so that HFO consumption could vary by almost 1,005 liters per day without significant changes in RPM. This proves that the assumption of "steady state = constant consumption" is not fully applicable in ship operational practice, because the main engine system is in a state of dynamic equilibrium that continues to adjust to changes in external loads and resistance, especially in bad weather and high waves.

Due to limitations, this study only relied on five noon reports with relatively short sailing conditions, thus limiting temporal coverage and route variation. Furthermore, other variables such as injector technical condition, fuel quality, and more granular ship speed data were not fully recorded in the noon reports, thus preventing in-depth analysis. Further research is recommended to combine noon report data with real-time sensor-based engine log data, expand the observation period, and integrate additional indices such as Added Resistance in Waves to measure the influence of sea conditions more quantitatively. Practical implications: ship operators and shipping companies need to integrate fuel rack, weather, and sea state monitoring into fuel efficiency audit systems, so that fuel management strategies can be designed more accurately, potentially reducing OPEX, and supporting decarbonization efforts in accordance with IMO CII and EEXI regulations.

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