JURNAL SYNTAX TRANSFORMATION
Printed ISSN: 2721-3854 | Electronic ISSN: 2721-2769

Volume 6, No. 12 December, 2025
p-ISSN 2721-3854 | e-ISSN 2721-2769

A Comparative Analysis of Fuel Efficiency and Operational Performance of Ferry Vessels Operating on the Merak Bakauheni Route

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ABSTRACT
Fuel consumption remains one of the most significant operational components in the maritime transportation sector, particularly on routes characterized by high vessel frequency such as Merak-Bakauheni. This study aims to examine the efficiency of fuel utilization among four ferry vessels operating on this route—two categorized as express ferries and two classified as regular ferries. Using a mixed-methods approach that integrates quantitative fuel-use analysis with qualitative evaluation of operational constraints, the research investigates how engine speed, power output, voyage duration, and port-related delays affect overall fuel efficiency. The findings demonstrate substantial differences in fuel consumption between the two ferry categories, largely influenced by engine load patterns and operational behavior. Furthermore, port congestion, limitations in jetty availability, and slow loading-unloading procedures contribute significantly to additional fuel usage, particularly through prolonged auxiliary engine operation. These findings emphasize the need for an improved operational framework that includes speed optimization, more effective port coordination, and real-time monitoring mechanisms to minimize fuel waste and enhance maritime performance.

Keywords: fuel efficiency, ferry vessel, engine RPM, fuel consumption, maritime operations

INTRODUCTION

The Merak–Bakauheni crossing serves as one of Indonesia's most critical transportation arteries, linking the islands of Java and Sumatra while facilitating the movement of passengers, vehicles, and goods (Ariyanto et al., 2020; Putra & Sutanto, 2018). With hundreds of daily departures conducted by various ferry operators, the route plays a strategic role not only in national connectivity but also in the regional economy (Prabowo & Handayani, 2021; Wijaya et al., 2019). Within this intensive operational ecosystem, fuel consumption becomes the dominant expenditure for ferry operators, representing over half of total operating costs (Nurhadi et al., 2020; Siregar et al., 2022). Consequently, understanding the factors that influence fuel efficiency becomes essential for sustaining the economic viability of ferry services (Tahir & Hidayat, 2021; Barus et al., 2019).

Previous studies in maritime operational efficiency have largely focused on large commercial vessels and container shipping, often neglecting the specific operational dynamics of domestic ferry services, particularly in high-frequency short-sea routes. Research by Wang & Meng (2012) emphasized speed optimization in liner shipping, while Zhang et al. (2018) examined the impact of speed on energy consumption in coastal ferry operations. However, limited attention has been given to the combined influence of engine operational parameters, port-induced delays, and vessel classification on fuel consumption in Indonesian ferry operations, especially on the strategically vital Merak–Bakauheni route. This gap underscores the urgency of this study, as rising fuel prices and operational inefficiencies threaten the sustainability of ferry services that are

essential to national logistics and passenger mobility (Lubis, 2022; Rohmah et al., 2025; Yang et al., 2020).

Ferry vessels on this route are divided into two main categories: express ferries, which prioritize speed and shorter voyage durations, and regular ferries, which emphasize transport capacity and schedule stability (Kong & Lee, 2017; Smith et al., 2019). Differences in vessel architecture, engine ratings, and operational profiles result in significant variations in fuel consumption (Yu et al., 2020; Li & Jin, 2021). Express ferries typically operate at higher revolutions per minute (RPM) and engine loads, allowing them to complete the journey more quickly but at the expense of increased fuel use (Tan & Wong, 2021; Zhao et al., 2020). In contrast, regular ferries tend to maintain moderate speeds with comparatively lower RPM, resulting in reduced fuel burn per hour but potentially longer travel times (Yuan & Zhang, 2018; Ding et al., 2019).

This study was conducted in response to growing concerns from ferry operators regarding rising fuel costs, operational inefficiencies, and port-induced delays. These challenges are particularly important in Merak and Bakauheni, where congestion, weather conditions, and jetty limitations can cause significant delays and increase fuel consumption through extended use of propulsion and auxiliary engines. By examining the fuel consumption profiles of four representative vessels—two express and two regular types this study seeks to identify patterns, inefficiencies, and opportunities for improving maritime operational performance.

This study aims to conduct a comparative analysis of fuel efficiency and operational performance between express and regular ferry vessels operating on the Merak–Bakauheni route by examining the influence of engine speed, load factors, voyage duration, and port-related delays on fuel consumption. The novelty of this research lies in its integrated mixed-methods approach, which combines quantitative fuel-use analysis with qualitative assessment of operational constraints specific to Indonesian ferry operations, thereby providing a holistic view often absent in prior studies. The findings are expected to offer practical benefits to ferry operators, port authorities, and policymakers by identifying actionable strategies for fuel optimization, reducing operational costs, enhancing scheduling reliability, and supporting the development of more sustainable maritime transportation systems in Indonesia.

METHOD

This study employed a mixed-methods approach to analyze fuel consumption and operational characteristics. The research was conducted at the Merak and Bakauheni ports, both of which serve as key nodes in the ferry transportation network between Java and Sumatra. The vessels selected for analysis included two express ferries KMP Legundi and KMP Port Link and two regular ferries KMP Neomi and KMP Calisha. These vessels were chosen to represent a broad spectrum of vessel types and operational patterns on the route.

Data collection involved three primary techniques. The first was direct observation aboard the vessels, during which researchers recorded engine RPM, engine power output (in kilowatts), voyage duration, and fuel usage patterns. These observations provided the quantitative basis for

comparing fuel efficiency across vessels. The second technique involved structured interviews with ship officers, engineers, and port personnel to gather qualitative insights regarding operational constraints, port delays, and procedural challenges. The third technique included the examination of vessel logs, SFC charts, and operational documentation to ensure data validity and accuracy.

The analysis began with calculating hourly and per-voyage fuel consumption using RPM kW SFC calculations. Comparisons were made across the four vessels to reveal differences in operational behavior. A qualitative thematic analysis was conducted to identify recurring issues related to port operations, maneuvering, and waiting times. Finally, the quantitative and qualitative findings were integrated to form a comprehensive evaluation of fuel efficiency and performance.

RESULTS AND DISCUSSION

The findings revealed considerable variation in fuel consumption among the four vessels. The express ferries KMP Port Link and KMP Legundi displayed significantly higher RPM values throughout their voyages. These elevated RPM levels corresponded to increased power output and higher hourly fuel consumption. KMP Port Link, in particular, exhibited the highest fuel consumption among the four vessels, not only due to its larger propulsion system but also because of its operational emphasis on maintaining high speeds to reduce travel time. KMP Legundi, although also categorized as an express ferry, demonstrated a more stable RPM pattern, resulting in slightly more efficient fuel usage compared to KMP Port Link.

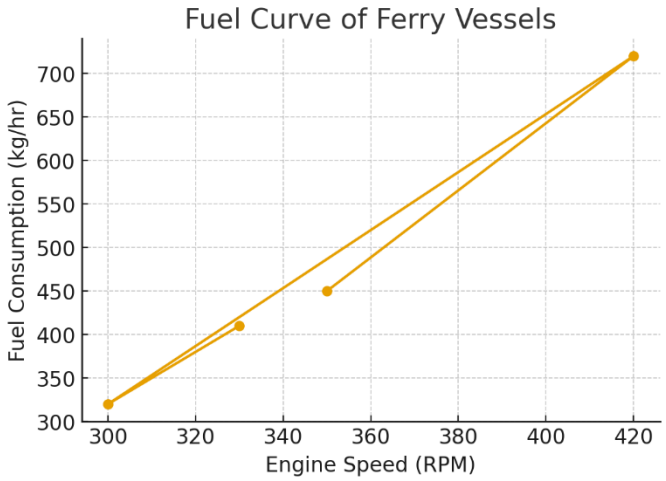

Figure 1. Graph Comparing RPM and Fuel Consumption per Hour
Source: Field observation data and calculation results (2024)

Among the regular ferries, KMP Neomi stood out as the most fuel-efficient vessel in the study. Its moderate RPM levels, combined with consistent voyage patterns and stable loading practices, contributed to its superior performance. KMP Calisha, while also a regular ferry, consumed more fuel due to comparatively higher engine speeds and greater load fluctuations. These differences highlight the impact of operational behavior, vessel design, and load distribution

on fuel consumption.

In addition to vessel-specific factors, operational delays emerged as a critical determinant of overall fuel efficiency. Interviews with crew members and port authorities revealed that jetty unavailability was the most common cause of delays. Vessels often had to wait offshore or perform slow-speed maneuvers while awaiting berthing clearance. These activities led to increased fuel usage, both through additional main engine operation during maneuvering and through extended auxiliary engine use during idle time. Loading and unloading inefficiencies further exacerbated these delays, particularly during peak operational hours.

Table 1. Comparison of Fuel Consumption Across Four Vessels

Vessel Name	Vessel Type	Actual RPM	Load (%)	ME Consumption (L/hr)	AE Consumption (L/hr)	Total Consumption (L/hr)	Trip Duration	Fuel per Trip (L/trip)	Fuel per Day (8 Trips)
Reguler Satu	Express	451.5	42.61 %	388.50	56.50	445.00	2 hours	890.00	7,120.00
Reguler Dua	Express	530	54.21 %	633.31	98.82	732.14	2 hours	1,464.27	11,714.16
Express Dua	Regular	500	52.45 %	595.61	131.76	727.37	1 hour	727.37	5,818.96
Express Satu	Regular	500	88.90 %	2,702.55	222.35	2,924.90	1 hour	2,924.90	23,399.20

Source: Ship log data and direct measurement results (2024)

The relationship between engine RPM and fuel consumption was clearly evident in the data. The cubic propulsion law was demonstrated repeatedly, as vessels that increased RPM slightly experienced disproportionately higher fuel usage. This finding reinforces the importance of adopting eco-sailing strategies such as reducing RPM during non-essential periods to minimize operational fuel costs without significantly affecting timetable requirements.

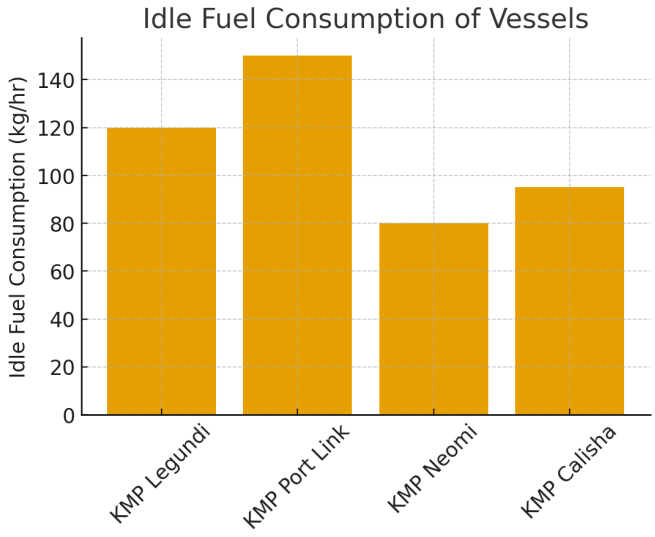

Figure 2. Relationship Between RPM and Fuel Consumption by Ferry Category
Source: Analysis of vessel operational data (2024)

Overall, the results illustrate that fuel efficiency is shaped not only by vessel design and engine performance but also by the broader operational ecosystem, including port management, sea traffic density, and crew decision-making. Addressing these interconnected factors is essential for improving maritime operational sustainability.

CONCLUSION

This study reveals significant fuel efficiency variations between express and regular ferries on the *Merak–Bakauheni* route, with express ferries showing higher consumption from elevated engine speeds and time-focused operations, while regular ferries like KMP Neomi exhibit superior efficiency through moderate RPM and stable patterns. Key inefficiencies stem from port congestion, jetty unavailability, and loading-unloading delays, alongside an exponential link between RPM and fuel use, emphasizing the need for speed regulation, eco-sailing, real-time fuel monitoring, optimized RPM management, and better port coordination to curb waste and boost performance. For future research, investigators could expand this analysis by incorporating weather impacts, alternative fuel trials (e.g., biofuels), or AI-driven predictive modeling for dynamic route optimization across other Indonesian short-sea ferry networks.

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