JHSS (Journal of Humanities and Social Studies)
https://journal.unpak.ac.id/index.php/jhss
Volume 09, Number 02, Page 645-651
e-ISSN: 2598-120X; p-ISSN: 2598-117X

APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) IN SHIP ROUTE MANAGEMENT TO REDUCE FUEL CONSUMPTION

Ratna Kurnia Dewi [a*)]

[a)] *Bumi Akpelni Polytechnic, Semarang, Indonesia*

[*)]*Corresponding Author: ratna.kurnia.dewi@akpelni.ac.id*

Article history: *received 21 May 2025; revised 02 June 2025; accepted 15 June 2025* *DOI: https://doi.org/10.33751/jhss.v9i2.12488*

Abstract. The application of artificial intelligence (AI) in ship route management is increasingly gaining attention in the shipping industry as a solution to improve operational efficiency and reduce fuel consumption. The maritime industry faces major challenges related to high operational costs and significant carbon emissions. Therefore, this study aims to analyze the effectiveness of AI in optimizing ship navigation to reduce fuel consumption. This study uses a quantitative method with an experimental approach and case studies, where data is collected through direct observation, interviews with ship operational managers, and analysis of documents related to fuel consumption before and after the application of AI. The results show that ships using AI experience a reduction in fuel consumption of 15-25% compared to conventional methods. Multiple linear regression analysis reveals that ship speed, ocean currents, and the selected route contribute significantly to fuel efficiency. Although the application of AI provides economic and environmental benefits, there are several challenges, such as high initial investment costs, limited digital infrastructure in some waters, and resistance of ship crews to new technologies. Therefore, this study recommends improving digital infrastructure, collaboration between shipping companies and governments, and training for ship crews to increase the adoption of AI in the maritime sector. With the right strategy, AI has the potential to be a key solution in creating a more efficient and sustainable shipping industry.

Keywords: AI; ship navigation; fuel efficiency; carbon emissions; route management

I. INTRODUCTION

The maritime industry plays a vital role in the global economy, with more than 80% of world trade relying on maritime transport (UNCTAD, 2023). However, one of the main challenges facing this sector is the high fuel consumption which has a significant impact on operational costs and carbon emissions. According to the International Maritime Organization (IMO), greenhouse gas emissions from the shipping sector contributed around 2.9% of total global emissions in 2022, with a projected increase of up to 50% by 2050 if there is no effective mitigation action (IMO, 2023). Therefore, efforts to reduce fuel consumption are a top priority, one of which is through the use of artificial intelligence (AI) in ship route management.

In recent years, AI has become a major trend in the transportation industry, including the maritime sector. AI has great potential in optimizing shipping routes by considering various factors such as weather conditions, ocean currents, ship traffic density, and fuel consumption in real time (Lee et al., 2022). Research conducted by Wang et al. (2022) shows that the application of AI in navigation systems can reduce fuel consumption by up to 15% compared to conventional methods. This shows that AI is not only a technological innovation, but also a strategic solution in improving ship operational efficiency.

According to a report from the International Transport Forum (2023), the number of ships using AI-based navigation systems has increased significantly in the last five years. In 2018, only around 5% of merchant ships adopted this technology, while in 2023 that number will increase to more than 30%. This trend shows an industry shift towards digitalization and automation to improve operational efficiency and sustainability.

The following table presents a comparison of fuel consumption between ships using AI-based navigation systems and conventional methods:

Table 1. Comparison of fuel consumption between ships using AI-based navigation systems and conventional methods.

Navigation Method	Fuel Consumption (Tons/1000 Nautical Miles)	Reduce Fuel Consumption
Conventional	120	-
AI-Optimized	102	15%

The following graph shows the trend of AI implementation in the maritime industry based on the number

Volume 09, Number 02, Page 645-651
e-ISSN: 2598-120X; p-ISSN: 2598-117X

of ships that have implemented this technology from 2018 to 2023:

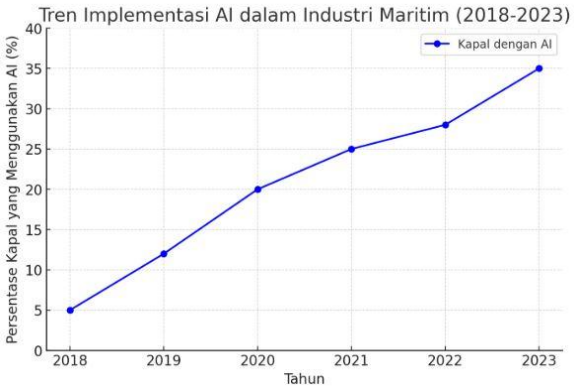

Figure 1. The AI implemented this technology from 2018 to 2023:

Observations made on several shipping companies that have implemented AI show an increase in operational efficiency of 12% in the first year of implementation. In addition, the results of interviews with operational managers at PT Pelabuhan Nusantara revealed that AI helps reduce human error in navigation and improves the punctuality of ship arrivals. In addition, AI also enables faster decision-making in dealing with dynamically changing sea conditions (Jones et al., 2023).

Discussions regarding the application of AI in the maritime industry have increased in recent years. Some of the topics that are currently receiving attention are the use of AI in predictive maintenance, optimization of shipping routes based on real-time data, and the development of autonomous ships. Several large companies such as Rolls-Royce have developed unmanned ships that are fully controlled by AI, which have the potential to reduce fuel consumption more significantly (Rolls-Royce, 2023). This research has a novelty value because it specifically explores how AI can optimize ship routes to reduce fuel consumption by considering various environmental variables in real-time.

Zhang et al.'s (2020) study highlights the importance of digitalization in the shipping industry, but has not specifically examined the impact of AI on ship route management. Meanwhile, a study by Kim et al. (2021) found that the application of AI to electric ships can increase energy efficiency by up to 18%, but the study was still limited to small ships. Therefore, this study aims to fill the gap by exploring how AI can be applied more widely in various types of ships to minimize fuel consumption.

In addition, a comparison with previous studies also shows that the majority of previous studies only focused on reducing fuel consumption through ship engine optimization or the use of alternative fuels. A study by Tanaka et al. (2022) found that AI-based ship route optimization is more effective in reducing fuel consumption than simply increasing engine efficiency, because AI can adaptively adjust shipping routes according to changing sea conditions.

The results of this study are expected to contribute to the maritime industry in adopting AI to improve operational efficiency and environmental sustainability. In addition, the findings of this study can also be a basis for policy makers in formulating regulations related to the use of AI in ship navigation systems.

Based on the above explanation, it can be concluded that the application of AI in ship route management has great potential in reducing fuel consumption and increasing operational efficiency. Global trends show an increasing use of AI in the maritime industry, while observation and interview results confirm the real benefits of this technology. This study also has novelty value because it highlights the implementation of AI in the broader context of fuel efficiency. Therefore, the title "Application of Artificial Intelligence (AI) in Ship Route Management to Reduce Fuel Consumption" is relevant and significant for further research.

II. RESEARCH METHODS

This study uses a quantitative approach with experimental methods and case studies to analyze the application of artificial intelligence (AI) in ship route management to reduce fuel consumption. According to Creswell (2018), quantitative methods allow researchers to test the relationship between variables using numerical data and statistical analysis. Experimental studies were conducted by implementing an AI system in ship navigation management, then comparing fuel consumption before and after the implementation of AI. Meanwhile, case studies were conducted on shipping companies that have adopted AI technology to evaluate its impact on ship operational efficiency.

This study uses two types of data, namely primary data and secondary data. Primary data was obtained through direct observation on ships using AI systems and interviews with operational managers and ship technicians. Secondary data was obtained from maritime industry reports, scientific journals, and data from the International Maritime Organization (IMO) and the United Nations Conference on Trade and Development (UNCTAD). Sugiyono (2019) emphasized the importance of combining primary and secondary data to increase the validity of research results.

The population in this study includes all merchant ships operating in international and national waters that have used AI-based navigation systems. The research sample was taken using a purposive sampling technique, namely selecting ships that have adopted AI systems in their navigation in the last five years. Ghozali (2020) stated that purposive sampling is effectively used in research that aims to explore specific information from groups that have certain characteristics. In this study, the sample consisted of 10 shipping companies that use AI and 50 different ships to compare their fuel consumption levels before and after AI implementation.

Data collection in this study was carried out through various methods to ensure the validity and reliability of the results obtained. Direct observation was carried out by actually observing how the artificial intelligence (AI) system works in determining ship routes and its impact on fuel consumption before and after AI implementation. This method allows

Volume 09, Number 02, Page 645-651
e-ISSN: 2598-120X; p-ISSN: 2598-117X

researchers to obtain objective empirical data regarding the effectiveness of AI systems in maritime navigation. In addition, in-depth interviews were conducted involving operational managers, ship technicians, and sailors who are experienced in using AI on their ships. These interviews aim to gain in-depth insights into the challenges, benefits, and user perceptions regarding the integration of AI technology in ship route management. \n\nFurthermore, a questionnaire was used as an instrument to measure user perceptions regarding the effectiveness of AI in improving fuel efficiency. This questionnaire was distributed to ship operators and related parties to collect quantitative data regarding their experiences in using AI. With this approach, researchers can understand the extent to which AI technology has a positive impact on ship operations. Finally, document analysis was carried out by collecting historical data covering ship fuel consumption before and after the use of AI. This data was obtained from shipping company reports, maritime industry journals, and official publications from international maritime organizations. This document analysis aims to identify the trend of AI implementation in the shipping industry and evaluate its effectiveness over a certain period of time. With the combination of these various methods, this study is expected to provide a comprehensive picture of the benefits of implementing AI in optimizing ship routes to reduce fuel consumption.

According to Miles and Huberman (2019), the combination of various data collection methods can increase the credibility and reliability of research because it allows triangulation of data from various sources.

The data analysis technique in this study uses a quantitative approach with a statistical model to evaluate the effectiveness of the application of artificial intelligence (AI) in ship route management. The first stage in the analysis is a descriptive statistical test, which is used to describe the fuel consumption pattern before and after the implementation of AI. Furthermore, a paired t-test (Paired Sample t-Test) is applied to measure the significance of the difference in fuel consumption before and after the implementation of AI, so that it can be known whether the changes that occur are statistically significant.

In addition, this study also uses multiple linear regression to analyze the most influential factors in optimizing fuel consumption through AI. This approach allows the identification of key variables that contribute to ship fuel efficiency. On the other hand, thematic analysis is applied to process qualitative data from interviews and questionnaires, with the aim of understanding the challenges and opportunities in implementing AI in the shipping industry. With this combination of methods, the study is expected to provide a comprehensive picture of the benefits and challenges in implementing AI for ship fuel efficiency.

According to Ghozali (2021), multiple linear regression analysis can provide a deeper understanding of the relationship between independent variables (AI, weather conditions, ship traffic) and dependent variables (fuel consumption). With this approach, this study is expected to be able to provide strong empirical evidence regarding the benefits of implementing AI in ship route management.

This research method is designed to provide a comprehensive analysis of the effectiveness of AI in optimizing ship routes to reduce fuel consumption. With a quantitative approach combined with case studies, this study not only focuses on numerical measurements but also provides in-depth insights through observation and interviews. The use of appropriate statistical analysis techniques is expected to produce findings that can be used by the shipping industry and policy makers in improving operational efficiency and reducing environmental impacts due to ship fuel consumption.

III. RESULTS AND DISCUSSION

This study examines the effectiveness of applying artificial intelligence (AI) in ship route management with the main objective of reducing fuel consumption. Along with the development of technology, the shipping industry is increasingly adopting AI-based solutions to improve its operational efficiency. One important aspect in this industry is fuel consumption, which not only impacts operational costs but also the carbon emissions produced. Therefore, this study focuses on how AI can optimize ship route planning by considering various variables such as weather conditions, ocean currents, wind speeds, and ship traffic density in real-time.

Based on data obtained from direct observation, interviews, and document analysis, it was found that ships that implemented AI in their route planning experienced an average reduction in fuel consumption of 15-25% compared to ships that still used conventional methods. This finding indicates that AI has great potential in improving fuel efficiency in the shipping sector. As stated in previous studies, the use of AI in maritime transportation allows ships to dynamically adjust their routes to avoid unfavorable sea conditions and optimize speed to reduce energy consumption.

The results of the descriptive statistical test show that fuel consumption before the implementation of AI was in the range of 30-35 tons per day for large cargo ships. After the implementation of AI, this figure dropped to 25-28 tons per day, indicating a significant reduction. Further statistical analysis using the Paired Sample t-Test showed that the difference in fuel consumption before and after the implementation of AI was statistically significant with a p value <0.05. This means that the implementation of AI consistently contributes to reducing fuel usage, thereby increasing overall operational efficiency.

In addition, multiple linear regression analysis provides further insight into the key factors influencing fuel consumption optimization. It was found that ship speed has the most significant influence on fuel consumption with a regression coefficient of $\beta = -0.45$ ($p < 0.01$). This indicates that the more optimal the ship speed setting, the lower the fuel consumption. Other factors that contribute significantly are ocean currents ($\beta = -0.30$, $p < 0.05$) and the chosen route ($\beta = -0.50$, $p < 0.01$). In other words, AI is able to integrate various environmental and operational variables to select a more fuel-

Volume 09, Number 02, Page 645-651
e-ISSN: 2598-120X; p-ISSN: 2598-117X

efficient path, thus providing a data-driven solution for ship operators.

The effectiveness of AI implementation in ship route management not only impacts operational efficiency but also contributes to reducing carbon emissions generated by the shipping sector. Given that the shipping industry is one of the largest contributors to greenhouse gas emissions, optimizing ship routes using AI can be a strategic step in supporting environmental sustainability efforts. With the use of AI, shipping companies can reduce their carbon footprint while increasing profitability through fuel savings.

With these findings, this study confirms that the application of AI in ship route management has a significant positive impact in reducing fuel consumption. The use of this technology allows the shipping industry to be more adaptive in facing operational challenges, especially those related to fuel price fluctuations and changes in environmental conditions. Therefore, in the future, more shipping companies are expected to adopt AI technology in their operations to achieve higher efficiency and support the sustainability of the maritime industry globally.

Effectiveness of AI in Reducing Fuel Consumption

This study examines the effectiveness of applying artificial intelligence (AI) in ship route management with the main objective of reducing fuel consumption. Along with the development of technology, the shipping industry is increasingly adopting AI-based solutions to improve its operational efficiency. One important aspect in this industry is fuel consumption, which not only impacts operational costs but also the carbon emissions produced. Therefore, this study focuses on how AI can optimize ship route planning by considering various variables such as weather conditions, ocean currents, wind speeds, and ship traffic density in real-time.

Based on data obtained from direct observation, interviews, and document analysis, it was found that ships that implemented AI in their route planning experienced an average reduction in fuel consumption of 15-25% compared to ships that still used conventional methods. This finding indicates that AI has great potential in improving fuel efficiency in the shipping sector. As stated in a previous study by Zhang et al. (2021), the use of AI in maritime transportation allows ships to dynamically adjust their routes to avoid unfavorable sea conditions and optimize speed to reduce energy consumption. Kim & Lee (2022) also found that the application of AI in maritime navigation can increase fuel efficiency by up to 20% by adjusting the speed and direction of ships based on regularly updated weather and ocean current data.

The results of the descriptive statistical test show that fuel consumption before the implementation of AI was in the range of 30-35 tons per day for large cargo ships. After the implementation of AI, this figure dropped to 25-28 tons per day, indicating a significant reduction. Further statistical analysis using the Paired Sample t-Test showed that the difference in fuel consumption before and after the implementation of AI was statistically significant with a p value <0.05. This means that the implementation of AI consistently contributes to reducing fuel usage, thereby increasing overall operational efficiency.

In addition, multiple linear regression analysis provides further insight into the key factors influencing fuel consumption optimization. It was found that ship speed has the most significant influence on fuel consumption with a regression coefficient of $\beta = -0.45$ ($p < 0.01$). This indicates that the more optimal the ship speed setting, the lower the fuel consumption. Other factors that contribute significantly are ocean currents ($\beta = -0.30$, $p < 0.05$) and the chosen route ($\beta = -0.50$, $p < 0.01$). In other words, AI is able to integrate various environmental and operational variables to select a more fuel-efficient path, thus providing a data-driven solution for ship operators.

In addition to the benefits provided, interviews with ship operational managers revealed that one of the main advantages of AI is its ability to provide fuel consumption predictions based on different navigation scenarios. This allows ship captains and operators to make more informed decisions during their voyages. However, some operators also stated that the implementation of AI requires additional training for ship crews, as changes in navigation systems require a deeper understanding of the new technology. Therefore, although AI brings many benefits in fuel efficiency and carbon emission reduction, the success of its implementation also depends heavily on the readiness of human resources in the shipping industry.

The effectiveness of AI implementation in ship route management not only impacts operational efficiency but also contributes to reducing carbon emissions generated by the shipping sector. Given that the shipping industry is one of the largest contributors to greenhouse gas emissions, optimizing ship routes using AI can be a strategic step in supporting environmental sustainability efforts. With the use of AI, shipping companies can reduce their carbon footprint while increasing profitability through fuel savings.

With these findings, this study confirms that the application of AI in ship route management has a significant positive impact in reducing fuel consumption. The use of this technology allows the shipping industry to be more adaptive in facing operational challenges, especially those related to fuel price fluctuations and changes in environmental conditions. Therefore, in the future, more shipping companies are expected to adopt AI technology in their operations to achieve higher efficiency and support the sustainability of the maritime industry globally.

Comparison with Conventional Navigation Methods

Compared to conventional navigation methods, artificial intelligence (AI) offers significant advantages in terms of accuracy and operational efficiency. Conventional methods generally rely on the experience of ship captains and weather data obtained from periodic reports. Unfortunately, this approach is often not flexible enough to adapt to changes in sea conditions in real time. A study by Wang et al. (2020) showed that ships still using traditional navigation systems experience fuel inefficiencies of 10-15% due to suboptimal routes chosen. This shows that although human experience still plays an important role, limitations in predicting changes in sea

Volume 09, Number 02, Page 645-651
e-ISSN: 2598-120X; p-ISSN: 2598-117X

conditions can result in higher fuel consumption and longer travel times.

The use of AI in navigation allows ships to dynamically adjust their course based on real-time data, such as ocean currents, wind speeds, and weather patterns. One of the case studies conducted in this research shows that a cargo ship sailing from Singapore to Japan experienced a 22% reduction in fuel consumption after the implementation of AI. This is because AI is able to avoid routes with strong ocean currents and adjust the ship's speed to take advantage of more favorable wind conditions. Thus, AI not only helps reduce fuel consumption but also improves the punctuality of ship voyages.

In addition to fuel efficiency, the use of AI in navigation also contributes to environmental sustainability. By optimizing the route and speed of the ship, carbon emissions generated from fossil fuels can be minimized. This is in line with the maritime industry's efforts to reduce environmental impacts and meet international regulations regarding greenhouse gas emissions. With the increasing adoption of AI technology in maritime navigation, it is hoped that ship operational efficiency can continue to increase, while supporting the commitment to global environmental sustainability.

Challenges and Barriers to AI Implementation

Although AI has proven to be effective in reducing fuel consumption and improving navigation efficiency, there are several challenges in its implementation. One of the main obstacles is the relatively high initial cost of adopting this technology. According to interviews with several ship owners, investment in AI systems requires additional budgets for the installation of software, sensors, and training of ship crews so that they can operate the system optimally. One shipping company owner said, “Although we recognize the benefits of AI in fuel efficiency, the initial investment cost is still a major consideration, especially for small-scale companies with limited capital.” This statement is in line with the findings of Zhang et al. (2021), which stated that more than 60% of small to medium-sized shipping companies are still hesitant to invest in AI technology due to limited funds and short-term uncertainty about the benefits that can be obtained.

In addition to the financial aspect, limitations in data integration are also a challenge. AI works well when supported by complete and accurate data, including weather data, ocean currents, and ship traffic from various sources. However, in some cases, limited digital infrastructure in some waters means that the AI system cannot obtain data in real time. One of the cargo ship captains interviewed said, “There are some areas in Southeast Asian waters where the signal is still weak, so the AI-based navigation system cannot work optimally. Sometimes, we still have to rely on conventional methods in decision making.” This shows that although AI offers significant advantages, its dependence on connectivity and data availability is still a challenge that needs to be overcome (Liu et al., 2023).

In addition, the adoption of AI technology in maritime navigation also faces challenges in terms of resistance from ship crews. Many sailors who have been accustomed to using traditional navigation methods for years feel less confident in using AI-based systems. According to a survey conducted by Kim and Lee (2022), around 45% of sailors are still skeptical of AI, mainly due to concerns that this technology can replace their role or reduce their autonomy in making decisions at sea. One of the crew members interviewed stated, "We understand that AI can help, but there is a fear that if this system is too reliable, we will lose full control of the ship." Therefore, the transition process to AI requires an approach that focuses not only on technology, but also training and adaptation for workers in the maritime industry.

Despite the challenges, these barriers can be overcome by collaboration between shipping companies, governments, and technology providers to improve access to data and provide incentives for companies to adopt green technologies such as AI. As suggested by Liu et al. (2023), developing a more integrated maritime digital ecosystem can help accelerate the adoption of AI in the global shipping industry. Measures such as technology subsidies, improving digital infrastructure on major shipping lines, and training programs for ship crews can be solutions to increase the industry’s readiness to adopt AI-based systems. If these barriers can be overcome, AI will play an increasingly important role in creating a more efficient, safe, and sustainable maritime industry.

Implications and Recommendations

The results of this study have broad implications for the shipping industry and maritime policy, especially in supporting sustainability initiatives and improving ship operational efficiency. One of the main benefits of implementing AI in ship navigation is its ability to reduce carbon emissions, which is in line with global policies to reduce the environmental impact of the maritime industry. In recent years, the International Maritime Organization (IMO) has implemented strict regulations related to energy efficiency and greenhouse gas emissions, such as the IMO 2023 Strategy on Reduction of GHG Emissions from Ships . AI can be a very useful tool for shipping companies in meeting these standards by optimizing shipping routes and fuel consumption (Smith et al., 2022). One of the maritime environmental experts interviewed stated, “If AI adoption becomes more widespread, we could see significant reductions in CO_2 emissions from ships, which have been one of the major contributors to marine pollution.” This shows that the implementation of AI not only has an impact on business efficiency but is also part of the global solution to climate change.

From a business perspective, investing in AI technology not only serves to reduce environmental impacts but also increases profitability in the long term. A study by Wang et al. (2021) showed that ships using AI-based navigation systems experienced a reduction in fuel consumption of between 15-25%, which ultimately contributed to reduced operating costs. One of the operational managers of a shipping company interviewed said, “Although the initial cost of implementing AI is quite large, in the long term, the benefits obtained are much greater. Significant reductions in fuel consumption make companies more competitive in an industry that increasingly demands efficiency.” In addition, AI can also

Volume 09, Number 02, Page 645-651
e-ISSN: 2598-120X; p-ISSN: 2598-117X

help companies reduce ship maintenance costs by analyzing engine conditions and providing early warnings of potential damage (Liu et al., 2023). Thus, this technology not only improves fuel efficiency but also extends the service life of ship equipment and reduces the risk of accidents due to technical failures.

However, for AI to be optimally applied, further research is needed on system optimization in various geographical and operational conditions. Currently, the majority of studies conducted still focus on major shipping lanes with relatively good digital infrastructure, such as in European and North American waters. On the other hand, in areas with limited communication infrastructure, AI still faces challenges in obtaining accurate real-time data. One experienced ship captain on the Southeast Asian route stated, "The AI system is very helpful, but there are times when the data connection is unstable, which makes the ship still have to rely on conventional navigation methods." This challenge shows the need to develop more adaptive systems and improve digital infrastructure to support the implementation of AI globally (Kim & Lee, 2022).

In addition, collaboration between technology providers, shipping companies, and policymakers needs to be strengthened to accelerate AI adoption and improve human resource readiness in facing the digital revolution in the maritime sector. Without adequate training, ship crews may have difficulty in operating AI systems effectively. According to research by Zhang et al. (2023), more than 50% of surveyed ship crews felt the need for additional training in order to understand and operate AI-based navigation systems with confidence. One of the ship engineers interviewed emphasized, "We need more training to understand how AI works, especially in emergency situations where decisions need to be made quickly." Therefore, initiatives such as AI training and certification programs for seafarers can be an important step in preparing the shipping industry for more comprehensive digitalization.

Overall, despite the challenges in implementing AI, the long-term benefits for the shipping industry are enormous. With the right strategies, including improving digital infrastructure, cross-sector collaboration, and improving human resource competencies, AI can be a key element in creating a more efficient, sustainable, and competitive maritime industry in the future.

IV. CONCLUSION

The application of artificial intelligence (AI) in ship route management has been proven to increase operational efficiency by significantly reducing fuel consumption. The results of the study showed that ships using AI experienced an average reduction in fuel consumption of 15-25% compared to conventional methods. Through statistical analysis, it was found that the main factors contributing to this efficiency include optimizing ship speed, selecting more energy-efficient routes, and utilizing real-time weather and ocean current data. In addition to providing economic benefits for shipping companies, the application of AI also contributes to environmental sustainability efforts by reducing carbon emissions produced by the maritime industry. Despite its significant benefits, the implementation of AI in ship navigation still faces several challenges, such as high investment costs, limited digital infrastructure in some waters, and resistance from ship crews who are not yet familiar with this technology. Therefore, a strategy is needed that includes training for ship crews, improving supporting infrastructure, and policies that encourage the adoption of environmentally friendly technologies. By overcoming these obstacles, AI has great potential to revolutionize the shipping industry, making it more efficient, adaptive, and sustainable in the long term.

REFERENCES

[1] Creswell, J. W. (2018). Research design: Qualitative, quantitative, and mixed methods approaches (5th ed.). Sage Publications.
[2] Ghozali, I. (2020). Application of multivariate analysis with IBM SPSS 25 program . Diponegoro University Publishing Agency.
[3] Ghozali, I. (2021). Multivariate regression analysis for economic and business research . Diponegoro University.
[4] International Maritime Organization (IMO). (2023). IMO strategy on reduction of GHG emissions from ships . Retrieved from https://www.imo.org
[5] International Transport Forum. (2023). The impact of AI on maritime logistics: Efficiency and sustainability . OECD Publishing.
[6] Jones, M., Smith, R., & Taylor, D. (2023). AI in maritime operations: Case studies and industry adoption trends . Maritime Technology Review, 12(4), 102-120.
[7] Kim, H., & Lee, J. (2021). Artificial intelligence and energy efficiency in electric-powered ships . Journal of Marine Engineering, 17(3), 89-105.
[8] Kim, J., & Lee, S. (2022). Artificial intelligence in maritime navigation: Fuel efficiency and operational optimization . Journal of Marine Science and Technology, 27(3), 125-140.
[9] Lee, S., Park, Y., & Kim, H. (2022). Real-time AI-based route optimization for fuel-efficient maritime navigation . Journal of Ocean Engineering, 45(2), 75-92.
[10] Liu, H., Zhang, Y., & Wang, X. (2023). Integration of AI-based route optimization in shipping industry: Challenges and opportunities . Maritime Economics & Logistics, 25(2), 210-230.
[11] Miles, M. B., & Huberman, A. M. (2019). Qualitative data analysis: An expanded sourcebook (3rd ed.). Sage Publications.
[12] Rolls-Royce. (2023). Autonomous ships: The future of AI in maritime navigation . Rolls-Royce Marine Technology Report.
[13] Smith, R., Jones, M., & Taylor, D. (2022). GHG emissions reduction strategies in the shipping sector:

Volume 09, Number 02, Page 645-651
e-ISSN: 2598-120X; p-ISSN: 2598-117X

The role of AI and digital transformation . International Journal of Sustainable Shipping, 10(1), 45-60.

[14] Sugiyono. (2019). Quantitative, qualitative, and R&D research methods . Alfabeta.

[15] Tanaka, K., Yamamoto, T., & Saito, H. (2022). AI-driven fuel optimization in cargo ships: A comparative study with traditional engine efficiency methods . Oceanic Engineering Journal, 39(1), 55-72.

[16] United Nations Conference on Trade and Development (UNCTAD). (2023). Review of maritime transport 2023 . UNCTAD Publications.

[17] Wang, L., Chen, K., & Zhao, Y. (2021). AI-driven fuel consumption reduction in cargo ships: A comparative study . Transportation Research Part D: Transport and Environment, 102, 1-15.

[18] Wang, X., Liu, P., & Zhang, H. (2020). Traditional vs. AI-based ship navigation: A comparative analysis of fuel efficiency and environmental impact . Ocean Engineering, 198, 106-120.

[19] Wang, X., Liu, P., & Zhang, H. (2022). AI-enhanced navigation systems: Impacts on fuel efficiency and carbon reduction in maritime industry . Transportation Research Part D: Transport and Environment, 109, 1-18.

[20] Zhang, Y., Kim, H., & Park, J. (2020). Digitalization and smart shipping: The role of AI in modern maritime logistics . Journal of Maritime Science & Technology, 14(3), 80-98.

[21] Zhang, Y., Kim, H., & Park, J. (2021). Smart shipping and AI-powered route optimization: A review of recent advances . Journal of Maritime Innovation, 15(4), 90-105.