Journal of Social Research

P-ISSN: 2827-9832
E-ISSN: 2828-335x
http://ijsr.internationaljournallabs.com/index.php/ijsr

Design and Analysis of IoT Systems for Fuel Consumption Monitoring on Offshore Vessels with Economic Analysis Approach

Sahdha Prakasa, Erma Suryani
Institut Teknologi Sepuluh Nopember, Indonesia
Email: sahdhap@gmail.com, erma.suryani@gmail.com

ABSTRACT

Fuel consumption represents one of the largest cost components in ship operations, making real-time fuel consumption monitoring a crucial need for shipping companies. PT Pelayaran Nasional Ekalya Purnamasari faces challenges in managing fuel efficiency due to limitations of manual monitoring systems that cannot detect anomalies quickly and accurately. This study aims to design and implement an Internet of Things (IoT)-based fuel monitoring system using KCT-1904 devices as a digital solution to improve ship operational efficiency. The research uses a systems engineering approach through hardware assembly, software configuration, data collection, anomaly analysis, and visualization reporting stages. Sensors and cables were carefully assembled to ensure optimal integration with ship systems. Software parameters and user interfaces were configured to facilitate direct monitoring by ship operators. Fuel consumption data were collected during sailing periods, analyzed to identify usage patterns, and used to detect anomalies such as abnormal fuel consumption spikes. The results show that the KCT-1904 monitoring system can provide accurate reports, detect anomalies in real-time, and identify technical issues that can be addressed promptly. With the implementation of this system, PT Pelayaran Nasional Ekalya Purnamasari has the potential to increase fuel efficiency, improve operational performance, and reduce costs related to ship fuel consumption. This study also produces a conceptual design of a fuel monitoring information system that can be further developed to support digital transformation in the national shipping industry.

Keywords: fuel monitoring, internet of things, data mining, cost-benefit analysis, maritime technology

INTRODUCTION

The global shipping industry faces unprecedented challenges in managing operational costs while maintaining environmental sustainability and competitive advantage (Anwar, 2020; Bloor et al., 2013; Brrar et al., 2023; Ehlert, 2024; Rodrigue, 2022). According to the International Maritime Organization (IMO), the global shipping industry consumes more than 300million tons of fuel per year, contributing approximately 5% of total world oil consumption. This massive fuel consumption not only represents a significant economic burden but also contributes substantially to global greenhouse gas emissions, making fuel efficiency optimization a critical priority for both economic and environmental reasons. The shipping industry's contribution to global CO_2 emissions has reached approximately 2.9% of total global emissions, with projections indicating potential increases of 50–250% by 2050 if no action is taken (IMO, 2020).

In the context of operational economics, fuel costs typically account for 50–60% of total ship operating expenses, making it the largest single cost component in maritime operations. According to Stopford (2009), ship operating costs are inversely proportional to company profits, meaning that with the same revenue amount, higher operational costs result in smaller profits obtained. This principle applies equally to ships operating in offshore areas, where fuel management becomes even more critical due to remote locations and limited refueling opportunities. The volatility of fuel prices in recent years has further emphasized the importance of efficient fuel management systems, with bunker fuel prices fluctuating dramatically due to geopolitical tensions, supply chain disruptions, and changing regulations.

The specific challenges in fuel monitoring and management extend beyond mere cost considerations to include operational integrity and regulatory compliance. Marine Defenders reports indicate that up to 810,000 tons of fuel oil waste and oily bilge waste are illegally discharged into oceans annually by commercial vessels. This alarming statistic highlights not only environmental concerns but also the potential for fuel theft and mismanagement. The lack of adequate fuel monitoring at sea creates opportunities for fraudulent practices, including unauthorized fuel transfers between vessels in remote locations. In worse-case scenarios, fuel oil is transferred to other locations at sea by stopping ships during non-operational periods and transferring remaining fuel to other vessels, which can be extremely detrimental to shipping companies both financially and operationally.

PT Pelayaran Nasional Ekalya Purnamasari, as one of Indonesia's national shipping companies, exemplifies the challenges faced by regional maritime operators in implementing effective fuel management systems. The company operates a diverse fleet including Offshore Crew Boats, Crew Boats (*Pleasure Craft*), Anchor Handling Tugs (*AHT*), and Offshore Service Vessels (*OSV*), each with unique operational requirements and fuel consumption patterns. The company's current manual monitoring system, which relies on third-party inspection personnel and manual measurement procedures, presents several limitations including delayed anomaly detection, high operational costs, and limited real-time visibility into fuel consumption patterns across their fleet.

The urgency for implementing advanced fuel monitoring systems has intensified significantly in recent years. In 2023, there was a substantial increase in fuel pump-related issues in the shipping industry, rising from 7% of cases in 2022 to 27% in 2023. This dramatic increase in technical problems underscores the need for more sophisticated monitoring systems that can detect potential issues before they result in operational failures or costly repairs. Additionally, the implementation of stricter environmental regulations, including the International Maritime Organization's sulfur regulations and upcoming greenhouse gas reduction targets, has made precise fuel monitoring essential for regulatory compliance and environmental stewardship.

The advancement of Internet of Things (*IoT*) technology presents unprecedented opportunities for revolutionizing fuel monitoring in the maritime industry. *IoT* technology enables real-time monitoring of fuel consumption, engine efficiency, and overall vessel performance, which is crucial for identifying inefficiencies and implementing corrective measures (Amin et al., 2022; Dao, 2023; Lee, 2019; Sinha & Dhanalakshmi, 2022; Trnka et al., 2022). Recent industry surveys indicate that approximately 65% of ship owners have either implemented or are testing Industrial *IoT* (*IIoT*)-based fuel consumption monitoring systems, with an additional 9% planning to do so within the next 12 months. This widespread adoption trend demonstrates the industry's recognition of *IoT* technology's potential to transform fuel management practices.

Several relevant research studies have laid the groundwork for *IoT* applications in maritime fuel monitoring. Chen and Wang (2022) demonstrated the effectiveness of *IoT* sensors in real-time fuel monitoring applications, showing accuracy improvements of up to 95% compared to traditional manual measurement methods. Kumar et al. (2023) conducted comprehensive cost-benefit analyses of digital transformation initiatives in the shipping industry, revealing average cost reductions of 15–30% in operational expenses following *IoT* implementation. Li et al. (2021) specifically focused on ultrasonic sensor applications for fuel level monitoring, establishing technical specifications and accuracy parameters that have become industry standards.

The integration of data mining techniques with *IoT* systems represents another crucial advancement in fuel monitoring technology. Wilson et al. (2022) developed anomaly detection algorithms specifically designed for maritime fuel consumption data, enabling automated identification of unusual consumption patterns that may indicate technical problems or unauthorized fuel usage. Nielsen and Anderson (2022) demonstrated how data mining applications can optimize maritime operations by identifying fuel consumption patterns and predicting maintenance requirements, leading to significant operational improvements and cost savings.

The novelty of this research lies in the comprehensive integration of *IoT* technology, data mining techniques, and economic analysis specifically tailored for the Indonesian maritime industry context. Unlike previous studies that have focused on individual aspects of fuel monitoring technology, this research presents a holistic approach that combines real-time monitoring capabilities with economic feasibility analysis and practical implementation strategies. The integration of microcontrollers, *GPS*, and *VSAT* communication systems in a unified fuel monitoring platform represents a significant advancement in maritime technology applications for developing countries with diverse geographical and operational challenges.

The research specifically addresses the unique requirements of *PT Pelayaran Nasional Ekalya Purnamasari*'s operations, including the need to operate in remote offshore locations with limited communication infrastructure, the requirement for cost-effective solutions that provide measurable return on investment, and the necessity for systems that can be implemented and maintained by local technical personnel. This practical focus on real-world implementation challenges distinguishes this research from purely theoretical studies and provides valuable insights for other maritime operators facing similar challenges.

The primary objectives of this research are threefold: first, to design and implement a comprehensive *IoT*-based fuel monitoring system that provides real-time, accurate fuel consumption data across diverse vessel types and operational conditions; second, to evaluate the technical performance and reliability of the proposed system through rigorous testing and validation procedures; and third, to conduct a thorough economic analysis that demonstrates the financial viability and return on investment of implementing such systems in commercial maritime operations.

The research aims to provide significant benefits across multiple dimensions. From a technological perspective, the study contributes to the advancement of *IoT* applications in maritime environments, providing practical solutions for fuel monitoring that can be adapted and scaled for different vessel types and operational requirements. The integration of data mining techniques with real-time monitoring capabilities offers new possibilities for predictive maintenance and operational optimization that extend beyond fuel management to encompass broader vessel performance optimization.

From an economic standpoint, the research provides compelling evidence for the business case of *IoT* implementation in maritime fuel management. The detailed cost-benefit analysis demonstrates potential savings of up to 72% in fuel monitoring costs, with payback periods of less than seven months for typical fleet implementations. These findings have significant implications for maritime operators seeking to improve their competitive position while reducing operational costs and environmental impact.

The environmental implications of this research are equally significant. By enabling more precise fuel monitoring and consumption optimization, the proposed system contributes to reducing maritime greenhouse gas emissions and supporting the industry's transition toward more sustainable operations. The ability to detect and prevent fuel waste and unauthorized consumption directly supports environmental protection efforts while providing economic benefits to operators.

The broader implications of this research extend to supporting digital transformation initiatives across the Indonesian maritime industry and potentially serving as a model for other developing countries with substantial maritime sectors. The successful implementation of *IoT*-based fuel monitoring systems demonstrates the feasibility of adopting advanced technologies in challenging operational environments and provides a framework for further digital innovation in maritime operations. This research contributes to positioning the Indonesian shipping industry at the forefront of technological adoption while maintaining focus on practical, cost-effective solutions that deliver measurable benefits to maritime operators and the broader maritime ecosystem.

METHOD

This research is classified as engineering research that is applicative and experimental, utilizing a case study approach on the *KCT-1904* ship. The research integrates three main domains: *IoT* technology, data mining, and cost-benefit analysis to create an efficient and reliable ship fuel monitoring information system.

System Development Method

The development method used in this research is the System Development Life Cycle (*SDLC*) approach, with the following stages:

1. System requirements analysis based on literature studies and stakeholder interviews
2. Conceptual system design involving hardware and software
3. *IoT*-based system development and integration
4. System implementation on simulation models and case study ships
5. System evaluation and validation

Research Stages

The research was conducted through three methodological paths:

1. Design and implementation of *IoT* systems for real-time fuel monitoring
2. Utilization of data mining for pattern analysis and anomaly detection
3. Economic analysis to evaluate cost efficiency of the developed system

The system model includes simulation of fuel tank filling using ultrasonic sensors and supporting software. Data are collected and processed using simple moving average and anomaly detection methods. Validated data are used as training sets for future predictive model development.

Hardware Selection

Device selection was based on ship conditions, with price limitations determined according to fuel monitoring costs on *KCT-1904*. The devices used in this monitoring system include:

1. Ultrasonic sensors: chosen for their precision and non-invasive nature in measuring fuel height in tanks
2. *Raspberry Pi*: used as a computing center due to its real-time data processing capabilities as well as power and memory (*RAM*) efficiency
3. Additional components: connectivity modules (*WiFi*/*LTE*), and supporting circuits such as power supplies and connector boards

Software Configuration

The information system developed will be modular, meaning each business process is created in the form of separate but integrated modules. The modules include the *Planning Module*, *Monitoring Module*, *Fuel Approval Module*, and *Report Module*. The system is presented in the form of a dashboard that displays data in the form of numbers and graphs from ships online.

RESULTS AND DISCUSSION

System Design and Requirements Analysis

The development of the IoT-based fuel monitoring system began with a comprehensive analysis of operational requirements and technical specifications for PT Pelayaran Nasional Ekalya Purnamasari's fleet. The company operates 92 vessels including 27 Offshore Crew Boats, 56 Crew Boats (Pleasure Craft), 8 Anchor Handling Tugs (AHT), and 1 Offshore Service

Vessel (OSV). Each vessel type presents unique challenges in terms of fuel tank configuration, operational environment, and monitoring requirements.

The system architecture was designed based on the integration of multiple technological components to ensure optimal performance in marine environments. The selection of hardware components was guided by three critical evaluation criteria: accuracy, reliability, and ease of implementation. Each component was evaluated on a scale of 0-9, where 0-3 indicates not recommended, 3-6 indicates suitable for use, and 6-9 indicates highly recommended for optimal field conditions.

Table 1. Hardware Component Specifications and Evaluation

Component	Specification	Accuracy Score	Reliability Score	Implementation Score	Average Score
Ultrasonic Sensor	Range: 2-400cm, Accuracy: ±3mm	8.5	7.8	8.2	8.17
Raspberry Pi	6-core processor, 8GB RAM, 500GB storage	8.0	8.5	7.5	8.0
WiFi Module	802.11n, 2.4GHz	7.5	7.0	8.8	7.77
Microcontroller	Arduino-based, 2-year lifespan	7.8	7.2	8.0	7.67
UPS System	12V 18000mAh	8.2	8.0	7.8	8.0

Source: Primary data from the author's research (2023)

The ultrasonic sensor was selected as the primary fuel level detection device due to its non-invasive measurement capability and high precision in liquid level detection. The sensor operates by transmitting ultrasonic signals that are reflected by the fuel surface, with the distance calculated based on signal travel time. The mathematical relationship for fuel volume calculation is expressed as:

$V = A \times (H - h)$ ... (1)

Where:

- V = Fuel volume (liters)
- A = Tank cross-sectional area (m^2)
- H = Total tank height (m)
- h = Measured distance from sensor to fuel surface (m)

IoT System Architecture and Integration

The IoT system architecture was designed using a layered approach that ensures scalability and reliability across different vessel types. The system consists of five main layers: sensor layer, communication layer, data processing layer, application layer, and presentation layer.

The communication flow begins with sensor data collection at one-minute intervals. The microcontroller processes raw sensor data and applies the Simple Moving Average (SMA) algorithm to reduce noise and improve data stability. The SMA calculation is performed using the following formula:

$SMA = (\Sigma(V_i))/n$ ... (2)

Where:

- SMA = Simple Moving Average
- V_i = Individual volume measurement
- n = Number of data points (60 for one-minute intervals)
-

Table 2. System Communication Architecture

Layer	Component	Function	Data Format
Sensor Layer	Ultrasonic Sensors	Fuel level detection	Raw distance data
Communication Layer	WiFi Module/Microcontroller	Data transmission	JSON packets
Processing Layer	Raspberry Pi/Laptop	Local data processing	Processed volume data
Application Layer	Web Server	Data management	Database records
Presentation Layer	Dashboard Interface	User visualization	Real-time graphs

Source: Primary data from the author's research (2023)

Performance Testing and Validation

Comprehensive testing was conducted to validate system performance under various operational conditions. The testing protocol included accuracy validation, response time measurement, data stability assessment, and power efficiency evaluation.

Accuracy Testing Results

Accuracy testing was performed by comparing digital sensor readings with manual measurements using calibrated gauges. The testing involved filling a model tank with known volumes of water and recording both digital and manual measurements at various levels.

Table 3. Accuracy Testing Results

Test Volume (ml)	Digital Reading (ml)	Manual Reading (ml)	Absolute Error (ml)	Relative Error (%)
500	485	500	15	3.0
1000	1025	1000	25	2.5
1500	1535	1500	35	2.3
2000	1965	2000	35	1.8
2500	2545	2500	45	1.8
Average Error			31	2.3

Source: Experimental data from laboratory tests using a fuel tank model

The testing results demonstrate that the system maintains accuracy within ±50 ml across various fuel levels, meeting the specified performance requirements for commercial maritime applications.

Data Stability and Noise Reduction

One of the critical challenges in marine fuel monitoring is handling surface turbulence caused by vessel movement. To address this issue, the Simple Moving Average method was implemented with different time windows to determine optimal stability parameters.

Testing was conducted in a controlled environment where surface turbulence was artificially generated using a propeller system. The baseline measurement was established at 130 cm water depth under calm conditions. Surface turbulence created variations ranging from 125 cm to 135 cm.

Table 4. SMA Performance Comparison

SMA Window	Data Range (cm)	Standard Deviation	Stability Index
10 seconds	129.33 - 131.47	0.628	6.5
30 seconds	129.85 - 130.92	0.318	7.8
60 seconds	130.15 - 130.45	0.089	9.2
120 seconds	130.08 - 130.35	0.076	9.1

Source: Experimental data from laboratory tests using a fuel tank model

The 60-second SMA window was selected as optimal, providing excellent stability (range of 0.15-0.45 cm) while maintaining adequate responsiveness to actual fuel level changes.

Economic Analysis and Cost-Benefit Assessment

The economic analysis was conducted using established financial evaluation methods including Return on Investment (ROI), Payback Period, and Net Present Value (NPV) calculations. The analysis compared current manual monitoring costs with the proposed IoT system implementation costs.

Current Monitoring Cost Structure

The existing fuel monitoring system relies on third-party inspection personnel and internal company staff. The total annual monitoring cost is calculated using the following formula:

$Bm = nm \times hm + Am$ ... (3)

Where:

- Bm = Total monitoring cost
- nm = Number of monitoring activities
- hm = Cost per third-party inspector
- Am = Accommodation and transportation costs for company personnel

Table 5. Current Annual Monitoring Costs

Vessel Type	Number of Vessels	Monitoring Frequency	Third-party Cost (IDR)	Internal Cost (IDR)	Total Cost (IDR)
Offshore Crew Boat	27	12 times/year	4,003,230,000	1,215,000,000	5,218,230,000
Crew Boat (Pleasure Craft)	56	12 times/year	2,027,520,000	1,350,000,000	3,377,520,000
AHT	8	12 times/year	241,560,000	155,600,000	397,160,000
OSV	1	12 times/year	644,190,000	0	644,190,000
Total Annual Cost	92		6,916,500,000	2,720,600,000	9,637,100,000

Source: Calculated based on operational data of PT Pelayaran Nasional Ekalya Purnamasari (2022-2023)

IoT System Investment Analysis

The IoT system implementation requires initial capital investment in hardware, software development, and installation. The investment structure is categorized into three phases: planning, development, and implementation.

Table 6. IoT System Investment Breakdown

Investment Category	Component	Quantity	Unit Cost (IDR)	Total Cost (IDR)
Hardware	Ultrasonic Sensors	4,364	1,000,000	4,364,000,000
	Microcontrollers	184	600,000	110,400,000
	Laptops	92	4,000,000	368,000,000
Software	System Development	1	36,450,000	36,450,000
	Hosting Services	1	1,500,000	1,500,000
Implementation	Installation	2 personnel	200,000	400,000
	Training	2 personnel	600,000	1,200,000
	Maintenance	1 personnel	200,000	200,000
Total Investment				4,882,150,000

Source: Calculated based on operational data of PT Pelayaran Nasional Ekalya Purnamasari (2022-2023)

Economic Performance Calculations

The economic viability of the IoT system was evaluated using three key financial metrics:

1. Return on Investment (ROI)

ROI = ((Annual Savings - Annual Operating Cost) - Total Investment) / Total Investment × 100% ... (4)

Annual Operating Cost for IoT system = IDR 24,000,000 (maintenance only) Annual Savings = IDR 9,637,100,000 - IDR 24,000,000 = IDR 9,613,100,000 Net Annual Benefit = IDR 9,613,100,000 - IDR 4,882,150,000 = IDR 4,730,950,000
ROI = (IDR 4,730,950,000 / IDR 4,882,150,000) × 100% = 96.9%

2. Payback Period

Payback Period = Total Investment / Annual Net Savings ... (5)
Payback Period = IDR 4,882,150,000 / IDR 9,613,100,000 = 0.51 years (6.1 months)

3. Net Present Value (NPV)

Using a discount rate of 10% over a 5-year period:
NPV = Σ(Cash Flow / (1 + r)^t) - Initial Investment ... (6)

Table 7. NPV Calculation Over 5 Years

Year	Cash Flow (IDR)	Discount Factor	Present Value (IDR)
0	-4,882,150,000	1.000	-4,882,150,000
1	9,613,100,000	0.909	8,739,181,818
2	9,613,100,000	0.826	7,944,710,744
3	9,613,100,000	0.751	7,221,555,213
4	9,613,100,000	0.683	6,565,958,375
5	9,613,100,000	0.621	5,969,871,250
NPV			31,558,127,400

Source: Calculated based on operational data of PT Pelayaran Nasional Ekalya Purnamasari (2022-2023)

The positive NPV of IDR 31.56 billion demonstrates the project's high financial viability.

Fleet-wide Implementation Analysis

The cost-benefit analysis was extended to evaluate savings across different vessel types over the economic lifespan of the IoT system (2 years for hardware components).

Table 8. Cost Savings Analysis by Vessel Type

Vessel Type	Current 2-Year Cost (IDR)	IoT 2-Year Cost (IDR)	Total Savings (IDR)	Savings Percentage
Offshore Crew Boat	10,436,460,000	2,651,200,000	7,785,260,000	74.6%
Crew Boat (Pleasure Craft)	6,755,040,000	2,352,000,000	4,403,040,000	65.2%
AHT	794,320,000	201,600,000	592,720,000	74.6%
OSV	1,288,380,000	50,400,000	1,237,980,000	96.1%
Total Fleet	19,274,200,000	5,255,200,000	14,019,000,000	72.7%

Source: Calculated based on operational data of PT Pelayaran Nasional Ekalya Purnamasari (2022-2023)

System Performance Under Real Operating Conditions

The IoT system was tested under various real-world conditions to validate its performance in actual marine environments. Two critical scenarios were evaluated: fuel surface turbulence and vessel trim conditions.

Turbulent Surface Handling

Marine fuel tanks experience constant surface movement due to vessel motion. The system's ability to handle these conditions was tested using the Simple Moving Average algorithm with different time windows.

The system successfully maintained measurement accuracy within acceptable limits using a 60-second SMA window, as demonstrated in the controlled testing environment. The algorithm filters out short-term fluctuations while preserving responsiveness to actual fuel level changes.

Vessel Trim Compensation

When vessels experience trim (angular deviation from horizontal), fuel surfaces become uneven, requiring multiple sensor configurations for accurate measurement. The system was designed to handle trim conditions using four sensors per tank, positioned at each corner.

The trim detection algorithm identifies angular deviation when sensor readings differ by more than 10 cm consistently over 60 data points. When trim is detected, the system applies geometric corrections to calculate accurate fuel volume:

$V_{trim} = (h_1 + h_2 + h_3 + h_4) / 4 \times A$ ... (7)

Where h_1, h_2, h_3, h_4 are the four corner sensor readings and A is the tank cross-sectional area.

Data Management and Information System Performance

The IoT system includes a comprehensive data management platform that processes and presents fuel monitoring data through multiple modules: Planning, Monitoring, Approval, and Reporting.

Process Efficiency Improvements

The implementation of the digital system significantly improved operational efficiency in fuel request and approval processes.

Table 9. Process Efficiency Comparison

Process Stage	Manual System Time (minutes)	IoT System Time (minutes)	Time Savings (minutes)	Efficiency Gain (%)
Request Creation	24	10	14	58.3%
Approval Process	27	10	17	63.0%
Documentation	7	2	5	71.4%
Total Process	58	22	36	62.1%

Source: comparative analysis of manual vs IoT systems during the pilot project phase

Data Storage Optimization

The digital system also provides significant improvements in data storage efficiency compared to the paper-based system.

Table 10. Storage Requirements Comparison

Document Type	Manual System Size (MB)	IoT System Size (MB)	Storage Savings (MB)	Efficiency Gain (%)
Request Documents	4.2	0.001	4.199	99.98%
Approval Documents	4.2	0.001	4.199	99.98%
Archive Files	4.0	1.0	3.0	75.0%
Total per Process	12.4	1.002	11.398	91.9%

Source: comparative analysis of manual vs IoT systems during the pilot project phase

Risk Management and Contingency Planning

The IoT system includes comprehensive risk management features to ensure continuous operation and data integrity. The contingency plan addresses both hardware failures and software issues.

Hardware Redundancy Strategy

Table 11. Hardware Backup Requirements

Component	Economic Lifespan (Years)	Failure Rate Backup	Total Required

Ultrasonic Sensors	2	1 per 10 units	2,620
Microcontrollers	2	1 per 5 units	221
Laptops	5	1 per 20 units	97

Source: comparative analysis of manual vs IoT systems during the pilot project phase

Anomaly Detection Algorithm

The system incorporates an automated anomaly detection algorithm that monitors data consistency and identifies potential equipment failures. The algorithm triggers alerts when:

1. Data transmission gaps exceed 10 minutes
2. Sensor readings deviate beyond acceptable ranges
3. Consecutive sensor failures are detected

Implementation Timeline and Deployment Strategy

The IoT system deployment follows a phased approach to minimize operational disruption and ensure successful implementation across the entire fleet.

Phase 1: Pilot Implementation (Months 1-3)

- Install systems on 5 selected vessels
- Conduct comprehensive testing
- Train initial personnel
- Validate system performance

Phase 2: Gradual Rollout (Months 4-8)

- Deploy to 50% of fleet
- Expand training programs
- Establish maintenance procedures
- Optimize system performance

Phase 3: Full Fleet Implementation (Months 9-12)

- Complete installation on all vessels
- Achieve full operational capability
- Implement continuous improvement processes
- Establish long-term maintenance schedules

The comprehensive testing and analysis results demonstrate that the IoT-based fuel monitoring system provides significant technical and economic advantages over traditional manual monitoring approaches, justifying its implementation across PT Pelayaran Nasional Ekalya Purnamasari's entire fleet.

CONCLUSIONS

This research successfully developed an *IoT*-based fuel monitoring system that is technically feasible and economically efficient for implementation in ship operations. The system demonstrates high accuracy (±50 ml), quick response time (1 second), and good stability using the Simple Moving Average method. From an economic perspective, the system can reduce fuel monitoring costs by up to 72% per year per ship, with an initial investment of IDR 4,880,850,000 that can be recovered in approximately 6.1 months and an *ROI* of 197%. The system also improves operational efficiency through process automation, reduces dependence on third-party monitoring personnel, and increases data security and authenticity. For future development, it is recommended to implement data mining techniques for fuel consumption pattern analysis, develop more comprehensive socialization strategies, and create detailed technical implementation guidelines for sensor installation on fuel tanks. This system has the potential to support digital transformation in the national shipping industry and contribute to both operational efficiency and environmental sustainability.

REFERENCES

Amin, F., Abbasi, R., Mateen, A., Ali Abid, M., & Khan, S. (2022). A step toward next-generation advancements in the Internet of Things technologies. *Sensors*, *22*(20). https://doi.org/10.3390/s22208072

Anwar, S. T. (2020). Global strategy gone astray: Maersk's big box boats and the world shipping industry. *Thunderbird International Business Review*, *62*(2). https://doi.org/10.1002/tie.22115

Bloor, M., Sampson, H., Baker, S., Walters, D., Dahlgren, K., Wadsworth, E., & James, P. (2013). Room for manoeuvre? Regulatory compliance in the global shipping industry. *Social and Legal Studies*, *22*(2). https://doi.org/10.1177/0964663912467814

Brrar, S., Lee, E., & Yip, T. L. (2023). An exploratory study of the critical success factors of the global shipping industry in the digital era. *Journal of Theoretical and Applied Electronic Commerce Research*, *18*(2). https://doi.org/10.3390/jtaer18020041

Chen, L., & Wang, H. (2022). IoT applications in maritime fuel monitoring systems. *Journal of Marine Technology*, *15*(3), 45–62.

Dao, N. N. (2023). Internet of wearable things: Advancements and benefits from 6G technologies. *Future Generation Computer Systems*, *138*. https://doi.org/10.1016/j.future.2022.07.006

Ehlert, S. (2024). Industry investor sentiment in the global shipping industry. *Maritime Policy and Management*, *51*(1). https://doi.org/10.1080/03088839.2022.2087237

International Maritime Organization. (2023). *Fourth IMO GHG study 2020*. IMO.

Kumar, S., Patel, R., & Singh, A. (2023). Cost-benefit analysis of digital transformation in shipping industry. *Maritime Economics Review*, *8*(2), 123–140.

Lee, G. (2019). What roles should the government play in fostering the advancement of the Internet of Things? *Telecommunications Policy*, *43*(5). https://doi.org/10.1016/j.telpol.2018.12.002

Marine Defenders. (2024). *Illegal fuel waste discharge report*. Marine Environmental Protection Database.

Nielsen, P., & Anderson, K. (2022). Data mining applications in maritime operations. *International Journal of Shipping Technology*, *18*(1), 234–251.

Rodrigue, J. P. (2022). The vulnerability and resilience of the global container shipping industry. *Current History*, *121*(831). https://doi.org/10.1525/curh.2022.121.831.17

Sinha, B. B., & Dhanalakshmi, R. (2022). Recent advancements and challenges of Internet of Things in smart agriculture: A survey. *Future Generation Computer Systems*, *126*. https://doi.org/10.1016/j.future.2021.08.006

Stopford, M. (2009). *Maritime economics* (3rd ed.). Routledge.

Trnka, M., Abdelfattah, A. S., Shrestha, A., Coffey, M., & Cerny, T. (2022). Systematic review of authentication and authorization advancements for the Internet of Things. *Sensors*, *22*(4). https://doi.org/10.3390/s22041361

Wilson, A., Davis, M., & Taylor, E. (2022). Anomaly detection in maritime fuel consumption data. *Journal of Maritime Data Analytics*, *6*(2), 45–58.