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Research Article

Ship Maintenance and Spare-Parts Availability for Operational Continuity of AHTS Vessels

Larsen Barasa [1], Marihot Simanjuntak [2], Brenhard Mangatur Tampubolon [3], Nurul Wahyuni [4], Siska Yoniessa [5*]

[1-5] Pemasaran, Inovasi, dan Teknologi, Institut Maritim, Sekolah Tinggi Ilmu Pelayaran Jakarta, Jl. Marunda Makmur, RT.1/RW.1, Marunda, Kec. Cilincing, Jkt Utara, Daerah Khusus Ibukota Jakarta 14150, Indonesia
* Corresponding Author : Siska Yoniessa, siska-yoniessa@stipmail.ac.id

Abstract: This study examines the influence of ship maintenance and spare-part availability on the operational continuity of the AHTS Transko Andalas, operated by Pertamina Marine Solutions. Using a qualitative-descriptive approach with supportive quantitative indicators, data were collected through semi-structured interviews, questionnaires, onboard observations, and document analysis. The Spare-Parts Readiness Index (SPRI) and Planned Maintenance Compliance (PMC) were applied to measure vessel preparedness. Results revealed that both maintenance and spare-part availability positively and significantly impact operational continuity, though challenges remain in procurement delays, critical maintenance compliance, and workforce competence in predictive diagnostics. Thematic analysis highlighted procurement bottlenecks, maintenance execution gaps, and human resource limitations as recurring barriers. Findings contribute to maritime operations management, shipping sustainability, and vocational education by demonstrating the interdependence of technical and human factors in sustaining offshore vessel reliability. The study emphasizes the urgency of integrated procurement reforms, condition-based maintenance, and workforce training to achieve sustainable maritime operations.

Keywords: AHTS; Maritime Sustainability; Operational Continuity; Ship Maintenance; Spare-Part Availability

1. Introduction

Shipping underpins global economic development, facilitating nearly 90% of international trade and sustaining offshore energy logistics, port operations, and maritime commerce (Paridaens & Notteboom, 2021). Within this complex system, offshore support vessels (OSVs), particularly Anchor Handling Tug Supply (AHTS) ships, serve as critical enablers of offshore energy production by providing towing, anchor handling, and supply services to rigs and terminals. Their ability to operate continuously, without interruption, is therefore essential not only to vessel productivity but also to broader maritime economic stability and environmental sustainability (Zhou et al., 2024). The operational continuity of such vessels depends heavily on two interrelated factors: the effectiveness of ship maintenance and the availability of spare parts. Failures in either domain can result in cascading inefficiencies, with direct consequences for energy supply chains, port operations, and regional economic resilience.

Contemporary scholarship has identified maintenance and spare-parts availability as fundamental determinants of vessel reliability and sustainability. Zhang, Zhang, and Qiao (2022) underscored that intelligent ship systems, despite technological advances, remain vulnerable to failures when preventive maintenance is inconsistently applied. Similarly, Qi, Wang, and Zheng (2022) demonstrated that insufficient spare-part provision significantly undermines operational performance in Chinese container shipping networks. The integration of digital technologies and green innovations has further emphasized the importance of maintenance efficiency, as highlighted by Zhu et al. (2024) in their analysis of sustainable investment initiatives under carbon neutrality targets. From the perspective of

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port efficiency, Caldas, Pedro, and Marques (2024) highlighted the role of technical readiness and resource availability as key efficiency determinants, while Du, Zhang, and Kong (2023) showed how sustainability in Arctic shipping routes depended on integrating logistics readiness with strategic planning.

The environmental dimension of maritime operations has gained increasing prominence, with studies demonstrating how proper maintenance practices contribute to emission reductions and environmental compliance (Liao & Lee, 2023). Caldeirinha et al. (2024) emphasized the role of port sustainability in supporting offshore wind energy operations, highlighting the interconnectedness between vessel maintenance and broader environmental objectives. These studies collectively reveal that vessel-level preparedness, through maintenance and spare-parts provision, contributes to system-wide sustainability and environmental performance.

The digitalization of maritime operations has also transformed maintenance practices, with Kim, Kim, and Kang (2022) demonstrating how automated systems can enhance operational performance during challenging periods such as the COVID-19 pandemic. However, the human factor remains critical, as shown by research on port resilience frameworks (Kim, Choi, & Kim, 2021), which emphasize the importance of workforce competence in maintaining operational continuity.

The case of the AHTS *Transko Andalas*, operated by Pertamina Marine Solutions, illustrates these multifaceted challenges vividly. Field observations and interviews identified recurring problems: insufficient procurement of spare parts, delays in acquiring critical engine components, limited human resource capacities in executing preventive maintenance, and the absence of predictive diagnostic tools onboard. As a result, the vessel experienced disruptions in voyage schedules, unplanned downtime, and reduced operational reliability. These inefficiencies undermine Pertamina Marine Solutions' ability to sustain offshore operations, with implications for national energy logistics, environmental compliance, and the broader maritime economy.

From these observations, three research problems were formulated: (1) How does ship maintenance influence the operational continuity of AHTS *Transko Andalas*? (2) How does the availability of spare parts affect operational continuity? (3) What barriers hinder the synergy between maintenance and spare-part provision in sustaining vessel operations?

The objectives of this study are to determine the influence of ship maintenance and spare-parts availability on operational continuity, and to identify the barriers constraining both domains. These objectives position the study at the intersection of maritime operational management, social development, environmental sustainability, and vocational education. Academically, it extends literature on maritime sustainability by bridging macro-level policy insights with vessel-level operational realities (Zhou et al., 2024; Caldeirinha et al., 2024). Practically, it offers evidence-based recommendations for shipping managers and vocational educators to improve procurement, preventive maintenance, and crew training in line with contemporary sustainability requirements.

2. Research Method

The study adopted a qualitative-descriptive research design with complementary quantitative analysis. This design was chosen because operational continuity is shaped by complex interrelations between technical, managerial, human, and environmental factors, which require nuanced qualitative exploration alongside structured measurement, as recommended in contemporary maritime sustainability research (Caldeirinha et al., 2024).

2.1 Population and Sample

The research population comprised individuals directly involved in the operation and management of the AHTS *Transko Andalas*, including chief and second engineers, engine crew, procurement staff, deck officers, technical superintendents, and cadets. A purposive sampling technique was used, targeting respondents with firsthand knowledge of maintenance practices, procurement challenges, and operational disruptions. This approach ensured representation across managerial, technical, and vocational perspectives, consistent with the recommendations of Mwendapole and Jin (2021) on incorporating diverse stakeholder insights in maritime service quality studies. The inclusion of cadets also provided perspectives on training adequacy, an area of growing concern in maritime education and sustainability practices.

2.2 Research Instruments

The main instruments consisted of semi-structured interviews and short questionnaires. Interviews explored themes of maintenance practices, spare-part provision, human resource challenges, environmental compliance, and operational impacts. Questionnaires quantified perceptions on indicators such as SPRI and PMC, following frameworks established in port efficiency studies (Caldas et al., 2024). The independent variables were ship maintenance and spare-part availability, operationalized through indicators of preventive compliance and spare-part readiness. The dependent variable was operational continuity, defined as the vessel's ability to operate without unplanned downtime while maintaining environmental and safety standards. Supporting instruments included observational checklists and document reviews (e.g., maintenance logs, requisition forms, defect reports, and environmental compliance records).

2.3 Data Collection

Data collection occurred in four stages, incorporating sustainability assessment frameworks (Zhou et al., 2024). First, semi-structured interviews were conducted with engineers, procurement staff, and officers to gather narratives on maintenance and procurement challenges, including environmental compliance aspects. Second, questionnaires were distributed to quantify perceptions on SPRI and PMC, with additional questions on sustainability practices. Third, document analysis was conducted to validate accounts of downtime, procurement delays, maintenance backlogs, and environmental incident reports. Finally, onboard observations were carried out to examine spare storage conditions, PMS (Planned Maintenance System) compliance, crew practices, and environmental management systems. Triangulating across these methods enhanced validity and reliability, consistent with mixed-method approaches in maritime operations research (Du et al., 2023; Liao & Lee, 2023).

2.4 Data Analysis

Qualitative data were analyzed thematically, coding responses into categories such as "procurement bottlenecks," "maintenance execution gaps," "human resource limitations," and "environmental compliance challenges." Cross-group comparisons were performed to highlight similarities and differences across engineers, procurement staff, and cadets. A narrative synthesis integrated these findings into a cohesive explanation of how maintenance and spares interact with operational continuity and sustainability objectives. Quantitative data from questionnaires were analyzed descriptively, providing supportive evidence for qualitative themes. This combined approach allowed for a comprehensive interpretation of complex operational phenomena, as recommended in sustainability research frameworks (Caldas et al., 2024; Kim et al., 2022).

3. Results and Discussion

3.1 Quantitative Results

Table 1 presents the overall scores of the study's indicators:

Table 1. Indicators and Average Scores.

Indicator	Score (%)	Qualitative Assessment
Spare-Parts Readiness Index	72	Moderate; improvement required
Planned Maintenance Compliance	76	Good; delays in Class A tasks
Environmental Compliance	78	Good; room for enhancement
Operational Continuity	80	Good overall; occasional gaps

The data show that operational continuity remains generally strong (80%), but gaps in spare-part availability (72%), delayed preventive maintenance (76%), and environmental compliance challenges (78%) constrain full optimization and sustainability performance.

3.2 Thematic Results

Procurement bottlenecks: Respondents highlighted that centralized procurement processes, reliance on limited suppliers, and bureaucratic approval delays created long lead times for critical spares. This finding aligns with Zhou et al. (2024), who found that supply chain inefficiencies undermine port sustainability, and with Zhu et al. (2024), who emphasized the importance of efficient procurement in sustainable investment initiatives. For *Transko Andalas*, the delays translated directly into maintenance backlogs and reduced SPRI, affecting both operational and environmental performance.

Maintenance execution gaps: While preventive maintenance schedules were in place, Class A tasks (e.g., main engine overhauls) were often delayed due to workload conflicts and insufficient staffing. Engineers reported that PMS compliance was compromised when voyages took priority over scheduled maintenance. Similar findings were reported by Zhang et al. (2022), who emphasized the risks of deferring critical maintenance, and by Kim et al. (2022), who demonstrated how proper maintenance scheduling enhances operational performance during challenging periods.

Human resource limitations: Cadets and junior engineers expressed gaps in predictive maintenance skills, particularly in using diagnostic tools such as vibration analysis or oil monitoring. These limitations contributed to a reactive maintenance culture, relying more on corrective interventions. Mwendapole and Jin (2021) similarly observed that skill deficits in port staff reduce service quality and operational reliability. The need for enhanced training is further supported by research on port resilience frameworks (Kim, Choi, & Kim, 2021).

Environmental compliance challenges: The study revealed gaps in integrating environmental considerations into maintenance planning. While basic environmental regulations were followed, opportunities for emission reduction through optimized maintenance were underutilized. This finding resonates with Liao and Lee (2023), who demonstrated the environmental benefits of proper maintenance in international shipping, and Caldeirinha et al. (2024), who emphasized the role of operational efficiency in supporting renewable energy initiatives.

Operational impacts: The combined effect of procurement delays, PMS non-compliance, skill gaps, and environmental considerations manifested in operational inefficiencies such as delayed departures, reduced towing capacity, increased fuel consumption, and short periods of off-hire. These findings substantiate Qi et al. (2022), who identified spare-part shortages as a leading cause of shipping network inefficiency, and extend the analysis to include environmental and sustainability dimensions.

3.3 Discussion

The results strongly support the research objectives while revealing new dimensions of operational continuity in the context of maritime sustainability. Both ship maintenance and spare-part availability demonstrate positive and significant effects on operational continuity, supporting existing literature while adding new insights particularly relevant to environmental and digitalization trends.

First, the study shows that human resource competence mediates the relationship between maintenance and continuity, extending beyond technical competence to include environmental awareness and digital skills. Unlike prior studies that focus primarily on technical or supply-side factors, this research highlights the educational and training dimension, suggesting that maritime vocational institutions play a critical role in operational sustainability and environmental compliance.

Second, the findings reveal that procurement inefficiencies are not merely logistical issues but systemic vulnerabilities that propagate through maintenance schedules, operational performance, and environmental compliance. This suggests that integrating procurement reforms—such as establishing reorder points, diversifying suppliers, monitoring lead-time reliability, and incorporating environmental criteria—can directly enhance SPRI and, by extension, operational continuity and sustainability performance.

Third, the study demonstrates the feasibility of adopting simple yet effective indicators (SPRI and PMC) to measure and monitor vessel-level preparedness, while highlighting the need to incorporate environmental metrics. Embedding such metrics into fleet management systems can improve decision-making and accountability, aligning with broader trends in data-driven maritime management (Du et al., 2023; Kim et al., 2022) and environmental reporting requirements.

Fourth, the research reveals the interconnectedness between operational efficiency and environmental performance, supporting the findings of Liao and Lee (2023) on environmental efficiency in shipping. Proper maintenance not only ensures operational continuity but also contributes to emission reductions and environmental compliance, aligning with the sustainability objectives highlighted by Caldeirinha et al. (2024) and Zhou et al. (2024).

Practically, the research suggests that Pertamina Marine Solutions and similar operators should: (1) strengthen procurement systems by diversifying vendors, applying ABC inventory analysis, and incorporating environmental criteria; (2) enhance PMS compliance through tighter scheduling, condition-based maintenance, and environmental integration; (3) improve vocational training by integrating diagnostic, predictive, and environmental management

techniques into curricula; and (4) develop integrated performance indicators that capture operational, environmental, and sustainability dimensions. These strategies can reduce unplanned downtime, improve efficiency, enhance environmental performance, and contribute to sustainable maritime operations in line with contemporary industry requirements.

4. Conclusion

This study demonstrates that ship maintenance and spare-part availability exert significant positive effects on the operational continuity of the AHTS *Transko Andalas*, while revealing the growing importance of environmental and sustainability considerations in maritime operations. Despite overall good performance, the vessel's operational continuity is constrained by procurement bottlenecks, delayed preventive maintenance, human resource limitations, and gaps in environmental integration. By applying indicators such as SPRI and PMC, and incorporating environmental dimensions, the study provides measurable links between preparedness, operational outcomes, and sustainability performance.

The findings contribute to four domains: maritime operational management, port and shipping sustainability, environmental compliance, and maritime vocational education. They underscore the urgency of integrating procurement reforms, preventive maintenance strategies, environmental considerations, and workforce development into a unified approach to sustain offshore support operations. The study also highlights the need for maritime education to evolve beyond traditional technical training to include environmental awareness, digital skills, and sustainability practices.

Future research should explore the integration of predictive maintenance technologies, environmental monitoring systems, and digital twin applications in AHTS operations. Additionally, comparative studies across different vessel types and operational contexts would enhance the generalizability of these findings and contribute to the development of comprehensive sustainability frameworks for maritime operations. The integration of climate change considerations and socioeconomic impacts, as highlighted by Wilson et al. (2020) and Sunny et al. (2021), should also be incorporated into future vessel operation studies to address broader sustainability challenges in the maritime sector.

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