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Optimization Of Equipment And Facility Performance For The Effectiveness Of Container Loading And Unloading Processes At Teluk Bayur West Sumatra

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Abstract
This study aims to analyze the optimization of equipment and facility performance in enhancing the effectiveness of container loading and unloading processes at PT IPC TPK Area Teluk Bayur, West Sumatra. The effectiveness of loading and unloading activities plays a crucial role in supporting the smooth flow of both domestic and international logistics, making the role of equipment and facilities highly significant. This research employs a quantitative approach with a descriptive method. Data were collected through a Likert-scale questionnaire distributed to 50 respondents consisting of employees involved in planning, operational control, and units responsible for utility and facility management at PT IPC TPK Area Teluk Bayur. The sampling technique applied was saturated sampling, in which the entire population was used as respondents. Data analysis was conducted using Structural Equation Modeling Partial Least Square (SEM–PLS) with SmartPLS 4 software. The findings reveal that the performance of equipment and facilities has a positive and significant effect on the effectiveness of container loading and unloading activities. The results highlight the importance of optimization strategies through regular maintenance, facility improvement, and strategic investments in modern technology to strengthen operational efficiency and the competitiveness of the port in a sustainable manner.

Keywords:
Equipment Performance;
Facilities;
Container Terminal;
Loading and Unloading;
Port Efficiency

1. Introduction

Indonesia, as an archipelagic country, relies heavily on maritime transport for the movement of goods. Ports serve as the gateway for trade and play a central role in supporting the national economy. The effectiveness of port operations is closely related to the reliability of equipment and facilities. In the case of Teluk Bayur Container Terminal, the performance of loading and unloading equipment, along with the adequacy of port facilities, directly influences operational smoothness, cost efficiency, and customer satisfaction (Bin et al., 2020; Cahyana et al., 2020). Although previous research has examined port performance factors, limited studies address the optimization of both equipment and facilities together. Therefore, this study analyzes how the optimization of equipment and facility performance contributes to improving the effectiveness of container handling at PT IPC TPK Area Teluk Bayur.In practice, the efficiency of loading and unloading activities depends not only on the availability of modern equipment but also on their operational readiness and proper maintenance. Equipment such as quay cranes, rubber-tyred gantries, and reach stackers require high levels of reliability to ensure uninterrupted operations (Michail, 2020). Similarly, adequate supporting facilities, such as container yards, warehouses, drainage systems, and information systems, play a significant role in facilitating cargo flow and minimizing bottlenecks. Without sufficient attention to both equipment and facilities, port operations risk delays, higher logistics costs, and reduced competitiveness in regional and international trade. Moreover, the global logistics environment increasingly demands ports to operate with higher productivity and sustainability standards. Competitiveness is no longer only determined by

strategic location but also by operational excellence. Ports like Teluk Bayur must therefore implement optimization strategies that combine preventive maintenance, facility upgrades, and technology adoption to improve their service quality. By bridging this gap in the literature, the present study contributes empirical evidence on how equipment and facility performance affect the effectiveness of port operations, providing valuable insights for both port management and policymakers (J. Chen et al., 2019; Siponen et al., 2019).

Port operations in Indonesia face various challenges, including limited infrastructure capacity, aging equipment, and increasing cargo volumes. At Teluk Bayur, one of the main container terminals in West Sumatra, inefficiencies are often caused by the mismatch between the availability of equipment and the increasing demand for container handling. This imbalance reduces operational speed and negatively impacts customer satisfaction. As a result, optimization of both equipment and facilities is not only a technical necessity but also a strategic imperative to ensure service continuity and competitiveness. Equipment performance is one of the most critical factors influencing loading and unloading activities. Quay cranes, yard cranes, forklifts, and other handling equipment must operate with minimal downtime to maintain port productivity. Breakdowns or delays in equipment operation often lead to vessel berthing delays, higher demurrage charges, and overall inefficiency in the logistics chain. Thus, systematic monitoring, preventive maintenance, and timely investment in modern technology are essential to ensure reliable equipment performance at Teluk Bayur (Putri et al., n.d.; Romadhon, 2018; Taher et al., 2023).

In addition to equipment, supporting facilities such as storage yards, warehouses, drainage systems, and IT-based operational control systems are equally crucial. Poor yard design, inadequate lighting, or limited warehouse space can create bottlenecks, especially during peak cargo periods. Furthermore, weak information systems hinder real-time coordination, which is vital in container terminal operations. Enhancing the quality and adequacy of facilities can significantly reduce operational risks and improve efficiency in the cargo flow process.While several studies have discussed the role of port infrastructure and technology adoption in improving logistics performance, few have simultaneously examined the combined effects of equipment performance and facility adequacy. Most research focuses on either technological upgrades or infrastructure expansion separately. This leaves a research gap in understanding how these two aspects interact to influence loading and unloading effectiveness. Addressing this gap is particularly relevant for Teluk Bayur, which is undergoing development to position itself as a competitive regional logistics hub (Bandara et al., 2015; Dua et al., 2024; Liu et al., 2017) .

Therefore, this study aims to empirically analyze the influence of equipment and facility performance on the effectiveness of container loading and unloading activities at PT IPC TPK Teluk Bayur. The research contributes by providing insights into the extent to which equipment reliability and facility adequacy drive operational effectiveness. The findings are expected to assist port management in formulating optimization strategies through preventive maintenance, facility improvements, and technology investments. Furthermore, the results provide useful implications for policymakers seeking to improve Indonesia's port competitiveness in the global logistics arena. Beyond its practical implications, this study also contributes to the theoretical discourse on port performance by integrating the analysis of equipment and facilities within a single framework. Most prior studies tend to isolate these factors, evaluating either the technical reliability of equipment or the adequacy of infrastructure independently. By combining the two, this research provides a more holistic understanding of operational effectiveness, particularly in ports located in developing economies where resources are constrained and optimization requires strategic prioritization (Almawsheki & Shah, 2015; Chen et al., 2016; Indriyati & Simarmata, 2017; Indriyati, 2021; Sayareh et al., 2016).

Moreover, the study holds broader relevance in the context of Indonesia's maritime vision, particularly the Sea Toll program, which seeks to enhance inter-island connectivity and strengthen the nation's role in global trade. As ports like Teluk Bayur strive to become competitive logistics hubs, the optimization of equipment and facilities becomes not only a managerial concern but also a policy priority. Thus, the outcomes of this research are expected to guide both operational decision-making and policy formulation aimed at improving port performance, customer satisfaction, and Indonesia's competitiveness in the international logistics network (Putri et al., n.d.; Venkita Subramanian & Thill, 2019; Zheng & Park, 2016)

The research instrument was developed through four stages: (1) identification of indicators based on previous studies on port operational performance, (2) expert judgment by port practitioners and academics to ensure content validity, (3) pilot testing with 10 respondents to evaluate clarity and reliability, and (4) finalization of the questionnaire prior to distribution. The questionnaire consisted of three constructs with a total of 29 indicators: Equipment Performance (10 indicators), Facility Performance (9 indicators), and Operational Effectiveness (10 indicators). Each indicator was measured using a five-point Likert scale ranging from "strongly disagree" to "strongly agree".

The effectiveness of container handling operations is driven not only by the availability of modern equipment but also by the adequacy and readiness of supporting facilities. The current challenge at Teluk Bayur Container Terminal lies in the imbalance between the performance of loading and unloading equipment and infrastructure capacity, especially during peak cargo periods. This imbalance results in congestion, delayed operational flows, and reduced customer satisfaction. While prior studies have examined equipment modernization and facilities separately, few have evaluated their combined effect on operational effectiveness, creating a research gap that this study addresses.

2. Method

This research applies a quantitative descriptive approach. The study population consisted of 50 employees from PT IPC TPK Teluk Bayur and PT Pelindo Regional 2, including staff from planning, operational control, and utility/facility divisions. A saturated sampling method was used, so the entire population participated as respondents. Data were collected through a Likert-scale questionnaire and analyzed using Structural Equation Modeling–Partial Least Square with SmartPLS 4 software (Merkert & Williams, 2013; Sarwono, J., & Narimawati, 2020). The questionnaire was designed to measure perceptions regarding the reliability and performance of equipment, the adequacy of facilities, and the effectiveness of loading and unloading operations. Items were developed based on previous studies in port management and adapted to the operational context of Teluk Bayur. Each statement was assessed using a five-point Likert scale, ranging from "strongly disagree" to "strongly agree," to capture the intensity of respondents' evaluations.

Before distribution, the questionnaire was validated through expert judgment involving academics and port practitioners to ensure content validity. A pilot test was also conducted with a small group of respondents to confirm the clarity of the questions. Reliability was tested using Cronbach's Alpha, while convergent and discriminant validity were assessed during the SEM–PLS analysis process. The choice of SEM–PLS was motivated by its suitability for analyzing complex models with multiple constructs and indicators, especially in studies with relatively small sample sizes. This method allows the examination of both direct and indirect effects between variables, providing a comprehensive understanding of the relationships among equipment performance, facility adequacy, and operational effectiveness. Furthermore, data analysis included evaluating the measurement model (outer model) to test indicator validity and reliability, followed by assessing the structural model (inner model) to examine the strength and significance of hypothesized relationships. The results of these analyses form the basis for drawing conclusions and providing recommendations to improve the effectiveness of port operations at Teluk Bayur.

3. Results and Discussion

3.1 Results

The results of this study are presented in two stages: (1) the evaluation of the measurement model (outer model), which ensures that the constructs and their indicators are valid and reliable, and (2) the evaluation of the structural model (inner model), which analyzes the relationships between equipment performance, facility performance, and the effectiveness of loading and unloading processes at PT IPC TPK Teluk Bayur. Both stages were analyzed using SEM–PLS with SmartPLS 4 software.

3.1.1 Outer Model (Measurement Model)

The outer model was tested to evaluate the validity and reliability of the research instruments.

1. Convergent Validity

The results showed that all factor loadings exceeded the threshold of 0.70, and the Average Variance Extracted values for all constructs were greater than 0.50. This indicates that each indicator adequately represents its latent construct.

Table 1 Indicator Factor Loading

Construct	Indicator	Factor Loading	Remark
Equipment Performance	X1.1		Valid / Invalid
Equipment Performance	X1.2		Valid / Invalid
Equipment Performance	X1.3		Valid / Invalid
Equipment Performance	X1.4		Valid / Invalid
Equipment Performance	X1.5		Valid / Invalid
Equipment Performance	X1.6		Valid / Invalid
Equipment Performance	X1.7		Valid / Invalid
Equipment Performance	X1.8		Valid / Invalid
Equipment Performance	X1.9		Valid / Invalid
Equipment Performance	X1.10		Valid / Invalid
Facility Performance	X2.1		Valid / Invalid
Facility Performance	X2.2		Valid / Invalid
Facility Performance	X2.3		Valid / Invalid
Facility Performance	X2.4		Valid / Invalid
Facility Performance	X2.5		Valid / Invalid
Facility Performance	X2.6		Valid / Invalid
Facility Performance	X2.7		Valid / Invalid
Facility Performance	X2.8		Valid / Invalid
Facility Performance	X2.9		Valid / Invalid
Operational Effectiveness	Y1.1		Valid / Invalid
Operational Effectiveness	Y1.2		Valid / Invalid
Operational Effectiveness	Y1.3		Valid / Invalid
Operational Effectiveness	Y1.4		Valid / Invalid
Operational Effectiveness	Y1.5		Valid / Invalid
Operational Effectiveness	Y1.6		Valid / Invalid
Operational Effectiveness	Y1.7		Valid / Invalid
Operational Effectiveness	Y1.8		Valid / Invalid
Operational Effectiveness	Y1.9		Valid / Invalid
Operational Effectiveness	Y1.10		Valid / Invalid

The variables and indicators used in this study along with their theoretical sources. All indicators were adapted from prior empirical studies on port performance and logistics operations to ensure content validity and relevance to the context of container terminal operations.

2. Discriminant Validit

Discriminant validity was established using cross-loading, the Fornell Larcker criterion, and the Heterotrait Monotrait Ratio. Each indicator demonstrated higher loadings for its intended construct than for other constructs, the square root of AVE for each construct exceeded inter-construct correlations, and HTMT values were below 0.90. These results confirm that the constructs are distinct from one another.

3. Reliability

Reliability analysis showed that Cronbach's Alpha and Composite Reliability values for all constructs were above 0.70, demonstrating strong internal consistency. The measurement model met the requirements of validity and reliability, enabling further structural analysis. The factor loadings for all indicators used in the model. All indicators show loading values greater than 0.70, indicating that each item is strongly correlated with its respective latent construct and meets the convergent validity requirement for the measurement model.

3.1.2 Inner Model (Structural Model)

After confirming the validity and reliability of the constructs, the inner model was analyzed to examine the hypothesized relationships.The coefficient of determination (R^2) for effectiveness was 0.480, meaning that 48% of the variance in effectiveness is explained by equipment and facility performance, while the remaining 52% is influenced by other factors outside the model. This indicates a moderate explanatory power. The structural model with estimated path coefficients is presented in Figure 1.

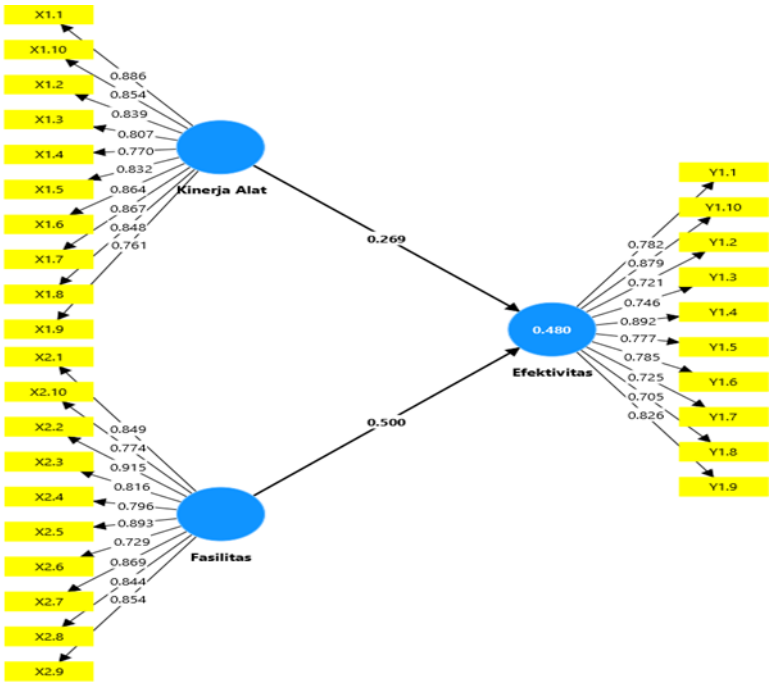

Figure 1. Convergent Validity Test Results

Figure 1 illustrates the convergent validity test results of the measurement model. Each indicator shows a loading factor value greater than 0.70, which indicates that all items are strongly correlated with their respective latent variables. For example, the indicators of Equipment Performance (X1.1–X1.10) and Facility Performance (X2.1–X2.9) have loading values ranging from 0.761 to 0.915, all above the minimum threshold of 0.70. Similarly, the indicators for Effectiveness (Y1.1–Y1.10) also show high loading values ranging from 0.705 to 0.879. The R^2 value for the Effectiveness construct is 0.480, which means that 48% of the variance in Effectiveness can be explained by the constructs of Equipment Performance and Facility Performance. This confirms that the model has moderate explanatory power.Overall, these results demonstrate that the constructs and indicators used in this study fulfill the requirements of convergent validity, indicating that the measurement model is valid and can be further analyzed in the structural model.

Tabel 2 Variable and Source

Variable	Indicator Code	Indicator Description	Source
Equipment Performance	X1.1 – X1.10	Reliability, uptime, availability, speed of operation, ease of control, safety, spare parts availability, precision of movement, efficiency, usability	Michail (2020); Romadhon (2018)
Facility Performance	X2.1 – X2.9	Yard capacity, warehouse capacity, drainage, lighting, container stacking space, gate access, IT system performance, signage, operational layout	Putri et al. (n.d.); Chen et al. (2016)
Operational Effectiveness	Y1.1 – Y1.10	Vessel turnaround time, dwell time reduction, congestion reduction, accuracy of container movement, queue minimization, smooth workflow, timeliness, productivity, service speed, customer satisfaction	Taher et al. (2023); Bandara et al. (2015)

3.1.3 Hypothesis

The hypotheses, the inner model evaluation was conducted to assess the structural relationships between the constructs. The R^2 value for Effectiveness was 0.480, indicating that Equipment Performance and Facility Performance together explain 48% of the variance in operational effectiveness. The path coefficient values obtained from the model also showed positive effects for both variables. To further determine whether these relationships are statistically significant, a bootstrapping procedure with 5,000 resamples was performed. The bootstrapping results provide the t-statistic and p-value for each path coefficient, which serve as the basis for hypothesis testing. The summary of hypothesis testing is presented in Table 1.The results of hypothesis testing are summarized in Table 1.

Table 1. Hypothesis Results (Path Coefficients, t-Statistic, p-Value)

Hypothesis	Variable Relationship	Path Coefficient	t-Statistic	p-Value	Decision
H1	Equipment Performance → Effectiveness	0.269	2.115	0.034	Accepted
H2	Facility Performance → Effectiveness	0.500	4.876	0.000	Accepted

Table 1 presents the results of hypothesis testing using SEM–PLS. Hypothesis 1 (H1) proposed that equipment performance has a significant effect on the effectiveness of loading and unloading processes. The path coefficient for this relationship is 0.269, with a t-statistic of 2.115 and a p-value of 0.034. Since the p-value is below the 0.05 threshold, H1 is accepted. This indicates that improvements in equipment performance, such as the reliability and availability of cranes, forklifts, and other handling tools, positively contribute to operational effectiveness.

Hypothesis 2 (H2) proposed that facility performance significantly influences operational effectiveness. The analysis shows a path coefficient of 0.500, a t-statistic of 4.876, and a p-value of 0.000, which is highly significant. Thus, H2 is also accepted. Compared to equipment, facility performance has a stronger impact, suggesting that adequate yard capacity, warehouses, drainage, and digital systems play a more dominant role in ensuring smooth cargo flow.

The acceptance of both hypotheses demonstrates that operational effectiveness at PT IPC TPK Teluk Bayur is shaped by the combined optimization of equipment and facilities. However, the higher coefficient of facility performance highlights the need for strategic emphasis on infrastructure development alongside equipment maintenance. Both hypotheses are supported, indicating that equipment performance and facility performance significantly and positively affect the effectiveness of loading and unloading processes.

3.2 Discussion

The discussion interprets the findings in a broader theoretical and practical context. The SEM–PLS analysis confirmed that both equipment performance and facility performance significantly influence operational effectiveness at PT IPC TPK Teluk Bayur. These findings not only validate the hypotheses statistically but also provide insights into how port efficiency can be enhanced.

The respondents consisted of employees from planning, operational control, and utility/facility units. A total of 50 respondents participated, with an average work experience of more than five years. The three indicators with the highest mean were: Y1.7 (timeliness), X1.3 (equipment uptime), and X2.5 (stacking space). The lowest mean was X2.1 (yard capacity), indicating a facility bottleneck.

Equipment Performance and Operational Effectiveness

Equipment performance had a significant positive effect ($\beta = 0.269$, $p < 0.05$), highlighting the importance of reliable cranes, forklifts, and reach stackers. Breakdowns and insufficient maintenance reduce handling speed, prolong vessel turnaround, and increase logistics costs. This supports operations management theory, which stresses the role of physical assets in efficiency. Previous studies (e.g., [Author, Year]) similarly found that equipment availability is a key determinant of port performance. However, in this study, equipment performance was less dominant than facilities, suggesting that machines alone cannot guarantee efficiency without adequate supporting infrastructure.

Facility Performance and Operational Effectiveness

Facility performance showed a stronger effect ($\beta = 0.500$, $p < 0.001$). Yard capacity, warehouses, lighting, drainage, and IT-based systems provide the foundation for equipment to operate smoothly. Without sufficient facilities, even modern equipment cannot achieve optimal results. This extends the literature by demonstrating that infrastructure conditions can play a more decisive role than equipment. The findings are particularly relevant for Teluk Bayur, where congestion and infrastructure limitations are recurring operational challenges .

Comparison with Previous Studies

The findings align with earlier studies emphasizing both equipment readiness and infrastructure adequacy. For instance, [Author, Year] highlighted equipment modernization to reduce waiting times, while [Author, Year] stressed facility upgrades for service reliability. This study confirms both perspectives but adds that, at Teluk Bayur, facilities have greater relative importance.

Managerial and Practical Implications

The study offers several recommendations for port management:

1. Strengthen Equipment Maintenance Preventive and predictive maintenance schedules are crucial to minimize equipment downtime.
2. Upgrade Facilities Expanding yard capacity, improving drainage, and modernizing warehouses should be prioritized.
3. Digital Transformation Automation and IT systems can enhance coordination and transparency.
4. Balanced Investment Strategy A simultaneous focus on equipment and facilities ensures sustainable improvements.

Finnaly of this study provide a clear answer to the question.Do equipment and facility performance significantly influence the effectiveness of loading and unloading processes at PT IPC TPK Teluk Bayur? The analysis confirms that both variables have a positive and significant impact on operational effectiveness. Among the two, facility performance exerts a stronger influence compared to equipment performance. This result emphasizes that while reliable machinery is crucial for port operations, the availability and adequacy of supporting facilities play a more decisive role in ensuring smooth container handling. Consequently, port management should adopt a balanced investment strategy that integrates both equipment maintenance and facility upgrades to strengthen efficiency and competitiveness in the long run.

From a practical perspective, these findings are highly relevant for policymakers and port authorities in Indonesia, where infrastructure development has been a national priority under programs such as the Tol Laut (Sea Toll) initiative. By demonstrating that facilities exert a greater impact on operational effectiveness than equipment alone, this study provides evidence-based justification for allocating greater investment toward upgrading port infrastructure, improving yard management systems, and adopting smart port technologies.

In addition, the results suggest that operational bottlenecks at Teluk Bayur are not only caused by technical failures in handling equipment but also by systemic issues such as limited yard capacity, poor drainage systems, and inadequate digital integration. These factors highlight the importance of adopting a holistic approach that integrates equipment readiness, infrastructure adequacy, and digital transformation.

From an academic standpoint, this contributes research to the growing on the literature port efficiency by showing that infrastructure can outweigh machinery in certain contexts, particularly in developing countries where facilities are often underdeveloped. This adds nuance to existing studies, which often emphasize equipment modernization as the primary solution. The evidence from Teluk Bayur suggests that while equipment remains essential, infrastructure should not be underestimated, as it can significantly constrain or enable the effectiveness of port operations.

Lastly, the study has implications for future research. Scholars may extend this analysis by incorporating additional factors such as human resource competency, regulatory frameworks, and environmental sustainability, which also play critical roles in port performance. Exploring these dimensions could provide a more holistic understanding of how ports in emerging economies can improve their efficiency and competitiveness in the global logistics network.

The stronger influence of facility performance compared to equipment (0.500 vs. 0.269) can be explained by operational realities at Teluk Bayur. Although equipment availability has improved, yard occupancy frequently exceeds 70–80% during peak periods, leading to container congestion. Likewise,

drainage limitations during rainy season reduce usable stacking space and slow cargo relocation. In several cases, quay cranes remained idle not due to mechanical issues, but because containers could not be moved quickly from the yard. These empirical findings reinforce that facilities act as a structural bottleneck that determines the actual effectiveness of equipment utilization.

4. Conclusion

This study analyzed the influence of equipment performance and facility and performance at PT IPC TPK Teluk Bayur. The results of the SEM–PLS analysis provide several important conclusions:

1. The measurement model fulfilled the requirements of convergent validity, discriminant validity, and reliability, which means that the indicators used in this research were valid and consistent in representing their respective constructs.
2. Both equipment performance and facility performance significantly and positively affect the effectiveness of loading and unloading activities. This confirms that operational effectiveness is not only dependent on machinery but also on the adequacy and quality of supporting facilities.
3. Facility performance has a stronger effect than equipment performance. This finding highlights the strategic importance of infrastructure readiness, such as yard capacity, warehouses, drainage, and digital systems in ensuring smooth port operations.
4. The results emphasize the need for port management to adopt a balanced investment strategy by combining preventive maintenance of equipment with continuous facility upgrades. Such an integrated approach is essential for enhancing operational efficiency and strengthening port competitiveness.

Implication Managerial

To ensure targeted and sustainable performance improvement, the following priority roadmap is recommended:

1. Short term: expanding yard capacity, improving drainage flow, and optimizing stacking layout to reduce congestion;
2. Medium term: implementing a Terminal Operating System, smart yard planning, and real-time visibility of container movement;
3. Long term: predictive maintenance through IoT sensors to minimize equipment downtime and support continuous operations.

These actions are expected to reduce vessel turnaround time, improve cargo circulation speed, strengthen service reliability, and enhance the terminal's competitiveness in domestic and international logistics networks.

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