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Mooring, Pilotage, and Towage Services Supporting Vessel Operations at Tanjung Emas Port, Semarang

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ABSTRACT

Pilotage, towage, and mooring are interdependent services that shape vessel turnaround and navigational safety at seaports. This study examines constraints affecting these services at Tanjung Emas Port, Semarang, and their association with perceived port operational effectiveness. A quantitative, cross-sectional correlational design was used, with purposive sampling of 60 respondents drawn from port operational personnel and service users. Data were gathered through Likert-scale questionnaires, interviews, and direct observation, and were analysed descriptively and through multiple linear regression. Field findings included an average pilotage time of approximately 1.5 hours, towage-related delays of 1–2 hours, limited availability of pilots and tugboats, and tidal flooding that disrupted mooring at Samudera Wharf. The regression model, comprising pilotage, towage, mooring, and weather impact, showed a strong association with port operational effectiveness ($R = 0.832$, $R^2 = 0.693$, $F(4, 55) = 30.97$, $p < .001$), with pilotage as the strongest predictor. The study recommends better pilot and tugboat availability, coordinated service scheduling, digital operational monitoring, and flood-resilient mooring arrangements. As the data are cross-sectional, the findings should be interpreted as associations rather than evidence of causality.

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1. INTRODUCTION

Ports connect maritime transport to hinterland production and distribution systems; their efficiency therefore depends on more than terminal handling equipment. Safe approach, movement within port waters, tug assistance, and secure berthing are sequential services that shape vessel waiting time and schedule reliability. Reviews of shipping-port performance identify resource allocation, efficiency, competitiveness, operational coordination, and sustainability as recurring research priorities (Kishore et al., 2024; Hardianto et al., 2023). The United Nations Conference on Trade and Development (UNCTAD, 2024) likewise treats port performance and transport facilitation as central to maritime trade efficiency.

Pilotage is particularly important when ships navigate restricted channels and congested harbor waters. The International Maritime Organization (IMO, 2003) describes pilotage as

work requiring local expertise, professional preparation, and close coordination with the bridge team. Evidence from studies of maritime pilots points to navigational risk, communication, and training as key safety considerations (Darbra et al., 2007; Issa-Zadeh & Garay-Rondero, 2025). The availability of qualified pilots and pilot transfer craft is consequently an operational capacity issue as well as a safety requirement.

Towage and mooring form the next interconnected stages. Tugboats supply maneuvering assistance under conditions that may exceed a ship's own capability, while safe mooring requires adequate berth arrangements and consideration of wind, current, water level, and available sea room. Studies of marine-service capacity identify a mismatch between available equipment and traffic demand as an important source of vessel delay (Mthembu & Chasomeris, 2023). Experiments on constrained berthing also underscore the need to match tug capability and ship maneuverability to berth conditions (Paulauskas & Paulauskas, 2025).

A central practical difficulty is that these services are often planned by separate units despite their operational dependence on one another. Research on pilotage planning and integrated vessel service scheduling shows that coordinating pilot assignments, tug availability, berths, and arrival windows can help reduce otherwise avoidable waiting (Wu et al., 2020; Wu et al., 2022; Nikghadam et al., 2025). Recent work on integrated pilotage and berth planning reinforces the importance of treating vessel arrival as a shared scheduling problem rather than a succession of isolated tasks (Xiao et al., 2025).

Environmental disruption must also be considered. Ports on low-lying coasts are exposed to high water levels, storms, and other hazards that can interrupt multiple parts of the transport chain (Verschuur et al., 2020; Lau et al., 2024). The relevance is particularly direct at Tanjung Emas Port in Semarang. Tide-related flooding has been documented in this coastal port area and has previously disturbed port activities, supporting the need to incorporate tidal conditions into operational preparedness (Rahili et al., 2023). Adaptation should therefore address both physical infrastructure and how port services respond when access or mooring areas are affected (Markolf et al., 2019).

Field conditions at Tanjung Emas Port indicate delays and service constraints affecting pilotage, towage, and mooring, together with tidal flooding around the lower Samudera Wharf area. However, empirical evidence that links these service-level constraints, together with weather conditions, to perceived port operational effectiveness at this port remains limited.

This study therefore aims to (1) describe the main operational constraints on pilotage, towage, and mooring at Tanjung Emas Port; (2) analyse the association of pilotage, towage, mooring, and weather impact with port operational effectiveness; and (3) identify practical

improvements to service capacity, coordination, information sharing, and tidal-flood preparedness. The contribution of the study is a combined operational and quantitative assessment grounded in an Indonesian port case.

2. LITERATURE REVIEW

Port effectiveness is commonly approached as a multidimensional outcome comprising service reliability, vessel turnaround, resource utilization, and stakeholder performance. A review of port-performance measurement emphasizes the importance of selecting indicators that correspond to actual service objectives and user expectations (Hardianto et al., 2023), while systems-thinking research shows how port outcomes emerge from the interaction of operating, infrastructural, and institutional factors (Sunitiyoso et al., 2022). These perspectives support examining pilotage, towage, and mooring as connected service functions, rather than as independent activities.

In resource-allocation terms, vessel service planning depends on the availability and sequencing of pilots, tugboats, berths, and access channels. Wu et al. (2020) formulated pilotage planning as a scheduling problem and subsequently demonstrated the advantages of integrated berth allocation and pilotage planning (Wu et al., 2022). Nikghadam et al. (2025) extended the coordination perspective to multiple vessel-service providers, while Xiao et al. (2025) examined the joint scheduling of berths, quay cranes, and pilotage. Related reviews also emphasize uncertainty in arrival and handling schedules (Rodrigues & Agra, 2022) and the potential benefits of integrated berth and crane operations (Abou Kasm et al., 2020).

Safety and environmental conditions influence the feasible schedule. IMO pilotage guidance stresses training, certification, and coordination among pilots and ship personnel (IMO, 2003). The pilotage sustainability review by Issa-Zadeh and Garay-Rondero (2025) links navigational safety to the broader economic, social, and environmental dimensions of port performance. Paulauskas and Paulauskas (2025) further show that restricted berth dimensions and hydrometeorological conditions should be accounted for when selecting towage and maneuvering arrangements. The Semarang-specific tidal analysis of Rahili et al. (2023) demonstrates why flood-related disruptions cannot be treated as merely hypothetical in this port setting.

Digitalization offers one route to reduce avoidable service gaps by sharing vessel arrival estimates, pilot assignments, tug schedules, berth readiness, and service completion times. Studies on digital port transformation report potential gains in visibility, planning, and resource allocation, while also identifying the need for process and institutional coordination

(Belmoukari et al., 2023; Alzate et al., 2024; Mendoza Heredia et al., 2024). Indonesian work on Inaportnet likewise identifies the integration of ship services as an area where digital platforms must be supported by effective operational processes (Malisan & Tresnawati, 2019). International and local findings therefore jointly support operational integration, but they do not imply that technology alone will eliminate maritime service delays.

3. METHODS

3.1. Research Design and Participants

This study adopted a quantitative cross-sectional correlational design to examine the association of port operational effectiveness with pilotage, towage, mooring, and weather conditions. The research was conducted at Tanjung Emas Port, Semarang. A total of 60 respondents were selected purposively from individuals with direct experience of vessel services, including pilots, tugboat crews, mooring personnel, and port service users.

3.2. Instruments and Data Collection

Three data-collection approaches were used. First, questionnaires on service quality and operational effectiveness used five-point Likert response scales. Second, interviews with port personnel and service users explored practical service bottlenecks. Third, direct observation recorded operational circumstances including pilotage and towage delays, waiting times, and weather or tidal disturbances during mooring. These sources were used to describe both perceived constraints and the operational situations in which service delays occurred.

3.3. Variables and Analytical Approach

The regression model contains four independent variables: pilotage service (X1), towage service (X2), mooring service (X3), and weather impact (X4). The dependent variable is port operational effectiveness (Y), treated as a composite outcome covering waiting time, cost, and user satisfaction.

The corresponding linear specification is $Y = \beta0 + \beta1X1 + \beta2X2 + \beta3X3 + \beta4X4 + \varepsilon$. The data were analysed by multiple linear regression using SPSS, and the results are presented as a model summary, an analysis of variance (ANOVA), and a coefficient table.

3.4. Interpretation and Limitations

Descriptive percentages and service times are reported as obtained from the questionnaires and field observations. Regression coefficients are interpreted as conditional associations; because the sample is cross-sectional and non-probabilistic, the results do not support causal interpretation or direct generalization to all vessels using the port.

4. RESULTS AND DISCUSSION

4.1. Pilotage and Towage Constraints

Pilotage required approximately 1.5 hours on average. This value indicates the duration observed in the study setting rather than a comparison against a formal service standard. Approximately 72% of respondents identified a shortage of available pilots as a constraint. Respondents also mentioned insufficient pilot craft capacity for accommodating vessels with different maneuvering and boarding requirements.

The pilotage finding highlights a relationship between crew availability, transfers to vessels, and the sequence of vessel arrivals. Theoretical and field-based research suggests that professional staffing is necessary but must be paired with scheduling systems that account for the location of available pilots and the time required to serve successive ships (Darbra et al., 2007; Wu et al., 2020; Mthembu & Chasomeris, 2023). A review of sustainable pilotage similarly indicates that well-designed service processes can support safe movement and reduce avoidable operational delay (Issa-Zadeh & Garay-Rondero, 2025).

For towage, delays of approximately 1–2 hours were observed, and 70% of respondents identified limited tugboat availability as an operating constraint, particularly during busy periods. Interviews additionally described coordination problems among personnel arranging tug service. These results are consistent with the broader finding that vessel-service capacity and demand synchronization matter for port call performance (Nikghadam et al., 2025). The percentages are indicators of respondent perceptions, not direct estimates of how frequently tug shortages caused an actual vessel delay.

4.2. Mooring Services and Tidal Disruption

At the lower Samudera Wharf area, mooring was disrupted by tidal flooding, locally called rob. Overall, 22% of respondents identified tidal flooding as a hindrance to mooring. Flooded or difficult-to-access quay areas can reduce the speed of safe line-handling and complicate the timing of vessel arrival, especially when tide and berth arrangements are not aligned. This finding is supported by an independent study that documented significant tidal-flood vulnerability in the Tanjung Emas port area (Rahili et al., 2023).

The significance of this issue extends beyond individual mooring events. Research on natural-disaster disruptions indicates that port resilience depends on both physical infrastructure and flexible operating arrangements (Verschuur et al., 2020; Markolf et al., 2019). Mooring in restricted waters also requires a realistic appraisal of ship dimensions, current, wind, and tug forces (Paulauskas & Paulauskas, 2025). Because this study did not include an engineering

assessment of quay capacity or flood elevations, the recommendations for infrastructure adaptation are presented as priorities for technical evaluation.

4.3. Summary of Descriptive Findings

Table 1. Operational constraints at Tanjung Emas Port

Service	Reported condition	Descriptive evidence	Operational implication
Pilotage	Limited pilots and pilot-boat availability	Mean time approximately 1.5 h; 72% reported pilot limitation	Potential mismatch between pilot capacity and vessel arrival pattern
Towage	Limited tugboat capacity and coordination	Delay approximately 1–2 h; 70% reported tug limitation	Waiting or rescheduling while assistance is unavailable
Mooring	Tidal flooding in the lower Samudera Wharf area	22% reported tidal flooding as hindrance	Restricted safe access and timing of mooring operations

Table 1 summarizes the findings for each service. The percentages describe respondent feedback, whereas the hour values refer to service times or delays; because these metrics have different bases, they are not aggregated into a single index or interpreted as measures of the same outcome.

4.4. Regression Model

The multiple regression model yields $R = 0.832$, $R^2 = 0.693$, adjusted $R^2 = 0.670$, and a standard error of the estimate of 1.609 (Table 2). The ANOVA results (Table 3) show a regression sum of squares of 320.845 and a residual sum of squares of 142.456, giving $F(4, 55) = 30.97$ with $p < .001$. The model is therefore statistically significant overall.

Table 2. Regression model summary

Statistic	Value
Multiple R	0.832
R^2	0.693
Adjusted R^2	0.670
Standard error of the estimate	1.609
F(4, 55)	30.968
Sig.	< .001

Table 3. Analysis of variance (ANOVA)

Component	Sum of squares	df	Mean square	F	Sig.
Regression	320.845	4	80.211	30.968	< .001
Residual	142.456	55	2.590	—	—
Total	463.301	59	—	—	—

The model explains approximately 69% of the variation in port operational effectiveness within the study sample. This proportion describes model fit; it does not imply that improving the services will necessarily produce an equivalent improvement in port outcomes.

4.5. Predictor Coefficients and Interpretation

Table 4. Multiple regression coefficients

Predictor	B	SE	Standardized β	t	p
Intercept	3.842	1.512	—	2.537	.014
Pilotage	.451	.134	.325	3.362	.001
Towage	.301	.121	.218	2.489	.016
Mooring	.245	.116	.197	2.115	.039
Weather impact	.189	.089	.152	2.123	.038

All four unstandardized coefficients are positive and significant at the 5% level (Table 4). Pilotage has the largest standardized coefficient ($\beta = 0.325$, $p = .001$), followed by towage ($\beta = 0.218$, $p = .016$), mooring ($\beta = 0.197$, $p = .039$), and weather impact ($\beta = 0.152$, $p = .038$). These results indicate that pilotage service is the strongest predictor of perceived port operational effectiveness. Because the coefficients are based on Likert-scale scores, they cannot be translated directly into units of saved waiting time or reduced costs.

Weather impact has the smallest, yet significant, coefficient. This indicates that perceived weather and tidal conditions contribute to variation in operational effectiveness, although to a lesser extent than the three vessel services, which is consistent with the tidal-flood disruption to mooring observed at Samudera Wharf.

4.6. Implications for Management and Port Modernization

The most immediate managerial implication is to coordinate vessel service assignments before a vessel reaches the pilot boarding location. Operations personnel could review vessel ETA, berth readiness, pilot availability, pilot-boat transfers, tug assistance requirements, and tidal windows within a shared scheduling procedure. Empirical and optimization studies show that integrated vessel service planning can reduce mismatches between complementary resources (Wu et al., 2022; Nikghadam et al., 2025; Xiao et al., 2025). Local experience with

Inaportnet further underscores the need to connect digital documentation to the actual availability of port services (Malisan & Tresnawati, 2019; Syaifullah et al., 2025).

A second priority is systematic capacity management. Port managers could examine peak-time assignment patterns to identify whether additional pilots, pilot craft, or suitably rated tugs are necessary, while avoiding a presumption that purchasing equipment alone will solve scheduling problems. The marine-service capacity literature suggests that operational procedures and asset availability should be assessed together (Mthembu & Chasomeris, 2023). A third priority is to prepare mooring contingencies for tidal flooding, including alternative service windows, communication protocols, and a technical review of access and quay resilience (Rahili et al., 2023; Verschuur et al., 2020).

For longer-term implementation, real-time monitoring dashboards could capture the planned and actual times of pilot dispatch, tug arrival, commencement of mooring, and berth readiness, with the reason for any exception recorded in a shared system. Smart-port research identifies visibility, data integration, and process coordination as potential enablers of service improvement (Belmoukari et al., 2023; Alzate et al., 2024; Zhang et al., 2024). Such proposals should be evaluated against clear operational indicators, rather than assumed to be effective without measurement.

Future studies should combine questionnaire data with service-event timestamps and instrument reliability testing to determine which service bottlenecks predict waiting time independently and whether weather disturbances alter the strength of the operational relationships.

Further references reinforce the diversity of improvement options. Studies of agency-level service bottlenecks and broader port performance point to the importance of operational coordination and indicator design (Jayanti et al., 2025; Kishore et al., 2024). Reviews of smart-port practice extend that perspective to organizational capacity and the design of digital processes (Mendoza Heredia et al., 2024; Toomeoja et al., 2025). These tools were not directly evaluated in the present survey.

5. CONCLUSION

This study identifies three interconnected constraints on vessel services at Tanjung Emas Port: limited availability of pilots and pilot craft, restricted tugboat capacity and coordination, and tidal-flood-related disruption of mooring around Samudera Wharf. It found an average pilotage duration of approximately 1.5 hours, towage-related delays of 1–2 hours, and respondent concerns regarding personnel availability, tug capacity, and tidal conditions. These

results support managerial attention to shared scheduling, appropriately matched service assets, and operational flood preparedness.

The regression analysis shows a strong and significant association between the four predictors (pilotage, towage, mooring, and weather impact) and port operational effectiveness, with approximately 69% of the variation explained ($F(4, 55) = 30.97$, $p < .001$). Pilotage is the strongest predictor, followed by towage, mooring, and weather impact.

Operational priorities comprise coordinated pilot-tug-berth planning, better readiness and deployment of personnel and equipment, integrated service-status information, and infrastructure and procedural measures responsive to tidal flooding. Future empirical research should incorporate reliable vessel timestamps, well-defined measures of effectiveness, and reproducible regression output so that proposed improvements can be assessed with greater precision.

6. DECLARATIONS

Author contributions: M.I.: Conceptualization, Methodology, Formal analysis, Writing – original draft; A.S.: Supervision, Validation, Writing – review & editing; O.C.K.: Investigation, Data curation; I.K.H.P.A.: Investigation, Resources; I.Z.S.: Data curation, Visualization, Writing – review & editing. All authors have read and approved the final manuscript.

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