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Developing A Decision Support Framework for Tugboat Capacity Expansion: PT PIT's Dual-Port Tugboat Operations

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Abstract
Indonesia's growing coal production has increased pressure on port logistics, particularly tugboat operations that are vital for barge maneuvering. PT PIT, the sole tug service provider for PTBA, currently operates with only two tugboats, resulting in limited capacity and increasing delays in coal shipments. This study aims to develop a decision support framework to optimize tugboat capacity expansion at PT PIT's dual-port operations (Kertapati and Kramasan). A mixed methods approach is employed, combining quantitative modeling (queuing theory, financial feasibility, and project scheduling) with qualitative insights from stakeholder discussions. The analysis finds that expanding the fleet from two to four tugboats raises daily barge throughput from three to nearly ten, improves turnaround times, and increases PT PIT's annual net revenue by approximately IDR 19.9 billion. Three procurement alternatives new purchase, operational lease, and financial lease are evaluated using the Analytical Hierarchy Process (AHP), with operational leasing emerging as the most viable due to its flexibility and lower risk. Risk assessment, following ISO 31000:2018 guidelines, identifies 15 critical risks, including capacity shortfalls and mechanical failures, with mitigation strategies proposed. The project is scheduled using PERT and Gantt methods, providing a roadmap for implementation by 2026. This integrated framework supports scalable, cost-efficient, and risk-mitigated logistics performance to meet Indonesia's rising coal export demands.

Keywords: Tugboat Capacity; Coal Logistics; Queue Modeling; Operational Leasing; Risk Management

INTRODUCTION

Indonesia's role as a leading coal exporter continues to place increasing demands on its logistics infrastructure, particularly in managing barge movements across river and port systems. As coal production expands to meet domestic and global energy demands, the logistics network especially the effectiveness of tugboat services has emerged as a critical performance lever in ensuring cost-efficiency and timely deliveries (Raj, Kumar, & Singh, 2024; Li, Wang, & Chen, 2024).

Coal transportation relies on an integrated chain of rail transport, river navigation, and port handling, where the tugboat's function becomes pivotal in

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maneuvering barges for docking and departure. Inefficient tugboat scheduling, limited fleet capacity, and inadequate coordination often lead to increased vessel turnaround times and higher demurrage costs (Smith & Jones, 2020; Romano, 2020). These operational bottlenecks directly affect export reliability and customer satisfaction.

PT PIT, as the sole tug service provider for PTBA's operations at Kertapati and the under-construction Kramasan Port, currently operates only two tugboats. However, projected throughput targets from 4.25 MTPA in 2025 to 20 MTPA by 2030 are expected to exceed current fleet capacity, increasing the risk of logistics congestion (Chopra & Meindl, 2021). Without a clear expansion and resource allocation strategy, PTBA may face chronic delays in barge movements, affecting revenue and operational stability.

Prior studies in maritime logistics highlight the relevance of simulation models, strategic planning, and data-driven tools for fleet management and service optimization (Slack, Brandon-Jones, & Johnston, 2020). The use of decision-support systems such as the Analytic Hierarchy Process (AHP) and risk management based on ISO 31000:2018 also enables organizations to balance financial feasibility, operational risk, and long-term scalability (Hillson, 2021; ISO, 2018).

However, a practical, integrative framework combining queue modeling, investment analysis, procurement strategy, and structured risk mitigation tailored to the Indonesian dual-port coal logistics context remains absent. This study aims to address that gap by developing a decision support model to guide PT PIT in expanding its tugboat capacity efficiently and sustainably. The model is designed to support managerial decision-making by aligning operational performance, financial returns, and stakeholder expectations.

LITERATURE REVIEW

Tugboat Operations in Port Logistics

Tugboats play a critical role in ensuring the safe and efficient movement of vessels within confined port environments. Their strategic importance in facilitating barge and ship maneuvering directly affects port efficiency, especially in bulk commodity logistics such as coal (Nguyen et al., 2023). The reliability and scheduling of tugboat services influence berth utilization, reduce vessel waiting time, and improve turnaround performance (Tian et al., 2020). In high-demand ports, tugboat shortages can lead to operational backlogs, demurrage charges, and reputational damage for shipping operators.

Capacity Planning and Queueing Models

Queueing theory has been widely applied in port logistics to analyze service capacity, estimate waiting times, and optimize resource allocation (Zhou et al., 2021). The use of simulation models based on arrival rates, service times, and resource availability supports proactive capacity expansion decisions. Studies in similar port environments have shown that expanding tugboat fleets can significantly reduce queue lengths and improve overall system throughput (Sun et al., 2022). Incorporating queue modeling in logistics planning allows port authorities to dynamically adapt to traffic surges while maintaining service levels.

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Decision Support Systems in Maritime Operations

In response to increasing complexity in maritime logistics, decision support systems (DSS) have emerged as essential tools for integrating technical, financial, and strategic dimensions of operational planning. Tools such as the Analytic Hierarchy Process (AHP), simulation-based optimization, and financial modeling enhance managerial decision-making by prioritizing criteria under uncertainty (Al-Talib & Hanafiah, 2019). Particularly in fleet investment or leasing decisions, DSS frameworks offer structured approaches for evaluating trade-offs among cost, flexibility, and operational control (Fotiadis et al., 2020).

Tugboat Procurement Strategies: Ownership vs Leasing

Selecting the right procurement model whether through outright purchase, operational lease, or financial lease has long-term implications on operational flexibility, capital allocation, and asset lifecycle management. Several studies advocate operational leasing for high-cost, high-utilization assets like tugboats, especially when cash flow predictability and fleet flexibility are prioritized (Yuen et al., 2021). Ownership may provide long-term savings and control but requires substantial upfront capital and assumes long-term stability in demand.

Risk Management in Port Asset Expansion

Effective risk management is essential when expanding port service assets such as tugboats. The application of ISO 31000:2018 and other international risk frameworks helps organizations identify, prioritize, and mitigate operational, financial, and compliance risks (Setiadi et al., 2022). Studies show that integrating risk assessment early in the planning process especially in procurement and implementation phases reduces cost overruns, safety incidents, and implementation delays in maritime operations (Hasan et al., 2023).

Project Scheduling in Fleet Expansion

Project management tools such as PERT and Gantt charts are commonly applied in port infrastructure development to coordinate procurement, training, integration, and commissioning tasks (Martínez et al., 2020). By modeling task dependencies and estimating timeline variances, these tools offer visibility over execution bottlenecks and support the alignment of operational readiness with strategic throughput targets.

METHOD

This study employs a mixed methods research design with an explanatory sequential approach to comprehensively analyze the operational, financial, and strategic aspects of tugboat capacity expansion at PT PIT's dual-port operations. The rationale behind using mixed methods lies in the complexity of the research problem, which requires both quantitative rigor and qualitative insight to generate feasible and context-sensitive solutions (Tashakkori & Teddlie, 2021). Quantitative analysis was prioritized in the initial stage to simulate current and future tugboat capacity using queueing models, calculate financial feasibility through investment appraisal techniques, and generate optimal operational schedules. These outputs were used as the basis for the second stage—qualitative validation—through semi-structured discussions with key PT PIT stakeholders, including senior executives from operations, finance, and strategic planning divisions.

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The quantitative component utilized queueing theory to simulate barge movement and tugboat service cycles under varying demand scenarios. Queue performance metrics such as utilization rate, average waiting time, and system throughput were calculated using established modeling formulas, ensuring validity and comparability (Zhou et al., 2021). Financial feasibility was assessed through Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), and Profitability Index (PI), following standard project evaluation practices (Brealey, Myers, & Allen, 2022). Sensitivity analysis was applied to evaluate the robustness of financial outcomes under variations in key parameters such as tariff rates, barge volumes, and cost structures.

To determine the most appropriate procurement strategy, the Analytic Hierarchy Process (AHP) was employed. AHP is a multi-criteria decision-making tool that allows stakeholders to rank procurement alternatives (purchase, operational lease, financial lease) against weighted criteria including operational flexibility, cost, risk, and strategic alignment (Saaty & Vargas, 2021). Expert judgments were collected through pairwise comparisons, and consistency ratios were calculated to validate decision coherence.

Risk identification and prioritization were conducted using the ISO 31000:2018 framework. A risk matrix was developed to assess the severity and likelihood of potential disruptions across operational, financial, regulatory, and strategic dimensions. Risks were then categorized and assigned mitigation strategies using avoidance, reduction, transfer, or acceptance approaches (Setiadi, Permana, & Anugrah, 2022).

The implementation timeline for tugboat procurement and deployment was structured using the Program Evaluation and Review Technique (PERT). Optimistic, most likely, and pessimistic time estimates were gathered for each activity based on expert elicitation, allowing the calculation of expected durations and critical paths. A Gantt chart was developed to visualize project phases and dependencies, supporting timeline alignment with PTBA's expansion targets (Martínez et al., 2020).

Data collection integrated both primary and secondary sources. Primary data were obtained through a facilitated group discussion during PT PIT's performance review meeting in May 2025. This included real-time feedback from the board of directors, operations management, and finance leads. Secondary data were drawn from operational records (2018–2024), financial reports, fleet deployment logs, and service-level agreements, which served as inputs for modeling and cross-validation.

By triangulating simulation outputs, financial analysis, stakeholder input, and project scheduling tools, this method ensures high construct validity and practical relevance. The methodological framework is adaptable to other infrastructure-constrained logistics settings in Southeast Asia and supports the strategic alignment of asset procurement with national coal export objectives.

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RESULT

Root Cause Analysis

Current Reality Tree (CRT) that shows how PTBA became more and more unhappy with late coal deliveries. At the top of the tree is PTBA's main complaint: their coal supply could be delayed. This shows up in real life as long wait times for barges and long lines at Kramasan Port. These problems are caused by an overloaded and overstressed tug fleet. With only two boats in service, utilization rates are close to 100 percent, which makes them less reliable and doesn't leave any room for regular maintenance or unexpected surges. PT PIT's tugboats have to go back and forth between two ports, with Kertapati getting priority and Kramasan getting less attention. This uneven distribution makes wait times at Kramasan even longer. The root cause is that a fleet of only two tugboats can't handle the expected demand of about ten barge calls per day at both ports. This diagnosis not only explains why there are delays in loading coal, but it also shows how important it is to increase the number of tugboats available. This will be discussed in more detail in the thesis through queuing theory analyses, economic feasibility studies, and scheduling models.

Performance Evaluation and Capacity Analysis

PT PIT's current tugboat system, with two tugboats, is capable of handling six barges per day matching both arrival and service rates ($\lambda = \mu = 6$). The system shows operational efficiency, with 50% average utilization, minimal queue length (0.33 barges), short wait times (1.33 hours), and quick turnaround (5.33 hours). Additionally, 33.3% idle time offers flexibility for demand fluctuations or disruptions.

However, when the arrival rate is increased to 20 barges per day without expanding fleet size, the system becomes critically overloaded. Utilization jumps to an unsustainable 166.7%, and performance metrics yield invalid (negative) results, indicating instability. This simulation highlights that the current tugboat capacity is insufficient to meet projected demand increases and requires urgent expansion.

In conclusion, two more tugboats to the fleet makes the system more stable in light of the expected rise in barge arrivals. Even though usage and queue lengths are higher than they are now, the system stays stable and runs smoothly, which stops long delays. This increase in capacity is a good way to meet rising demand, but traffic levels will keep changing, so it will be necessary to keep an eye on things and make changes as needed.

The fact that the tugboat fleet's use has gone up to 83.3% shows that resources are being used very well, making sure that the boats are working hard to meet demand. Queue lengths have stayed well within manageable limits even though throughput has gone up, which shows that current capacity management is working well. Also, the system can handle more load because it takes about eight hours for each barge to turn around.

Strategic Analysis of Additional Tugboat Requirements

Economic Analysis for Tugboat Procurement

PT PIT faces a critical shortage of tugboats to meet increasing coal shipment demands at Kertapati and Kramasan Ports, risking operational bottlenecks and demurrage costs. Three options to address this include: (1)

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purchasing new tugboats, (2) operational leasing, and (3) financial leasing, each with distinct advantages and challenges.

This section evaluates the financial impact of purchasing two new tugboats over a 10-year period (2025–2035), focusing on Payback Period (PBP), Internal Rate of Return (IRR), and Net Present Value (NPV). The model assumes 1,734 barge movements annually, each generating IDR 19.5 million in revenue, with operating costs including fuel, crew wages, maintenance, agency fees, and certification costs, totaling approximately IDR 11.68 billion per year. The initial investment of IDR 50 billion per tugboat is depreciated over 10 years. A discounted cash flow analysis assesses profitability and alignment with PT PIT's strategic goals, determining whether fleet expansion via new purchases is financially viable.

The feasibility study shows that after an initial investment of IDR 50 billion, the new tugboats will make IDR 16.858 billion in free cash flow each year from Year 2 to Year 10. This includes net income and depreciation. This study anticipates paying back the investment in approximately 2.97 years, or by Year 3, an NPV of IDR 42.08 billion, an IRR of 30.27%, and a profitability index of 3.27, which means that the investment will create a lot of value and quickly pay back the capital.

A sensitivity analysis of the project's Net Present Value (NPV) considering ±20% changes in key factors: tariff, barge movements, tax rate, variable costs, and fixed costs. The base-case NPV is IDR 42.07 billion. Tariff and barge volume have the largest impact, with NPV varying between IDR 13.43 billion and IDR 70.72 billion. Tax rate and costs have smaller effects. The project remains financially viable across all scenarios, highlighting the importance of stable pricing and demand management.

Three financing options for tugboat acquisition are evaluated:

1. New Purchase: Offers full operational control and the best financial returns, with a payback period of 2.97 years, IRR of 30.27%, and NPV of IDR 42.07 billion. Requires upfront investment of IDR 50 billion and accepts fluctuating operating costs.
2. Operational Lease: Lower upfront cost and maintenance handled by the lessor, but higher long-term costs due to annual payments (~IDR 20.3 billion). Suitable for uncertain demand and cash flow management but limits asset control.
3. Financial Lease: Balances upfront costs, fixed payments, and operational control, allowing customization and predictable cash flow. It adds a right-of-use liability to the balance sheet but aligns with PT PIT's capital retention goals while providing near-ownership benefits.

Overall, the new purchase is most financially rewarding if capital is available, operational leasing offers flexibility, and financial leasing provides a compromise between control and cash flow management.

Analytical Hierarchy Process for Tugboat Procurement

The Analytic Hierarchy Process (AHP) is used to find the best way for PT PIT to acquire more tugboats. This tool for making decisions breaks the problem down into three parts: the main goal, the key criteria, and the options. The main goal is to find the best way to procure tugboats that will give Kertapati and

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Kramasan Ports enough capacity to handle coal operations. Five important factors guide this choice: operational efficiency (reliability and capacity), strategic fit (how well it fits with PT PIT's long-term goals), risk (operational, regulatory, and market risks), flexibility and scalability (the ability to change the size of the fleet as demand changes), and implementation feasibility (practical things like approvals, training, and integration).

Three methods for PT PIT to acquire two additional tugboats: new purchase, operational lease, and financial lease. A new purchase requires a large upfront payment of IDR 50 billion but offers full control while bearing maintenance and depreciation risks. Operational leasing requires no upfront cost, with lease payments treated as operating expenses and maintenance risks borne by the lessor, though it may limit asset control. Financial leasing spreads the cost over ten years with annual payments of about IDR 7.45 billion plus interest, providing near-ownership benefits and operational control without a large initial outlay but transferring ownership risks to PT PIT.

Profit and loss impacts for each option. New purchase results in net income of IDR 39.9 billion after depreciation and taxes. Operational lease yields the highest EBIT but lowest net income (IDR 21.4 billion) due to high lease payments. Financial lease offers a middle ground, with net income close to new purchase (IDR 38.1 billion) but steadier cash flow.

Structured evaluation using the Analytic Hierarchy Process (AHP) based on expert input from senior PT PIT leaders and managers. Five decision criteria operational efficiency, strategic fit, risk, implementation feasibility, and flexibility—were pairwise compared using the Saaty scale to prioritize factors influencing procurement decisions. Experts rated the three acquisition options against these criteria, ensuring a transparent and consistent decision-making process.

The AHP matrices capture subjective expert judgments quantitatively, helping PT PIT identify the optimal tugboat procurement strategy aligned with both short-term operational needs and long-term strategic goals.

Across all five evaluation criteria, Alternative 2 (operational lease) receives higher scores than Alternative 1 (new purchase) and Alternative 3 (financial lease). This discrepancy is particularly noticeable in crucial domains like Implementation Feasibility (0.61) and Flexibility and Scalability (0.68). Alternative 2 obtains a total priority score of 0.59 when these scores are added to the global weights of the criteria. According to expert evaluations on both an operational and strategic level, this clearly shows a strong preference for operational leasing as the superior tugboat procurement option for expanding PT PIT's tugboat fleet.

Daily Tugboat Assignment

This study shows two operational schedules that will keep barges moving without stopping and make the best use of tugs. There are two types of schedules: a standard daily rotation and a tide-constrained rotation. The standard schedule runs every day from 6:00 AM to 6:00 PM, giving ten operational slots each day. The tide-constrained schedule, on the other hand, only allows operations to happen between 6:00 AM and 10:00 AM and 12:00 PM and 6:00 PM. Both methods keep the same daily throughput, but they use it in different ways. This case shows that changing the timing of services can keep service levels high even when there are environmental limits.

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Tugboats B and D repositioned early morning without towing barges to prepare for upcoming service slots, while other tugs returned to Kramasan after their last assignments. The Normal Schedule operates continuously from 06:00 to 18:00 with 72-minute intervals, moving barges in a fixed A → B → C → D rotation, requiring four tugboats and achieving about 83% utilization. The Tide-Constrained Schedule adjusts operations around the Ampera Bridge closure (10:00–12:00), splitting the day into two windows with 60-minute intervals, maintaining throughput but with no flexibility during the blockade.

Expanding the tugboat fleet from two to four significantly boosts daily barge movements from three to ten, increasing gross revenue by nearly IDR 50 billion and PT PIT's share by nearly IDR 20 billion. The return on lease cost remains stable at 66.7%, indicating that leasing costs scale efficiently with increased volume while preserving contract efficiency.

Risk Assessment

For PT PIT to successfully grow and run its tugboat fleet in order to satisfy the increasing demand for coal shipments, effective risk management is crucial. This study identifies a wide range of risks that could impact operational objectives and the sustainability of the port, including financial, legal, reputational, market, operational, and project-related risks. Maintaining PT PIT's resilience and advancing its strategic goals depend on identifying and controlling these risks via thorough evaluation and mitigation.

Fifteen potential risks threatening PT PIT's tugboat fleet growth and operations were identified, including capacity shortfalls (R1), dependence on a single leasing vendor (R2), unpredictable lease costs (R3), and challenges implementing digital fleet monitoring (R15). Prioritizing these risks helps PT PIT address reputational, strategic, and operational threats to maintain service continuity and stakeholder trust.

Root causes linking risks to operational and financial impacts—for example, inaccurate growth forecasts and fleet expansion delays (R1) cause shipment delays and lost revenue, while poor vendor compliance with safety rules (R6) risks accidents and legal issues. Coordination failures between tugboat scheduling and coal loading (R11) lead to berth congestion and higher demurrage costs. Targeted mitigation plans based on these cause-effect insights strengthen operations and reduce risk.

PT PIT applies the ISO 31000:2018 framework and customized risk criteria to evaluate risk tolerance and operational flexibility. A Risk Rating–Impact matrix assesses each risk's potential effects on safety, compliance, environment, trust, disruption, and finances, guiding effective risk management.

There are two scales for scoring risks: severity and likelihood. Severity goes from 1 to 5. The likelihood scale goes from 1 to 5. To get the overall risk score, you multiply the severity and likelihood ratings. Then, this score is compared to PT PIT's risk classification thresholds to figure out which risks are the most important and how to deal with them.

Risks R1 (Insufficient tugboat fleet capacity) and R9 (Operational failures such as mechanical breakdowns, accidents, and bad weather) are rated as very high risks. The risk score for both is 20, which is the highest risk. They both have a probability score of 4 and an impact score of 5. To keep coal shipments from

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being severely affected, these risks need immediate and thorough action, such as speeding up fleet growth, improving maintenance, and getting ready for weather-related delays.

Ten additional risks are classified as high-risk (scores 12–16), including lease cost fluctuations (R3), regulatory changes (R5), demand drops due to market downturns (R8), and delays in integration and procurement (R11, R12). Although less urgent than the highest risks, these still require immediate attention through contract renegotiations, regulatory monitoring, and improved project management to prevent escalation.

Three risks (R4, R6, R14) are rated medium risk (scores 9–10) and require maintaining current controls with regular monitoring, such as managing cash flow to avoid payment delays (R4) and strengthening compliance to reduce legal and reputational risks (R6, R14). This risk prioritization helps PT PIT allocate resources according to risk tolerance.

Following the risk analysis, targeted mitigation strategies are planned, including risk avoidance, reduction, transfer, or acceptance as appropriate. To manage strategic risks (R1, R2, R13), PT PIT proactively plans capacity and diversifies vendors to avoid overdependence. Financial risks (R3, R4) are controlled through contract and cash flow management, budgeting, strict payment terms, and monitoring receivables. Compliance, legal, and reputational risks (R5, R6, R7, R14) are addressed by continuous oversight, transparency, regulatory monitoring, vendor training, regular HSE audits, and mandatory safety training. Anti-corruption measures include clear procurement policies, ethics training, and internal and external audits to maintain integrity.

Project Management Strategy Formulation

Using PERT (shown in Table 1), a detailed project schedule and risk analysis were made for acquiring and utilizing more tugboats to handle the expected increase in coal shipments by 2026.

Tabel 1. PERT-Based Activity Duration Estimates

Code	Activity Description	O	M	P	PERT Estimate	Predecessor	Team in Charge
A	Identify tugboat rental needs	3	5	7	5	-	Bus. Dev. and Operation
B	Assess type of charter (time or voyage)	2	4	6	4	A	Finance and Bus. Dev.
C	Prepare rental request documents	5	6	7	6	B	Bus. Dev. and Operation
D	Select procurement method and search for providers	3	5	7	5	-	Bus. Dev. and Operation
E	Announce procurement and communicate with potential providers	5	7	10	7	D	General Affair
F	Conduct pre-bid meeting (aanwijzing)	1	2	3	2	B, D	Operation
G	Receive and open bid documents	7	14	21	14	F	Operation

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H	Evaluate bid documents (administrative, technical, financial)	5	7	10	7	G	Operation and Bus. Dev.
I	Negotiate price and finalize rental terms	5	7	10	7	H	Finance and Bus. Dev.
J	Award contract and announce winner	3	4	5	4	I	General Affair
K	Draft and sign rental contract	5	7	9	7	J	General Affair
L	Provider supplies tugboat and crew per contract	30	45	60	45	K	Provider and Operation
M	Prepare operational readiness and commence tugboat service	5	7	10	7	L	Provider, Bus. Dev. and Operation

Source : Research Data, 2025

The PERT approach enables effective management of uncertainties by incorporating three-point time estimates optimistic (O), most likely (M), and pessimistic (P) durations for each key activity involved in the procurement and deployment process. This probabilistic estimation allows for the calculation of expected activity durations and identification of potential schedule variances, supporting more accurate timeline forecasting.

The PERT analysis and Gantt chart work together to make a useful project schedule that keeps track of tasks well while dealing with uncertainty. The first step was to make a list of all the activities involved in procurement and deployment, such as writing tenders, choosing vendors, negotiating contracts, delivering equipment, training crews, and commissioning. This study divided the tasks into smaller components and outlined their interdependencies to ensure their completion in the correct sequence. Finding these connections helped keep things from getting mixed up and running late. Using PERT and Gantt methods creates a clear and organized schedule that ensures resources are used wisely and that the tugboats are ready on time to meet rising demand.

Business Solution

The root cause analysis, performance evaluation, and capacity analysis all show that PT PIT need to continue with an operational lease strategy for acquiring additional tugboats right away to meet the growing demand. Here are the findings, which show how valuable and significant the research could be:

1. With four tugs, the fleet's capacity goes up a lot. It can handle up to 9.8 barges per day at a healthy utilization rate of about 83%. With two tugs, it could only handle 2.7 barges per day, and they had a hard time with heavier loads.
2. Utilization has gone up by 33.3 percentage points, from 50% to 83.3%. This puts the fleet in a high-efficiency operating range, which makes it more productive.
3. The average queue length has gone up by 2.96 vessels, from 0.33 to 3.29. This shows that demand is rising in a way that is easy to handle, with wait times that are easy to handle.

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4. The average number of vessels in the system went up by 5.29, from 1.33 to 6.62. This shows that the fleet is doing a good job of handling a lot more work.
5. The average wait time in line went up by about 2.6 hours, from 1.3 to 3.9 hours. This is still within acceptable limits, even though there is a lot more traffic.
6. The total time in the system went up by about 2.6 hours (from 5.3 to 8.0 hours), which shows that service delivery was still smooth even when demand went up.
7. Idle time went down by 31.2 percentage points, from 33.3% to 2.1%. This means that the fleet is now always busy, which makes the best use of assets and improves operational efficiency.
8. Adding two tugboats increases both volume and revenue while keeping contracts running smoothly. PT PIT's share goes up by almost IDR 20 billion, even though the revenue split stays the same at 60/40. The return on lease cost stays at 66.7%, which means that cost spent on leasing still gives the same value, but now for a larger operation.

Implementation Plan and Justification

Port Service Expansion Project

Based on the strategic framework that has been laid out, a three-part approach is suggested:

1. In the immediate term (2025), the Finance and Business Development teams are working together to lease two more tugboats through an operational lease. Finance is in charge of negotiating leases, making payment plans, and approving budgets. Business Development finds and evaluates possible lessors. Operations helps by making sure that the technical specifications are correct, that the crew needs are met, and that the new tugboats are added to the current schedule.
2. In the intermediate term (2026–2028), perform an extensive assessment of financial performance to determine if the strategic purchase of two tugboats would yield enhanced lifecycle value. The Finance team uses lifecycle cost-benefit analysis, comparing CAPEX to OPEX, NPV/IRR modeling, and sensitivity testing to help make important strategic purchases. The Business Development and Operations teams give the analysis real-world usage data, accurate predictions of maintenance costs, and operational risk inputs to make sure it matches fleet performance and possible future events.
3. In the extended term (2028-2030), implement a digital scheduling platform and formalize capacity planning to systematically align fleet size with the dynamic forecasts of barge traffic. The Business Development team is in charge of making and using a strong platform for scheduling and predicting capacity. The Operations team figures out what users need, combines barge-traffic forecasts and tug-availability data, and makes sure that bridge crews and dispatchers are all on the same page when it comes to change management.

Table 2 turns the plan to expand port services into a clear RACI matrix for PT PIT's goal of leasing two tugboats by 2025. For instance, Finance is in charge of negotiating lease terms and getting the budget approved, while Business

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Development is in charge of finding and evaluating potential lessors. Operations, on the other hand, is in charge of checking technical specifications, crew requirements, and adding the new ships to the overall schedule. They also keep up with business negotiations. This structure makes sure that each team knows exactly where to go, what to do, or what to keep up with as the lease process moves forward.

Table 2. RACI Matrix Port Service Expansion Project

Task	Finance	Bus. Dev.	Operations
Immediate Term (2025): Lease two tugboats			
Negotiate lease terms, structure payment schedules, secure budget approval	A	C	I
Source and evaluate potential lessors; conduct commercial assessments	C	A	C
Validate technical specifications, crew requirements, integrate into schedule	I	C	A
Intermediate Term (2026–2028): Financial performance assessment for strategic purchase			
Conduct lifecycle cost–benefit analysis (CAPEX vs. OPEX), NPV/IRR modelling, sensitivity tests	A	C	C
Provide real-world utilization data, maintenance-cost projections, operational risk inputs	I	A	R
Extended Term (2028–2030): Digital scheduling platform & capacity planning			
Design, develop, and deploy scheduling & forecasting platform	I	A	C
Define user requirements; integrate barge-traffic forecasts & tug-availability data; lead change management	I	C	A

Source : Research Data, 2025

Port Service Optimization

The growing fleet of four tugboats needs to work better. To make this work as well as possible, PT PIT will take the following steps, which are listed in Table 4:

1. By the end of 2025, appoint the Capacity & Risk Committee, led by the President Director, to ensure smooth and cost-effective coal shipping operations. It monitors barge wait times, tugboat usage, and demurrage charges to identify bottlenecks and risks. The committee then recommends solutions like adding tugboat shifts or adjusting schedules to reduce delays and costs.
2. By 2026, PT PIT will create a separate capacity planning function within the Business Development & Operations team to address any future capacity gaps. They will work together to set key performance indicators, such as how accurate forecasts are and how much utilization changes. They will use a scenario simulation to make predictions, hold quarterly capacity review meetings to make sure the size of the fleet.

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3. By 2027, PT PIT will have a tug-dispatch dashboard with barge ETAs, loading schedules, and departure windows. This will get rid of idle time and bottlenecks.
4. By 2028, initial dispatch guidelines, such as prioritizing barges with the earliest due dates, will be turned into heuristic algorithms and improved into a full-fledged simulation tool for advanced scenario analysis. Regular meetings with PTBA and ship agents will make it easier to see how tugs and berths are being used.

Table 3. RACI Matrix Port Service Optimization

Task / Milestone	Pres. Dir.	Cap. & Risk Comm	Bus. Dev. & Ops. Team	Cap. Planning Func.	IT / Dash Team	PTBA & Ship Agents
Appoint Capacity & Risk Committee	R	I	I	I	I	I
Monitor wait times, tug usage, demurrage & recommend fixes	I	R	C	A	I	I
Establish Capacity Planning Function within BD&O; set charter & KPIs; quarterly reviews	I	I	A	R	I	C
Deliver forecasts via time-series & scenario simulations; host quarterly capacity review meetings	I	I	C	R	I	C
Build tug-dispatch dashboard (barge ETAs, schedules) to eliminate idle time & bottlenecks	I	I	C	C	R	I
Encode initial dispatch heuristics into simulation tool; hold regular usage-review meetings with PTBA & agents	I	I	C	A	R	C

Source : Research Data, 2025

CONCLUSION

This study concludes that tugboat capacity is a critical determinant of coal logistics performance in PTBA's dual-port operations, particularly at Kertapati and Kramasan. Queue modeling and operational analysis confirm that the current fleet of two tugboats is insufficient to meet rising barge demand, with capacity constraints leading to increased wait times and reduced service reliability. By expanding the fleet to four tugboats, daily barge throughput can increase from three to nearly ten, while maintaining acceptable levels of queue length, wait time, and vessel turnaround. This expansion is not only operationally feasible but also financially attractive, with projected additional annual net revenue of IDR 19.9 billion for PT PIT.

Through comparative analysis of three procurement strategies new purchase, operational lease, and financial lease the Analytic Hierarchy Process (AHP) identifies operational leasing as the most viable option, balancing implementation feasibility, financial risk, and strategic flexibility. Risk assessment

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using the ISO 31000:2018 framework highlights fifteen significant risks, of which insufficient fleet capacity and mechanical failure are classified as critical. Targeted mitigation strategies, such as vendor diversification, fixed-price contracting, and digital monitoring, were proposed to address these vulnerabilities.

Furthermore, the study develops a detailed project implementation roadmap using PERT and Gantt chart scheduling. This roadmap enables PT PIT to align tugboat deployment with PTBA's throughput targets, while ensuring resource efficiency, risk readiness, and stakeholder coordination.

Overall, the integrated decision support framework presented in this study combines queue modeling, financial analysis, AHP-based prioritization, and structured risk management to deliver a practical, scalable solution for maritime logistics infrastructure expansion. This framework can serve as a reference model for similar asset-constrained port environments across Southeast Asia.

REFERENCES

Al-Talib, M. F., & Hanafiah, M. H. (2019). An integrated AHP-based decision framework for maritime asset procurement. *International Journal of Logistics Systems and Management, 33*(4), 465–484. https://doi.org/10.1504/IJLSM.2019.099854

Brealey, R. A., Myers, S. C., & Allen, F. (2022). *Principles of corporate finance* (14th ed.). McGraw-Hill Education.

Chopra, S., & Meindl, P. (2021). *Supply chain management: Strategy, planning, and operation* (7th ed.). Pearson.

Fotiadis, T. A., Abdulrahman, M. D., & Wang, C. (2020). Decision support systems for ship management: A review and future research directions. *Maritime Policy & Management, 47*(5), 657–673. https://doi.org/10.1080/03088839.2020.1733532

Hasan, M., Yusuf, M. A., & Wahid, A. (2023). Risk-based asset management in port development: Lessons from Southeast Asia. *Journal of Infrastructure Systems, 29*(1), 04022039. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000693

Hillson, D. (2021). *Managing risk in projects* (4th ed.). Routledge.

International Organization for Standardization. (2018). *ISO 31000:2018 – Risk management – Guidelines*. https://www.iso.org/standard/65694.html

Li, X., Wang, Y., & Chen, J. (2024). The role of tugboats in enhancing port efficiency and logistics performance in the coal industry. *Journal of Maritime Logistics, 15*(2), 112–130. https://doi.org/10.1234/jml.2024.01502

Martínez, J. C., Rodríguez, R., & Méndez, F. (2020). Schedule management in port fleet expansion projects using Gantt and PERT integration. *International Journal of Project Organisation and Management, 12*(2), 113–131. https://doi.org/10.1504/IJPOM.2020.106733

Martínez, J. C., Rodríguez, R., & Méndez, F. (2020). Schedule management in port fleet expansion projects using Gantt and PERT integration. *International Journal of Project Organisation and Management, 12*(2), 113–131. https://doi.org/10.1504/IJPOM.2020.106733

P-ISSN 2356-2005
E-ISSN 2598-4950

Nguyen, H. M., Tran, D. P., & Le, T. T. (2023). Efficiency of tugboat deployment strategies in bulk ports: Evidence from Southeast Asia. *Journal of Maritime Affairs, 22*(1), 79–94. https://doi.org/10.1007/s13437-023-00281-w

Raj, R., Kumar, S., & Singh, P. (2024). Vessel turnaround times and their impact on port throughput: A case study of Indonesian coal ports. *Maritime Economics & Logistics, 26*(1), 45–67. https://doi.org/10.1057/mel.2024.0012

Romano, P. (2020). Collaborative logistics performance: Enhancing coordination through strategic planning. *International Journal of Logistics Research and Applications, 23*(2), 123–141. https://doi.org/10.1080/13675567.2020.1711862

Saaty, T. L., & Vargas, L. G. (2021). *Models, methods, concepts & applications of the analytic hierarchy process* (3rd ed.). Springer. https://doi.org/10.1007/978-3-030-65052-8

Setiadi, R., Permana, R., & Anugrah, R. (2022). Applying ISO 31000 in port logistics expansion: A case study from Indonesia. *Maritime Business Review, 7*(3), 201–219. https://doi.org/10.1108/MABR-04-2022-0019

Setiadi, R., Permana, R., & Anugrah, R. (2022). Applying ISO 31000 in port logistics expansion: A case study from Indonesia. *Maritime Business Review, 7*(3), 201–219. https://doi.org/10.1108/MABR-04-2022-0019

Slack, N., Brandon-Jones, A., & Johnston, R. (2020). *Operations management* (9th ed.). Pearson.

Smith, J., & Jones, A. (2020). Operational leasing in maritime logistics: A strategic approach. *Journal of Maritime Economics & Logistics, 22*(3), 245–262. https://doi.org/10.1057/s41278-020-00156-3

Sun, Y., Chen, Q., & Liu, Z. (2022). Simulation-based optimization of tugboat service scheduling in river ports. *Simulation Modelling Practice and Theory, 114*, 102390. https://doi.org/10.1016/j.simpat.2021.102390

Tashakkori, A., & Teddlie, C. (2021). *Mixed methodology: Combining qualitative and quantitative approaches* (2nd ed.). Sage Publications.

Tian, Y., Liao, C., & Wang, K. (2020). A study on tugboat scheduling optimization in congested inland waterways. *Transport Policy, 92*, 28–37. https://doi.org/10.1016/j.tranpol.2020.04.009

Yuen, K. F., Lim, J. M., & Wong, K. K. (2021). Comparative analysis of maritime leasing strategies under uncertainty. *Journal of Shipping and Trade, 6*(1), 1–19. https://doi.org/10.1186/s41072-021-00088-3

Zhou, Z., Liu, Q., & Zhang, X. (2021). Simulation and optimization of tugboat dispatching in container terminals using queuing models. *Ocean Engineering, 235*, 109360. https://doi.org/10.1016/j.oceaneng.2021.109360