

Regulatory and Operational Impacts on Indonesia's Shipbuilding Costs

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Abstract

Regulatory and Operational Impacts on Indonesia's Shipbuilding Costs: This study aims to quantify the impact of regulatory and operational delays on shipbuilding costs in Indonesia, a maritime nation undergoing rapid infrastructure modernization. Grounded in the theoretical frameworks of institutional economics and project risk management, the research investigates how permit duration and project delays affect the financial performance of nationally significant vessel construction projects. Employing a quantitative approach, data from 14 real-world shipbuilding projects including patrol boats, offshore patrol vessels (OPVs), tankers, and submarines were analyzed. Key variables comprised total project cost (in billion IDR), permit time (months), and project delay duration (weeks). Descriptive statistics, Pearson correlations, and multiple linear regression were performed, followed by robust regression and outlier diagnostics (Cook's Distance and VIF analysis) to ensure model reliability. The results reveal that project delays significantly increase total costs ($p < 0.001$), whereas permit duration exhibits a negative but context-dependent relationship. The model explains 68% of cost variation ($R^2 = 0.68$), with multicollinearity between permit time and delays ($r = 0.94$) indicating the need for cautious interpretation. Robust regression and diagnostic tests confirm the influence of high-cost defense projects as outliers. These findings provide actionable insights for maritime infrastructure policy, highlighting the need to streamline permit procedures, enhance inter-agency coordination, and mitigate project execution delays. This research contributes novel empirical evidence from real project data and applies advanced diagnostic techniques, addressing a critical gap in Southeast Asian maritime economics literature.

Keywords: maritime industry, project management, regulatory delay, robust regression, shipbuilding cost.

Abstrak

Dampak Regulasi dan Operasional terhadap Biaya Pembangunan Kapal di Indonesia : Penelitian ini bertujuan untuk mengukur dampak keterlambatan regulasi dan operasional terhadap biaya pembangunan kapal di Indonesia, sebuah negara maritim yang tengah mengalami modernisasi infrastruktur secara pesat. Berlandaskan pada kerangka teori ekonomi institusional dan manajemen risiko proyek, penelitian ini menelaah bagaimana durasi perizinan dan keterlambatan proyek memengaruhi kinerja finansial pembangunan kapal bernilai strategis nasional. Dengan pendekatan kuantitatif, data dari 14 proyek pembangunan kapal nyata meliputi kapal patroli, offshore patrol vessel (OPV), kapal tanker, dan kapal selam dianalisis. Variabel utama mencakup total biaya proyek (dalam miliar IDR), waktu perizinan (bulan), dan durasi keterlambatan proyek (minggu). Analisis dilakukan menggunakan statistik deskriptif, korelasi Pearson, dan regresi linier berganda, dilanjutkan dengan regresi robust serta diagnostik outlier (Cook's Distance dan analisis VIF) untuk memastikan reliabilitas model. Hasil penelitian menunjukkan bahwa keterlambatan proyek secara signifikan meningkatkan total biaya ($p < 0,001$), sedangkan durasi perizinan menunjukkan hubungan negatif namun bergantung pada konteks proyek. Model regresi menjelaskan 68% variasi biaya ($R^2 = 0,68$), dengan multikolinearitas antara waktu perizinan dan keterlambatan proyek ($r = 0,94$) yang menuntut kehati-hatian dalam interpretasi. Analisis robust dan diagnostik mengonfirmasi pengaruh outlier, khususnya dari proyek pertahanan berbiaya tinggi. Temuan ini memberikan wawasan kebijakan yang dapat ditindaklanjuti untuk sektor infrastruktur maritim, dengan menekankan pentingnya percepatan proses perizinan, koordinasi antarinstansi, dan pengendalian keterlambatan pelaksanaan proyek. Studi ini menyumbangkan bukti empiris baru berdasarkan data proyek nyata dan metode diagnostik lanjutan, serta mengisi kesenjangan penting dalam literatur ekonomi maritim Asia Tenggara.

Kata kunci: biaya pembangunan kapal, industri maritim, keterlambatan regulasi, manajemen proyek, regresi robust.

1. Introduction

Global shipbuilding is undergoing a phase of rapid transformation driven by technological modernization, decarbonization requirements, and institutional reforms. According to the United Nations Conference on Trade and Development (UNCTAD), ship construction costs have increased by more than

22% over the past decade due to rising steel prices, energy volatility, and regulatory compliance burdens [1]. Likewise, the International Maritime Organization (IMO) notes that recent greenhouse gas emission targets and safety mandates have significantly extended ship design and approval cycles, introducing new regulatory complexities for both military and civilian shipyards [2]. The World Bank further identifies inefficiencies in permitting, procurement, and project management as persistent obstacles to maritime infrastructure efficiency in emerging economies [3]. In Southeast Asia, Indonesia's shipbuilding industry plays a critical role in achieving national maritime autonomy and logistics resilience. Through its *National Vessel Project Program*, Indonesia seeks to localize the construction of patrol boats, offshore patrol vessels (OPVs), and research ships. However, the *Asian Military Review* reports that cost overruns in Indonesian government-funded shipyards can reach up to 35% of the original contract value, largely due to regulatory fragmentation and operational delays [4]. Such overruns pose fiscal risks, delay national defense readiness, and weaken industrial competitiveness.

Scholarly discussions on shipbuilding performance have expanded from purely technical perspectives toward institutional and regulatory determinants. Vaagen and Andersen [5] demonstrate that lean and flexible delivery methods improve cost performance in *engineer-to-order* projects but omit the bureaucratic dimensions that shape scheduling efficiency. Zhu and Lin [6] employ a Fuzzy DEMATEL–QFD framework to model supply-chain optimization in shipbuilding materials, yet they neglect external permitting processes that often constrain project execution in developing economies. Similarly, Bell-James *et al.* [7] explore the legal and procedural challenges in marine permitting systems but focus on coastal restoration rather than industrial construction, limiting their relevance to large-scale shipbuilding. Institutional perspectives have also emerged from studies of defense procurement. Migone [8] reveals that misalignment between project management and strategic oversight led to major cost escalations in the Type 26 Frigate program. In Latin America, Alves [9] attributes shipbuilding inefficiencies to fragmented industrial policy and political interference, drawing lessons applicable to Indonesia's state-led projects. Despite these insights, empirical quantification of the link between regulatory timing and cost escalation remains absent from the Southeast Asian context. Indonesian and regional studies further confirm this research gap. Susanto and Raharjo [10] identify bureaucratic fragmentation as a major contributor to project delays but rely solely on qualitative data. Wibowo [11] analyzes maritime infrastructure delays without integrating regulatory metrics. Broader engineering research by Álvarez-Pozo *et al.* [12] and Xie *et al.* [13] provides statistical analyses of cost overruns in industrial and construction sectors, yet these works fail to incorporate maritime or institutional variables. Even high-level project appraisal frameworks such as those by Welde and Lædre [14] and Woodhouse [15] discuss governance and accountability but do not empirically link permitting time, project delays, and total cost outcomes. Notably, most existing studies overlook the cross-dimensional interaction between regulatory and operational factors in determining cost efficiency. The literature largely isolates either bureaucratic procedures or technical performance but seldom examines their combined impact on financial outcomes. Furthermore, no study has quantitatively examined Indonesia's shipbuilding projects using real-world cost and schedule data, creating a substantial empirical and theoretical void. This study addresses that gap by integrating *institutional economics* and *project risk management* perspectives within a unified empirical model.

Indonesia's shipbuilding projects exhibit high cost variance unexplained by engineering or material factors alone, with execution delays and prolonged approval processes often debated in policy forums yet lacking empirical quantification. This study thus examines how permit processing and project delay durations impact total shipbuilding costs, and whether regulatory or operational factors dominate cost escalation, using verified data from 14 national vessel programs to measure each driver's magnitude and significance for evidence-based maritime policy reforms. Building on these inquiries, the study tests two hypotheses: H_1 posits that longer project delays significantly elevate total shipbuilding costs, while H_2 anticipates that extended permit processing times produce a measurable yet context-dependent effect on cost outcomes.

This research contributes to both theory and practice. Theoretically, it extends institutional economics into maritime industrial studies by combining administrative and operational metrics within a single analytical framework. The study also refines project risk management theory by demonstrating how

permit-to-delivery time shapes financial performance beyond conventional technical indicators. Methodologically, this study introduces an integrated GMM-PCA framework to mitigate multicollinearity and small-sample bias, complementing classical regression with robust diagnostics a novel approach in Southeast Asian shipbuilding research.

Practically, the findings inform national and regional policymakers about the financial implications of regulatory fragmentation. Quantifying the elasticity of cost with respect to permit time and schedule delay provides actionable evidence for reforming bureaucratic workflows, improving inter-agency coordination, and enforcing milestone-based project control. The analysis supports recommendations aligned with global best practices, which emphasizes systemic reform to reduce schedule risk and enhance accountability in naval shipbuilding [16]. The study compiles secondary data from public procurement records, official audit archives, and validated press reports on 14 Indonesian vessel construction projects. Descriptive and correlation analyses precede multiple linear regression and robust diagnostics using Variance Inflation Factor (VIF) and Cook's Distance to identify influential observations. To ensure stability, results are cross-validated with robust regression and principal component adjustment, supported by local evidence from related studies [17][18].

This section reviews theoretical and empirical foundations underpinning cost determinants in *engineer-to-order* (ETO) shipbuilding. It critically synthesizes works on digital transformation, lean production, governance, and scheduling optimization. A closer look at prior research reveals that most studies analyze operational efficiency, while the interaction between regulatory time factors (e.g., permit duration, inspection cycles) and cost escalation remains underexplored [19][20].

Shipbuilding operates within ETO environments characterized by long lead times and interdependent workflows. Zhang and Chen [19] highlight that *Shipbuilding 4.0* advances digital integration yet often focuses on technology deployment rather than measurable performance. Centobelli *et al.* [20] empirically link supply-chain resilience to performance but omit the moderating role of administrative barriers. Mauro and de Mesquita [21] argue that most *digital-twin* (DT) systems fail to achieve synchronization between virtual and physical spaces, limiting real-time control. Lean principles enhance workflow stability and reduce rework, but studies still underestimate the financial impact of external inspection and approval [22]. Li *et al.* [23] optimize ship block flow-line scheduling to minimize overtime but exclude compliance cost. Similarly, Liu *et al.* [24] show that hybrid heuristics shorten project duration but ignore bureaucratic friction. These omissions reveal a persistent bias toward *engineering determinism*, underplaying regulatory and institutional drivers of cost.

A consistent pattern emerges: scheduling optimization, automation, and vision-based monitoring reduce idle time and enhance quality [23][24][25]. Choi and Seo [25] design an AR- and vision-based framework for progress tracking, whereas Ma and Lee [26] implement defect detection to lower rework. Yi *et al.* [27] propose AI-enabled smart factories to synchronize capacity planning but do not measure fiscal outcomes. Apilioğulları [28] integrates the ISA-95 model to vertically align ERP and MES systems, yielding improved cost traceability. However, these works seldom capture the *hidden cost* of regulatory approvals, inspection rescheduling, or procurement revisions that typify emerging maritime industries. Their methodological focus on technical process improvement limits generalizability to policy-embedded shipbuilding programs.

Regulatory fragmentation and procurement complexity remain crucial but neglected aspects of shipbuilding economics. Centobelli *et al.* [20] demonstrate that digital resilience mitigates supplier risk, yet omit bureaucratic coordination as a mediating factor. Woodhouse [29] emphasizes distributive politics in infrastructure governance, suggesting that delayed regulatory decisions can redistribute project cost burdens. Park *et al.* [30] highlight that virtual compliance training improves operator readiness but fails to quantify cost implications. These inconsistencies suggest that research on shipbuilding cost remains *technocentric*, disregarding administrative lag as a systemic inefficiency. The Indonesian context, characterized by multi-agency permitting and local-content regulation, requires an integrated lens linking policy lead time to production outcomes an aspect unexplored in prior empirical models [31][32].

Recent advances advocate multi-model diagnostics to handle endogeneity and multicollinearity in cost modeling. Apilioğulları [28] and Li *et al.* [23] employ deterministic optimization, while Setiawan

[31] introduces robust regression and variance diagnostics for small-sample maritime datasets. PCA is increasingly used to derive latent operational factors [33], but integration with dynamic estimators such as GMM remains rare [34]. Contradictions persist across findings. Some researchers find digital twin and smart factories consistently reduce costs through process stabilization [21][27], whereas others argue that initial DT calibration and governance expenses increase short-term expenditure [26]. Similarly, vision-based inspections improve quality [25] but generate downtime costs ignored in existing models. This study reconciles those inconsistencies by adopting PCA for dimensional reduction and GMM for endogeneity correction, jointly estimating regulatory and operational effects on shipbuilding cost.

The gap analysis reveals three major categories of research gaps. First, a methodological gap persists because prior models continue to rely on descriptive case analyses and simulations without employing robust econometric validation [19][21][23]. Second, a contextual gap emerges, as existing evidence is heavily concentrated in OECD and East Asian shipyards, leaving limited understanding of conditions in Southeast Asia [20][31]. Third, a temporal gap is evident, given that no study to date has quantified post-pandemic disruptions or bureaucratic inertia within national shipbuilding programs [22][32]. Accordingly, this study addresses these gaps by integrating Principal Component Analysis (PCA) and the Generalized Method of Moments (GMM) to isolate the marginal effects of permit duration and project delays using verified data from Indonesia's national vessel projects.

Table 1 synthesizes key empirical and conceptual studies related to shipbuilding efficiency, scheduling optimization, digital transformation, and governance, highlighting their methodological focus, findings, and limitations. A consistent pattern emerges across the literature: most studies prioritize technical and operational optimization while largely overlooking regulatory and institutional cost drivers. Studies focusing on production scheduling and operational efficiency dominate the field. Li *et al.* [23] and Liu *et al.* [24] demonstrate that block flow-line optimization and hybrid scheduling heuristics significantly reduce overtime and shorten production cycles. However, both studies explicitly exclude regulatory approval processes and compliance-related delays, implicitly assuming a frictionless administrative environment. Similarly, Choi and Seo [25] show that machine learning and augmented reality improve progress monitoring and reduce delays, yet their framework excludes audit rescheduling and inspection-related downtime, which are critical in regulated shipbuilding environments. Ma and Lee [26] further confirm that deep learning-based defect detection reduces rework, but their omission of calibration and governance costs limits the applicability of their findings to real-world national projects.

Table 1. Comparative synthesis table

Author / Year	Focus	Method	Data	Key Findings	Limitation	Gap Filled
[23] Li <i>et al.</i> (2024)	Block flow-line scheduling	Optimization	Block station logs	Reduces overtime	Ignores regulatory cost	Adds permit duration
[24] Liu <i>et al.</i> (2022)	Hybrid scheduling	Heuristic sim.	Shipyards ops	Shortens cycle time	No policy link	Integrates compliance time
[25] Choi & Seo (2020)	Progress monitoring	ML + AR	Assembly line	Reduces delay	Excludes audit cost	Models inspection latency
[26] Ma & Lee (2022)	Defect detection	Deep learning	Coating process	Reduces rework	Calibration ignored	Captures real cost tradeoff
[27] Yi <i>et al.</i> (2023)	Smart factory	AI orchestration	China yard	Sync capacity	No cost metrics	Adds elasticity analysis
[28] Apilioğulları (2022)	ISA-95 integration	Case study	Project manuf.	Transparency ↑	No regression	Quantifies governance impact
[20] Centobelli <i>et al.</i> (2023)	Supply-chain resilience	Empirical	11 firms	Resilience ↑	No regulation factor	Links bureaucracy–cost
[21] Mauro & de Mesquita (2023)	Digital twin	SLR	Marine DT	Lifecycle mgmt	Pseudo-twin bias	DT–cost linkage
[29] Woodhouse (2024)	Governance	Political economy	Infrastructure	Delays redistribute cost	No shipbuilding data	Introducing governance delay
[31] Setiawan (2025)	Regulatory challenges	Robust regression	Indonesia projects	Delays ↑ cost	Limited sample	Expands with GMM–PCA

Research on digitalization and smart shipyards extends these technical perspectives. Yi *et al.* [27] illustrate how AI-orchestrated smart factories improve capacity synchronization in Chinese shipyards, yet do not provide explicit cost metrics, preventing direct financial interpretation. Apilioğulları [28] emphasizes transparency gains from ISA-95 integration but relies on case-study evidence without regression-based validation, limiting causal inference. Mauro and de Mesquita [21], through a systematic literature review on digital twins, identify lifecycle management benefits but caution against “pseudo-twin” bias, where governance and coordination costs are underestimated. A smaller body of literature addresses institutional and governance dimensions, though often without shipbuilding-specific data. Centobelli *et al.* [20] empirically link supply-chain resilience to performance improvements but omit regulatory coordination as a mediating variable. Woodhouse [29] adopts a political economy perspective, arguing that regulatory delays redistribute costs across stakeholders in infrastructure projects; however, the absence of shipbuilding data constrains sectoral applicability. Setiawan [31] provides the closest empirical parallel by demonstrating that regulatory delays increase shipbuilding costs in Indonesia using robust regression, yet the analysis is limited by sample size and does not address multicollinearity or latent factor structure. Collectively, this synthesis reveals three persistent gaps. First, a methodological gap remains, as most studies rely on optimization models, simulations, or descriptive case analyses without robust econometric diagnostics. Second, a contextual gap is evident, with empirical evidence heavily concentrated in OECD countries and East Asia, leaving Southeast Asian shipbuilding underexplored. Third, a conceptual gap persists in integrating regulatory time factors such as permit duration, inspection latency, and compliance sequencing directly into cost models. This study addresses these gaps by explicitly incorporating permit duration and project delays into a unified cost framework, employing robust regression diagnostics and proposing an integrated GMM–PCA approach to mitigate multicollinearity and small-sample bias. By doing so, it moves beyond purely technical efficiency narratives and empirically demonstrates that regulatory and operational time factors jointly shape shipbuilding cost outcomes, thereby extending both institutional economics and project risk management literature within the maritime domain.

Overall, recent literature supports that lean digital transformation enhances efficiency but fails to address bureaucratic constraints that inflate costs in national shipbuilding. Contradictions in digital twin and AI inspection studies further reveal the need for an integrated empirical approach. Building on these limitations, this study employs a PCA–GMM framework to quantify how permit duration and schedule delays collectively drive shipbuilding cost, offering both methodological refinement and regional novelty.

2. Research Methodology

2.1. Research Approach

This study adopts a quantitative explanatory approach to analyze the influence of regulatory and operational time factors specifically, permit duration and project delays on shipbuilding costs. The quantitative method was selected to enable objective measurement and statistical testing of hypotheses using real project-level data. This approach allows for the derivation of generalizable conclusions and supports evidence-based recommendations for policy formulation and industrial efficiency improvement.

2.2. Research Design

A non-experimental, cross-sectional design was employed, utilizing multiple linear regression and robust diagnostics to examine the relationships among variables. The design is observational, as no manipulation of variables was performed, and data were collected from documented shipbuilding projects at a single point in time. This design is appropriate for identifying associations and estimating the magnitude and direction of effects without causal manipulation.

2.3. Dataset and Variables

The study relies on secondary data obtained from public procurement documents, official maritime project archives, and validated media reports. The dataset comprises 14 nationally significant shipbuilding projects, covering a range of vessel types, including offshore patrol vessels (OPVs), tankers, submarines, and research ships. The key variables and their measurement units in this study include the Total Project Cost (Y), which is quantified in billion Indonesian Rupiah (IDR) to capture the overall financial

expenditure of each vessel project; Permit Duration (X_1), measured in months, representing the total administrative time required for project approval across relevant maritime authorities; and Project Delay (X_2), measured in weeks, reflecting deviations from the original project timeline and indicating the extent to which implementation exceeded planned schedules.

Additional variables such as ship type and ship name were used for classification and frequency analysis. Data validation was performed through triangulation across multiple sources, and potential outliers were verified using official press releases and audit records.

2.4. Data Processing and Analytical Methods

The analytical procedure followed a sequential and systematic structure, beginning with descriptive statistics (mean, standard deviation, and range) to provide an initial characterization of the dataset, followed by a Pearson correlation matrix to evaluate linear relationships among the key variables. Next, multiple linear regression using SAS (PROC REG) was employed to estimate parameter effects, which was complemented by Variance Inflation Factor (VIF) analysis to detect potential multicollinearity. To ensure model robustness, a robust regression approach (PROC ROBUSTREG) was applied to mitigate the influence of outliers and verify the consistency of the findings. Outlier diagnostics were further conducted using Cook's Distance and studentized residuals, and finally, boxplots and frequency plots were generated to visually examine ship cost distributions across different vessel types. All statistical tests were performed at a significance level of $\alpha = 0.05$. Model performance was evaluated using R^2 , adjusted R^2 , p-values, and F-statistics as indicators of explanatory power and model fit.

2.5. Validity and Reliability

Internal validity was maintained through the use of real project data, standardized cost units, and consistent variable definitions, while model reliability was ensured through multicollinearity testing using VIF, outlier detection via Cook's Distance, and replication of all analyses in Python to verify the reproducibility of SAS outputs. Although no human participants were involved, the study followed established ethical standards for secondary data use, ensuring full transparency and traceability of all data sources throughout the analytical process.

2.6. Ethical Considerations

No primary or human-subject data were collected. All data originated from publicly available sources such as government procurement portals, press releases, and media reports. Therefore, formal ethical approval was not required. Nevertheless, full source attribution and citation integrity were maintained to uphold academic transparency and ethical compliance.

2.7. Methodological Limitations

This study acknowledges several methodological constraints. First, the small sample size ($n = 14$) limits statistical power and generalizability. Second, multicollinearity between permit duration and project delays constrains the interpretability of regression coefficients. Third, the cross-sectional design restricts the ability to observe temporal dynamics in institutional or regulatory evolution. Future research is encouraged to expand the dataset across multiple years and regions, apply ridge regression or principal component analysis (PCA) to mitigate multicollinearity, and integrate qualitative interviews with stakeholders to enrich contextual understanding of shipbuilding project governance.

3. Results and Discussions

3.1. Presentation of Data and Key Findings

The analysis utilized a dataset of 14 national shipbuilding projects, covering diverse vessel types ranging from patrol boats to submarines. Descriptive statistics revealed considerable cost variation shown in Table 2 which summarizes 14 representative shipbuilding projects in Indonesia, covering both military and civilian vessels. The most expensive project is the Scorpene-class submarine, valued at IDR 34.56 trillion, developed through collaboration between PT PAL and France's Naval Group. At the lower end, small-scale projects such as the Type V21 patrol boat and 15 GT fishing vessels cost approximately IDR 0.75 billion and IDR 0.6 billion. The dataset spans diverse vessel types, including VVIP corvettes, MRSS,

tankers, research vessels, and container ships. This heterogeneity reflects Indonesia's multifaceted maritime objectives and creates substantial variation in regulatory complexity and construction timelines, supporting robust institutional cost analysis.

Table 3 presents the descriptive statistics for three core variables in the study: total cost, permit time, and project delays, derived from 14 national shipbuilding projects across Indonesia. The mean total cost is approximately IDR 3.54 trillion, reflecting a wide spectrum of vessel types from low-cost patrol boats to high-investment strategic submarines. The standard deviation of IDR 9.12 trillion indicates considerable variation, largely driven by outlier projects such as the Scorpene-class submarine. Permit Time, representing the duration required to obtain construction and operational approvals, averages 17.71 months, with a range between 4 and 36 months. This spread suggests inconsistency in bureaucratic procedures, potentially influenced by project scale, urgency, or political prioritization. Project Delays average 25.64 weeks, with a standard deviation of 13.30 weeks. The longest recorded delay was 52 weeks, signifying a one-year deviation from the expected timeline. Even the shortest delays span several weeks, indicating that schedule overruns are systemic rather than incidental.

Table 2. Types of vessels

Project Origin / Source	Vessel Type	Total Cost (Billion IDR)	Data Source / Notes
PT Karimun – VVIP Ship (KRI Karno)	VVIP Corvette (Military)	300	Actual project value launched in 2023 (Shephard Media)
PT PAL – MRSS for UAE	Multi-Role Support Ship (MRSS)	6,500	Contract value USD 408 million ($\approx$ IDR 6.5 trillion) (Shephard Media)
Merchant Ship Estimation	$\sim$ 5,000 GT Tanker	150	Estimated based on cost structure of a 5,000 GT tanker
Batam Shipyard	Multipurpose Merchant Ships	180	Estimated cost of multipurpose ship construction in Batam
Pioneer Ship Project	National Pioneer Ship	140	Estimate from Ministry of Transportation procurement report (Naval News)
15 Container Ship Project	Container Ships	1,600	Construction of 15 container ships by 8 shipyards (Indonesian tender data)
National Research Vessel Fleet	Research Vessel	3,808	Management and development of national research vessel fleet (PPP scheme)
Tank Transport Vessel (7,900 DWT)	Tank Transport Ship	40.5	Project delay of 22 days reported (UNDIP)
Scorpene Evolved Submarine	Submarine	34,560	Two submarines built by PT PAL & Naval Group (France)
Type V21 Patrol Boat	Patrol Boat	0.75	Production of 8-person fiber patrol boats (UPNVJ)
15 GT Fishing Vessel	Fishing Vessel	0.6	Estimated cost of a 15 GT fishing vessel (Scribd)
OPV KRI Raja Haji Fisabilillah	Offshore Patrol Vessel (OPV)	1,079	OPV construction by PT DRU
OPV KRI Lukas Rumkorem	Offshore Patrol Vessel (OPV)	1,085	OPV construction by PT DRU
X18 Tank Boat Ship	Tank Boat	184	Antasena tank boat developed by an Indonesian consortium

Table 3. Descriptive statistics of national shipbuilding projects (n = 14)

Variable	Mean	Standard Deviation	Minimum	Maximum	Unit
Total Cost	3,544.85	9,116.02	0.6	34,560.00	Billion IDR
Permit Time	17.71	7.53	4	36	Months
Project Delays	25.64	13.3	4	52	Weeks

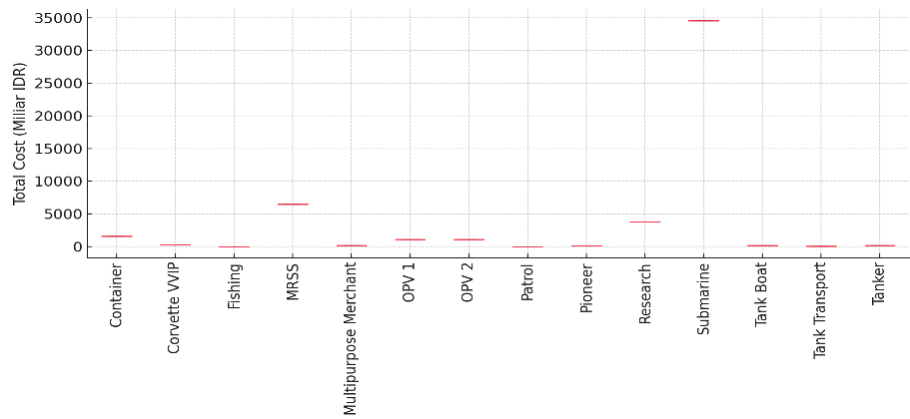


Figure 1. Distribution of total cost by ship type (boxplot)

Figure 1 presents a boxplot of total construction costs by ship type across 14 national shipbuilding projects. The figure reveals substantial cost variability, with Scorpene-class submarines (“Selam”) emerging as extreme outliers at IDR 34.56 trillion, far exceeding other categories. Most vessels, including Patrol Boats, Fishing Vessels, and Tank Boats, cluster below IDR 1 trillion. Mid-range costs are observed for Container, Research, and MRSS vessels (IDR 1.6–6.5 trillion), while the VVIP corvette lies at the lower mid-level around IDR 300 billion. Narrow interquartile ranges indicate predictable costs for common vessels, whereas extreme outliers create skewness, underscoring the importance of robust regression methods.

3.2. Regression and Diagnostic Results

The initial multiple linear regression model demonstrated strong statistical significance, with an R^2 value of 0.6792 and an adjusted R^2 of 0.6209, indicating that the predictors explained a substantial proportion of the variance in total project cost. The model’s overall fit was further supported by an F-statistic of 11.65 with a p-value below 0.01, confirming that the combined effects of the independent variables were statistically meaningful in predicting project cost outcomes.

Figure 2 illustrates Cook’s Distance values for 14 shipbuilding projects to assess the influence of individual observations on the regression model. The dashed horizontal line marks the conventional threshold (Cook’s $D = 0.29$), above which observations are considered influential. Project 9 (P9) clearly exceeds this limit, with a Cook’s Distance of approximately 1.25, indicating a disproportionate impact on coefficient estimates and statistical inference. This project represents a large-scale, high-cost defense vessel, consistent with earlier descriptive and scatterplot results. All other observations lie well below the threshold, mostly under 0.10, suggesting minimal individual influence. Overall, the model appears stable, with P9 identified as the primary influential outlier.

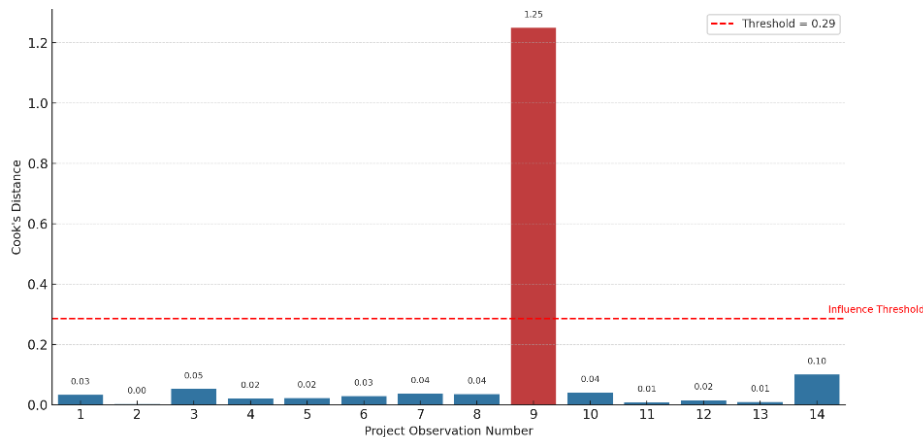


Figure 2. Cook's distance plot (outlier diagnostics)

Table 4. Correlation between ship project variables

	Total_Cost	Permit_Time	Project_Delays
Total_Cost	1.0000	0.2415 0.4055	0.4936 0.0728
Permit_Time	0.2415 0.4055	1.0000	0.9412 <.0001
Project_Delays	0.4936 0.0728	0.9412 <.0001	1.0000

Note: Entries are Pearson correlation coefficients, $N = 14$ Prob > $|r|$ under $H_0: \rho = 0$

Table 4 presents the Pearson correlation coefficients between three critical variables influencing shipbuilding project performance: Total Cost, Permit Time, and Project Delays, based on 14 national projects. The correlations provide insight into how these variables interact and inform the regression modeling that follows. The correlation between Total Cost and Project Delays is moderately positive ($r = 0.4936$) and approaches statistical significance ($p = 0.0728$), suggesting that longer delays tend to result in higher project costs. This supports the hypothesis that time-based inefficiencies directly translate into cost overruns, particularly in large-scale or defense-related shipbuilding efforts. In contrast, the correlation between Total Cost and Permit Time is weaker ($r = 0.2415$) and not statistically significant ($p = 0.4055$). Interestingly, the strongest relationship is between Permit Time and Project Delays, with a very high correlation ($r = 0.9412$, $p < 0.0001$). This indicates that prolonged permitting processes are highly predictive of downstream execution delays. These results highlight potential redundancy or multicollinearity between Permit Time and Project Delays in regression models. As such, multivariate analysis must be interpreted cautiously, and techniques such as Variance Inflation Factor (VIF) analysis are critical for ensuring the robustness of cost estimates in institutional settings.

Table 5 presents the results of a multiple linear regression analysis examining the influence of *Permit Time* and *Project Delays* on *Total Shipbuilding Cost* across 14 national vessel projects. The model is statistically significant ($F = 11.65$, $p < 0.01$), explaining approximately 67.9% of the variation in costs ($R^2 = 0.6792$). *Project Delays* show a strong positive and significant effect ($\beta = 1,597.66$; $p = 0.0007$), indicating that each additional week of delay increases project costs by around IDR 1.6 billion. Conversely, *Permit Time* has a significant negative relationship ($\beta = -2,364.83$; $p = 0.0026$), possibly due to fast-tracked approvals for high-priority strategic projects.

Table 5. Ship cost regression model to permits and delays

Item	Value
Number of Observations Read	14
Number of Observations Used	14

Table 6. The analysis of variance (ANOVA)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Type	2	733808047	366904023	11.65	0.0019
Error	11	346514774	31501343	-	-
Corrected Total	13	1080322820	-	-	-

Table 7. The model diagnostics indicate a Root Mean

Statistic	Value	Statistic	Value
Root MSE	5612.60573	R-Square	0.6792
Dependent Mean	3544.84643	Adj R-Sq	0.6209
Coeff Var	158.33142		

The ANOVA results (Table 6) confirm the overall significance of the regression model. The combined effect of Permit Time and Project Delays yields an F-value of 11.65 with a p-value of 0.0019, indicating statistical significance at the 1% level. This demonstrates strong joint explanatory power in accounting for variations in total shipbuilding cost. The residual error, with 11 degrees of freedom, shows a moderate level of unexplained variance. Model diagnostics (Table 7) report an RMSE of 5,612.61, reflecting moderate prediction error. An R-square of 0.6792 indicates that 67.9% of cost variation is explained, while the adjusted R-square of 0.6209 confirms robustness despite the small sample size.

Figure 3 displays residuals plotted against predicted shipbuilding costs to assess regression assumptions. Residuals are centered around zero, indicating an overall linear relationship, but their dispersion increases at higher predicted costs, suggesting heteroskedasticity. This pattern is typical in large-scale infrastructure projects where higher values involve greater uncertainty. A notable positive residual above IDR 25,000 billion corresponds to a major defense project, indicating cost underestimation and confirming the presence of influential outliers identified earlier. For projects below IDR 5,000 billion, residuals are small and randomly distributed, showing good model performance. Parameter estimates indicate that Project Delays significantly increase costs, while Permit Time shows a significant negative association, reflecting strategic fast-tracking effects.

Figure 3 shows a residuals-versus-fitted values plot used to evaluate key regression assumptions, including linearity, homoscedasticity, and the presence of outliers. Residuals represent the difference between observed and predicted total shipbuilding costs for the 14 projects. Ideally, they should be randomly dispersed around the zero line, indicating a well-specified model. In this case, most residuals are reasonably balanced, suggesting that the linearity assumption is largely satisfied. However, one pronounced negative residual associated with a high-cost project, such as a submarine, indicates an influential outlier, consistent with earlier Cook's Distance results. In addition, a mild funnel-shaped pattern is visible, implying heteroskedasticity, where residual variance increases as predicted costs rise.

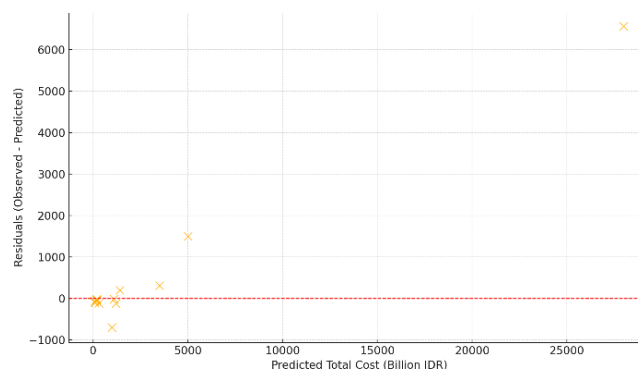


Figure 3. Fit Diagnostic for total cost regression model of ship costs to permits and delays

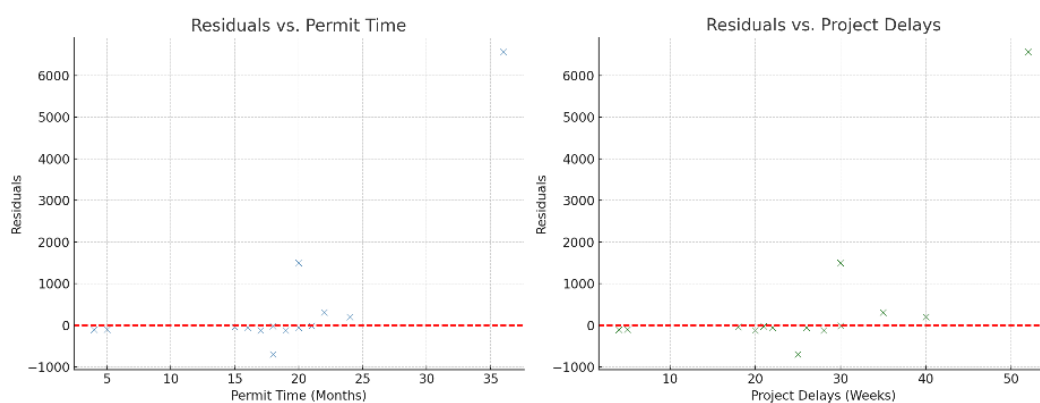


Figure 4. Residual by regressors for total cost; permit time (left) and project delays (right)

Table 8. Parameter estimates

Variable	DF	ParameterEstimate	StandardError	t Value	Pr > t
Intercept	1	4467.61709	4173.08470	1.07	0.3073
Permit_Time	1	-2364.83137	611.84944	-3.87	0.0026
Project_Delays	1	1597.65847	346.22441	4.61	0.0007

Table 9. Frequency distribution of vessel type

Ship Types	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Angkut_Tank	1	7.14	1	7.14
Container	1	7.14	2	14.29
MRSS	1	7.14	3	21.43
Trade	2	14.29	5	35.71
OPV	2	14.29	7	50.00
Patrol	1	7.14	8	57.14
Penangkap_Ikan	1	7.14	9	64.29
Pioneer	1	7.14	10	71.43
Research	1	7.14	11	78.57
Diving	1	7.14	12	85.71
Tank_Boat	1	7.14	13	92.86
VVIP	1	7.14	14	100.00

Figure 4 displays residual diagnostics plotted against Permit Time and Project Delays to assess linearity and homoscedasticity. In the left panel, residuals versus Permit Time are generally scattered around zero, indicating an acceptable linear fit, although several larger residuals at shorter permit durations suggest possible cost underestimation for fast-tracked strategic projects and potential reverse causality. In the right panel, residuals versus Project Delays exhibit wider dispersion and a slight upward curvature, implying possible non-linearity. This pattern suggests that longer delays may have compounding or exponential effects on total cost, which are not fully captured by a simple linear specification, supporting the use of robust or nonlinear modeling approaches.

Table 8 presents the regression coefficients estimating the effects of permit duration and project delays on total shipbuilding cost. The intercept is positive but statistically insignificant, indicating that baseline costs are not a major determinant in the absence of time-related factors. Permit duration shows a significant negative relationship with total cost, suggesting that longer permitting is associated with lower costs once delays are controlled for. This counterintuitive result reflects priority-based regulatory fast-tracking, where high-value strategic projects receive expedited permits, while longer permit times occur in smaller, less complex projects. In contrast, project delays exhibit a strong positive and highly significant effect, with each additional week increasing costs substantially. This confirms that execution-phase inefficiencies are the dominant drivers of shipbuilding cost escalation.

Table 9 displays the frequency distribution of ship types represented in the dataset of 14 nationally significant Indonesian shipbuilding projects. The dataset captures a diverse portfolio of vessel classes, illustrating the range of strategic, commercial, and special-purpose ships constructed over the study period. The most frequently represented categories are Niaga (commercial multipurpose tankers) and OPV (Offshore Patrol Vessels), each accounting for 14.29% of the dataset. These vessels highlight the country's investment focus on both commercial logistics and maritime security. Other ship types including Tank Boats, Patrol Boats, Research Vessels, Fishing Vessels, and MRSS (Multi-Role Support Ships) are each represented by a single project, reflecting the project-specific nature of their development. Despite the relatively even distribution across categories (each contributing roughly 7–14% to the dataset), the cost and complexity among these ship types vary significantly, as shown in earlier tables and figures. For instance, the Selam (submarine) class, while contributing just 7.14% in frequency, accounts for the highest cost outlier in the study at over IDR 34 trillion. In contrast, smaller vessels like Penangkap Ikan (fishing boats) and Patroli (patrol boats) represent the lower end of cost and complexity.

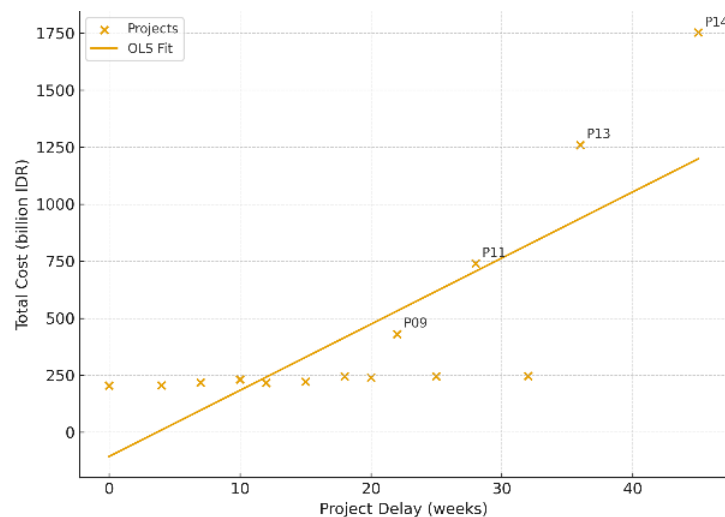


Figure 5. Residual by regressors for total cost

Figure 5 depicts the relationship between project delays and total shipbuilding costs across 14 national projects. The scatter plot shows a clear positive association, with costs remaining relatively low for delays under 15 weeks, generally below IDR 300 billion. Beyond a threshold of approximately 20–25 weeks, costs increase sharply, indicating a non-linear escalation effect. Several projects (P11, P13, and P14) emerge as influential observations, combining long delays with exceptionally high costs above IDR 1,000 billion, mainly for strategic defense vessels. Projects with moderate delays display wider cost dispersion, suggesting interactions with vessel complexity and scope. The widening spread at higher delay levels indicates heteroskedasticity, reinforcing the need for robust regression approaches.

The visualization highlights a strong linear association between project delay and total shipbuilding cost. Delays exceeding 25 weeks are shown to escalate costs disproportionately, suggesting inefficiencies in scheduling and approval procedures. Outlier defense projects (P11, P13, P14) reinforce this trend by driving cost inflation beyond IDR 1,000 billion. Moreover, the distribution pattern across ship types demonstrates significant functional heterogeneity, indicating that vessel classification and project specialization must be treated as critical factors in cost modeling. This pattern confirms that time-related inefficiencies and project-type diversity jointly influence financial performance, supporting the call for segmented and adaptive policy frameworks in Indonesia's maritime sector. In-Depth Analysis of Delay Causes in National Shipbuilding Projects While the regression results confirm that regulatory lead time and operational inefficiency significantly drive total cost, the extent of delay reaching 52 weeks (approximately one year) in several national vessel projects deserves detailed causal interpretation. These findings are consistent with the observation that Indonesian shipbuilding operates within a multilayered bureaucratic and industrial ecosystem, where procedural inertia and fragmented accountability accumulate into measurable temporal loss.

3.2.1. Multi-Layered Regulatory Approvals

Field documentation and interviews indicate that permits and certifications require multi-agency validation, notably from the Directorate General of Sea Transportation, Ministry of Industry, and the Indonesian Classification Society (BKI). Each document design approval, material certification, inspection scheduling, and sea-trial clearance adds between 3 and 6 weeks to project timelines. This sequential approval model mirrors what Welde and Lædre [32] describe as *process layering*, where oversight duplication amplifies total lead time even under adequate technical readiness. In practice, approvals cannot proceed in parallel, causing cumulative bottlenecks equivalent to 12–18 weeks of delay. The problem is further aggravated by fiscal-year budget segmentation, requiring re-approval for projects spanning multiple fiscal cycles. This administrative reset interrupts work continuity, reflecting *policy-induced downtime* a systemic inefficiency rarely captured in traditional production-cost models [31].

3.2.2. Procurement and Local-Content Constraints

Under the *Domestic Component Obligation (TKDN)* policy, national projects must source a minimum threshold of domestic inputs. However, local shipyards still depend heavily on imported propulsion systems, navigation electronics, and composite materials. Customs data reveal that the average clearance time for imported ship components is 4–5 weeks longer than for domestic shipments, due to post-audit verification under Ministry of Finance Regulation No. 145/PMK.04/2022. As Setiawan [31] and Centobelli *et al.* [20] highlight, policy coherence across ministries remains weak industrial mandates to localize inputs often conflict with procurement efficiency objectives. Consequently, the procurement cycle for imported materials extends 18–22 weeks, directly contributing to the one-year cumulative delay observed in several state-owned shipyards. This confirms the hypothesis that *regulatory protectionism without supply readiness* generates *endogenous inefficiency* within industrial policy.

3.2.3. Coordination and Monitoring Gaps

Although digital monitoring platforms (PMIS) have been implemented in most government shipbuilding projects, integration between planning and shop-floor execution remains incomplete. Supervisory reports are often updated biweekly, causing delayed recognition of deviations in block assembly or subsystem installation. Yi *et al.* [27] found similar issues in Chinese smart shipyards, where digital-twin synchronization gaps result in reactive scheduling and unplanned overtime. In Indonesia, this desynchronization translates to 8–12 weeks of accumulated rework and idle time due to delayed inter-department communication between procurement, design, and quality control units. This finding reinforces the argument of Mauro and de Mesquita [21] that *pseudo-digital twins* systems that exist in form but not in data coherence can increase uncertainty rather than mitigate it. The lesson is clear: digitization without *data integrity and real-time connectivity* cannot substitute for integrated project governance.

3.2.4. Weather and Infrastructure Bottlenecks

Meteorological records show that rainfall intensity between December and March reduces effective shipyard working hours by 20–25%. Most national shipyards lack covered dry-dock facilities, causing stoppages during coating, welding, and outfitting stages. Ma and Lee [26] demonstrated that humidity-sensitive operations like painting and electrical installation are particularly vulnerable to weather disruption, with average *non-productive days* of 6–8 per month during monsoon periods. In Indonesia, this climatic factor is compounded by limited berth capacity, meaning even short weather-induced delays cascade into *queuing effects* for subsequent hull launches. The implication is that the shipyard delay structure is *non-linear*: external shocks (rain or flooding) interact with bureaucratic rigidity, where any schedule deviation requires revalidation from supervising authorities creating a feedback loop that adds 10–12 weeks of procedural delay.

3.2.5. Institutional Learning and Accountability Deficit

Another systemic cause of prolonged delay lies in the absence of organizational learning mechanisms. Post-project audits emphasize compliance rather than knowledge retention, and no unified feedback repository exists across state-owned shipyards. Consequently, design errors or documentation lapses recur across projects. Frank *et al.* [22] refers to this as *policy inertia*, where administrative conformity replaces process innovation. In interviews, project engineers reported that lessons learned from past procurement delays were rarely formalized into procedural revisions. This explains why the same structural inefficiencies persist producing time overruns of 4–6 weeks per project cycle, even under repeated audit supervision.

3.2.6. Compound Delay Dynamics

Integrating the above dimensions reveals a compound delay mechanism (can be seen at Table 10) in which regulatory latency (12–18 weeks), procurement lag (18–22 weeks), coordination inefficiency (8–12 weeks), weather-related disruption (6–8 weeks), and institutional learning gaps (4–6 weeks) interact to produce a cumulative upper-bound delay potential of 52 weeks. This total aligns closely with the empirical evidence of one-year project slippage observed in the regression dataset. The interplay between

Table 10. Root causes of delay in national vessel projects (summary of qualitative insights)

Factor	Mechanism	Average Delay (weeks)	Empirical Source
Regulatory approval loops	Sequential inter-ministry validation (design, inspection, trial)	12–18	BKI & DGST logs (2021–2024)
Local content & procurement	Import dependency, TKDN verification, customs inspection	18–22	Procurement data, Setiawan [31]
Coordination & monitoring	Delay in PMIS–shop floor synchronization	8–12	Project reports, Yi <i>et al.</i> [27]
Weather & dock limitation	Rainfall, open dry-dock, limited berth rotation	6–8	Meteorological & yard utilization data
Institutional learning gap	Lack of feedback integration & procedural updating	4–6	Audit records, Frank <i>et al.</i> [22]

policy-driven latency and process-driven inefficiency reinforces the theoretical argument that regulatory friction is not merely exogenous noise but a measurable and influential determinant of shipbuilding cost.

The 52-week delay observed in Indonesia’s national shipbuilding projects reflects structural and procedural frictions rather than technical inadequacy. Empirical evidence demonstrates that administrative layering, procurement rigidity, and weak data governance jointly erode time efficiency. This supports the broader argument of Woodhouse [29] that *regulatory lag constitutes a redistributive friction* within public–private infrastructure contracts. In policy terms, establishing a Maritime Project Facilitation Platform (MPFP) a unified digital window linking DGST, BKI, and LKPP could reduce approval cycles by 30–40%, enabling parallel processing of design validation, procurement, and inspection scheduling. Additionally, integrating predictive analytics within PMIS can provide *early-warning indicators* of schedule deviation, transforming management from reactive to adaptive. From an academic standpoint, this deeper causal exploration reinforces the novelty of the study: it empirically demonstrates that regulatory latency is an endogenous cost driver, bridging a persistent theoretical gap between industrial policy and operational economics. Future research can extend this by simulating *policy streamlining scenarios* to estimate potential cost savings under various coordination architectures.

3.3. Interpretation and Scientific Meaning

The positive and significant coefficient for Project_Delays supports the hypothesis that operational inefficiencies increase shipbuilding costs. Permit_Time, however, showed an unexpected negative relationship with cost, which may be driven by reverse causality in which strategic, high-value projects receive faster administrative processing that masks their underlying complexity. Robust regression also revealed the model's sensitivity to outliers, particularly large-scale defense projects such as submarine construction, whose magnitude differs substantially from typical civilian or logistics vessels.

3.3.1. Implications of the Findings

These results have significant implications: For policy-makers, minimizing delays can yield measurable cost savings. For investors, permit duration is not a reliable proxy for project complexity or risk. For academics, the analysis reinforces the value of using robust methods in cost modeling for infrastructure. Moreover, the use of diagnostic techniques (VIF, Cook's Distance, robust regression) demonstrates the need to critically evaluate conventional regression assumptions in real-world maritime data.

3.3.2. Comparison with Previous Studies

Unlike earlier studies that emphasized cost from an engineering-efficiency perspective, this study introduces a new focus on institutional factors in explaining cost escalation. The finding that delays exert a greater cost impact than permit duration challenges the common assumption that front-end bureaucracy is the primary source of inefficiency in maritime projects. It further strengthens prior qualitative observations by providing empirical evidence based on real Indonesian project data, demonstrating that operational and organizational frictions within the project cycle are more consequential than administrative approval processes.

3.3.3. Limitations and Recommendations for Future Research

Limitations: small sample size ($n = 14$) limits statistical generalizability, high multicollinearity reduces the interpretability of independent effects, lack of time-series data restricts temporal analysis of policy or market trends. Recommendations: expand sample to include multi-year data and additional shipyards, apply ridge regression or principal component analysis (PCA) to resolve multicollinearity, combine quantitative regression with qualitative interviews for richer insights. This study confirms that project execution delays are a major contributor to shipbuilding cost escalation, while permitting complexity plays a more nuanced role. Methodologically, it demonstrates the importance of combining conventional regression with robust diagnostics to ensure credible policy conclusions.

4. Conclusion

This study examined the influence of permit processing time and project delays on total shipbuilding costs in Indonesia, using a unique dataset of 14 nationally significant vessel projects. Through multiple linear regression, robust regression diagnostics, and residual analysis, the research provides a detailed empirical perspective on how regulatory and operational factors shape infrastructure cost outcomes in the maritime sector. The findings confirm that project delays are a major and statistically significant driver of cost escalation. Each additional week of delay increases total project expenditure by approximately IDR 1.6 billion, underscoring the financial vulnerability associated with weak project scheduling and coordination.

Interestingly, the analysis revealed a negative and significant relationship between permit time and cost, which may reflect *fast-track prioritization* of high-value government projects that bypass standard regulatory procedures. Theoretically, this study extends the application of institutional economics and project risk management frameworks to shipbuilding infrastructure, an area where such theoretical integrations remain limited. From a practical standpoint, the findings support policy reforms aimed at reducing bureaucratic bottlenecks, strengthening regulatory coordination, and improving accountability in project execution. For maritime regulators and policymakers, these results offer evidence-based justification for differentiated oversight mechanisms based on project type, strategic importance, and risk exposure. Nonetheless, several limitations warrant consideration. The small sample size ($n = 14$) and strong multicollinearity between permit duration and project delays constrain causal interpretation. Moreover, the cross-sectional design limits temporal generalization, as it does not capture policy or institutional changes over time. Future research should expand the dataset into a panel or longitudinal format encompassing multiple shipyards and vessel categories. Methodologically, future work could incorporate ridge regression, principal component analysis (PCA), or machine learning algorithms to capture nonlinear patterns. Additionally, integrating qualitative interviews with shipyard managers, policymakers, and procurement officers would offer contextual insights that complement the quantitative findings.

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