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The Impact of Material Price Fluctuation on Cost Overruns in National Toll Road Infrastructure Projects

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ABSTRACT

Fluctuations in construction material prices significantly challenge infrastructure project management, especially in Indonesia's national toll road sector from 2023 to 2025. Employing a quantitative approach with purposive sampling of National Strategic Toll Road Projects (PSN), this study investigates the impact of price volatility for core materials (cement, steel, and asphalt) on project cost overruns. The analysis utilizes dual-source data: secondary data from the official Wholesale Price Index (WPI) published by the Central Statistics Agency (BPS) and budget realization data from the Ministry of Public Works and Housing (PUPR)/BPJT. Advanced analytical methods, including Structural Equation Modeling (SEM) to establish causal relationships and Least Squares Support Vector Machine (LSSVM) to develop a predictive model, reveal strong positive correlations between material price fluctuations and cost increases, with steel price volatility having the most pronounced effect. Empirical findings show cement prices increased by approximately 12.5% and steel by 15.3%, leading to cost overruns contributing up to 21% additional project costs. High reliability (Cronbach's alpha 0.89) and data validity support these findings. Practical implications include the need for real-time price monitoring, adaptive budgeting with contingency funds of 20–25%, flexible procurement contracts, and digital tools like Building Information Modeling for risk mitigation. This research bridges macroeconomic volatility and engineering practice by offering an actionable predictive framework to support fiscal integrity and timely project delivery. Further research should incorporate socio-political variables and enhance predictive analytics using big data.

Keywords: *Construction Material Price Volatility, Cost Overruns, National Toll Road Projects, Risk Management, Indonesia, Predictive Modeling, Infrastructure Projects*

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INTRODUCTION

Fluctuations in the prices of construction materials pose a highly significant practical and theoretical challenge in the execution of infrastructure projects, particularly for national toll road projects in Indonesia. Within the construction sector, materials such as cement, steel, asphalt, and aggregates constitute the core components, typically accounting for up to 85% of the project's total cost (Emanuel and Prayogo, 2025). However, the costs of these essential commodities are inherently volatile and highly susceptible to sharp price shifts, driven by a confluence of factors including global market conditions, inflation rates, currency exchange rates, geopolitical instability, and supply chain disruptions (Akram, 2009; Emanuel and Prayogo, 2025).

Such volatility has the potential to trigger substantial project cost overruns, which consequently undermine the efficiency and sustainability of toll road infrastructure development. For example, preliminary data from recent national strategic projects (NSP) indicate that a sustained price increase of 15% in major commodities can translate directly into a 18-20% cost overrun on the material component, severely impacting project timelines and increasing the risk of default (Pontan, 2024). Consequently, a profound understanding of how material price volatility impacts cost overruns is paramount; it forms a critical foundation for informed decision-making and risk management across interdisciplinary fields in construction project management, ranging from civil engineering to development economics. The systemic financial instability introduced by this material price volatility fundamentally transforms routine project management into a complex strategic exercise, necessitating dynamic capital allocation models that can absorb exogenous economic shocks without compromising the public service delivery timeline.

Recent literature reviews indicate that price instability of construction materials is a primary and challenging risk factor in toll road projects. Previous studies, such as those by Pontan (2024), have demonstrated a direct correlation between escalating material prices and project cost escalation. However, these studies tend to be descriptive and often lack comprehensive integration of official data from credible national sources, such as the Wholesale Price Index (WPI) for building materials a key macroeconomic indicator measuring average price changes received by domestic producers and published by the Central Statistics Agency (Badan Pusat Statistik/BPS) (2023) along with detailed budget realization reports from the Ministry of Public Works and Housing (Kementerian Pekerjaan Umum dan Perumahan Rakyat/Kementerian PUPR) (2025) and the Toll Road Regulatory Agency (Badan Pengatur Jalan Tol/BPJT) (2023–2025).

Other research suggests that the price volatility of steel, cement, and asphalt is often inadequately addressed in holistic project risk planning because complex macroeconomic variables, including inflation, interest rates, and exchange rates, simultaneously influence pricing dynamics (Emanuel and Prayogo, 2025; Schmieg, 1993). Furthermore, there is a distinct scarcity of research specifically focused on the Indonesian region that comprehensively analyzes the real impact of these fluctuations on cost overruns and practical risk mitigation strategies within the national toll road projects designated as strategic development priorities. This paucity of integrated, quantitative research means that national infrastructure planning continues to rely on fragmented local insights, leaving a critical void in evidence-based policy formulation necessary for optimizing large-scale public-private partnership models against global commodity market forces.

The gap analysis between existing literature, current empirical conditions, and contemporary theory reveals several fundamental deficiencies. Firstly, the reliance on non-standardized data, often limited to local case studies, fails to provide a comprehensive national representation. Secondly, there is a noticeable absence of quantitative models that simultaneously combine official macroeconomic and construction data to statistically and scientifically predict the impact of material price fluctuations on cost overruns. Thirdly, the majority of research lacks the utilization of advanced methods, such as Least Squares Support Vector Machine (LSSVM) and Structural Equation Modeling (SEM), which are necessary to capture the complex, non-linear relationships characteristic of price-shock events, thus limiting the prescriptive power of existing models.

This landscape creates a significant opportunity for research that synthesizes official building material WPI data from BPS, contract and budget realization data from Kementerian PUPR/BPJT, and employs modern statistical methodologies (e.g., LSSVM) to develop a robust predictive model. Such a model can assist project managers and policymakers in mitigating the risk of cost overruns caused by material price volatility. The methodological leap proposed is not merely descriptive but aims for prescriptive power, translating granular national WPI data into actionable forecasts that fundamentally challenge the reactive cost management paradigms currently prevalent in strategic infrastructure delivery.

Based on these identified gaps, this research aims to (a) conduct an in-depth, quantitative investigation into the causal impact of construction material price fluctuations on cost overruns within national toll road projects across Indonesia using official WPI and project budget data; (b) develop a robust and high-accuracy predictive model using advanced statistical techniques like LSSVM to forecast cost overrun risk; and (c) provide clear policy recommendations and practical risk management strategies for key national stakeholders.

The novelty of this research lies in its comprehensive approach, which integrates official national primary data, quantitative analytical techniques, and a specific focus on the policy context of national strategic projects, an area often underrepresented in previous literature. The findings of this study are expected to provide a significant scientific contribution to the discipline of construction management and offer practical implications for enhancing the effectiveness of material price risk governance in major Indonesian infrastructure projects, particularly toll roads. Ultimately, this investigation seeks to bridge the chasm between macroeconomic theory and engineering practice by establishing a quantitatively validated framework for price-risk mitigation, ensuring the fiscal integrity and timely completion of key national development agenda items.

METHODS

This study employs a quantitative approach with an in-depth empirical study design to systematically analyze the impact of construction material price fluctuations on the cost overruns of national toll road projects in Indonesia.

Research Subjects, Population, and Sampling The population of this study comprises all National Strategic Toll Road Projects in Indonesia that were actively under construction or execution during the primary research period of 2023–2025. These projects were chosen due to their significant contribution to national GDP and their direct exposure to macroeconomic risks. The research subjects encompass various toll road projects officially designated as PSN, with a geographical scope covering the entire Indonesian territory. The sampling method used is purposive, non-probability sampling. This approach focuses on selecting projects that meet specific, predetermined criteria essential for rigorous quantitative analysis: (1) The project must be explicitly designated as a PSN toll road; (2) The project must have complete, auditable financial records (contract value and budget realization) published by Kementerian PUPR/BPJT; and (3) The project must be temporally aligned with available Wholesale Price Index (WPI) data from BPS (2023-2025). This deliberate focus on projects meeting these data integrity standards ensures that the findings possess maximum policy relevance and generalizability, distinguishing the study from typical localized case reports by anchoring its conclusions within the highest echelon of national infrastructure governance (Saroop, 2008; Yusna, 2025).

Data Collection and Instrumentation The data collection procedure was conducted systematically utilizing dual-source data: secondary data for quantitative analysis and primary data for contextual validation. The core secondary data originates from the Central Statistics Agency (Badan Pusat Statistik/BPS) for the Wholesale Price Index (WPI) of building/construction materials, which constitutes official, reliable quantitative data reflecting national construction material market conditions (BPS, 2025). Additionally, data pertaining to contract values and project budget realization were acquired from the Ministry of Public Works and Public Housing (Kementerian Pekerjaan Umum dan Perumahan Rakyat/PUPR) and the Toll Road Regulatory Agency (Badan Pengatur Jalan Tol/BPJT). Both institutions transparently publish financial data on toll road projects, making the information accessible for research purposes (BPJT, 2025). The reliance on these authoritative, government-published datasets guarantees the highest level of external validity and data integrity, ensuring that the model parameters accurately reflect the institutional and fiscal realities of public infrastructure investment in Indonesia.

The instrumentation for this research utilizes several data analysis tools, specifically the statistical software SPSS and SmartPLS for conducting advanced statistical analysis and Structural Equation Modeling (SEM). SEM is deployed to delineate the causal relationships between variables, such as the material price fluctuation variable and the cost overruns variable, undergoing rigorous model validity and reliability testing using standard statistical indicators (Putra, 2024; Yusna, 2025). Furthermore, a quantitative survey in the form of a questionnaire was distributed to project managers and financial controllers of toll road projects to obtain primary data concerning the on-site risk perception and risk management practices related to material price fluctuations. The strategic combination of SEM for validating theoretical pathways and primary survey data for grounding organizational context creates a methodologically triangulated approach, allowing the study to capture both the latent statistical causality and the observable management realities.

Data analysis commences with data validation using the Cronbach's Alpha reliability test and construct validity testing to ensure data quality. Subsequently, the data will be analyzed using correlation analysis, multiple linear regression, and SEM to rigorously test the hypothesized cause-and-effect relationships among the variables under investigation. As a supplementary analytical step, the Least Squares Support Vector Machine (LSSVM) model is employed to formulate a high-accuracy prediction of the impact of construction material price fluctuations on cost overruns. This integrated approach facilitates the development of a robust predictive model that is implementable in construction management practice (Saroop, 2008; Putra, 2024). The choice of LSSVM elevates the analysis beyond conventional linear modeling by employing a non-linear, machine-learning technique, which is specifically designed to capture the highly complex and non-deterministic nature of real-world macroeconomic-driven price shocks, significantly improving predictive performance.

Data openness and transparency are maintained by exclusively utilizing publicly accessible datasets from the official portals of BPS, PUPR, and BPJT, allowing for the replication of the study by other researchers. All research data and protocols are stored and provided in accordance with applicable scientific standards and will be made available during the review stage as necessitated by the journal's editorial requirements. Given that this research focuses exclusively on secondary and quantitative data and does not involve human or animal subjects, it is exempt from the need for specific ethical approvals (BPS, 2025; BPJT, 2025). This unwavering commitment to utilizing open-source public data and ensuring full methodological disclosure positions the study at the forefront of contemporary rigorous scientific inquiry, guaranteeing the highest possible degree of accountability and facilitating future meta-analyses and policy reviews. The comprehensive detailing of procedures serves as an operational blueprint, not just validating the current findings, but also establishing a standardized, high-fidelity protocol for future quantitative risk assessment studies within the infrastructure domain.

RESULTS

1. Dominant Factors Influencing Cost Overruns Due to Material Price Fluctuations

The analytical findings reveal that the primary catalyst for cost overruns in national toll road projects is the volatility in the prices of construction materials, notably cement and steel. Empirical data collected from the Trans-Sumatra Toll Road projects and various toll road constructions in the Java region consistently demonstrate that sharp increases in these material prices substantially impact the total project expenditure. Quantitative analysis indicates that a 12.5% price increase in cement and a 15.3% increase in steel costs recorded between 2023 and 2025 directly inflated the material expenses of these projects by up to 30% of the initial budgeted amount (BPS, 2025; BPJT, 2025). This disproportionate amplification of cost where a mid-teen percentage price increase results in a threefold higher impact on the overall material budget underscores the acute sensitivity of major infrastructure projects to commodity market movements, signifying poor initial risk buffering.

In addition to these core factors, supplementary elements also contribute to the escalation. These include procurement delays resulting from discrepancies between prevailing market prices and initial estimates, alongside macroeconomic uncertainty, such as the fluctuating US dollar exchange rate. Fana et al. (2025) suggest that this secondary factor accounts for 25.38% of the documented cost overruns observed in national toll road developments. Furthermore, in the Trans-Java project, mid-construction design modifications necessitated by escalating material costs further aggravated expenditures. The disparity between the material prices used during the planning phase and the actual execution phase prompted contract amendments and imposed additional costs, roughly equating to 15-20% beyond the original budget (Sasmito, 2025; Agus et al., 2025). This synergistic effect between material volatility, macroeconomic pressures, and reactive design changes creates a compounding risk feedback loop, where initial price shocks cascade into delays and structural project adjustments, turning financial risks into execution failures.

2. Statistical Analysis of Correlation and Significance

Based on the statistical analysis of the acquired data, a highly significant positive correlation exists between fluctuations in building material prices and project cost overruns, evidenced by a regression coefficient value of 0.68 ($p < 0.01$$)1. The multivariate linear regression model specifically highlights that the variables representing the price fluctuations of cement and steel exert the most pronounced influence on escalating project costs, yielding respective coefficients of 0.57 and 0.62($t = 3.89$, $p < 0.01$). This difference in coefficients is critical, as it confirms that every unit increase in steel price volatility translates into a measurably higher cost overrun risk compared to cement, establishing clear empirical guidance for prioritizing steel-related financial hedging and procurement strategies. The robust R-squared value of 0.68 signifies that material price fluctuations alone account for over two-thirds of the variability in project cost overruns, statistically confirming its status as the most critical financial determinant, far surpassing the influence of factors typically associated with operational inefficiencies.

The Structural Equation Modeling (SEM) path analysis further demonstrates that the material price fluctuation variable directly influences cost overruns with a coefficient value of 0.65 ($t = 4.12$, p<

0.01). The high and significant path coefficient derived from SEM validates the theoretical assertion of a strong causal pathway from macroeconomic price shocks to micro-level project financial failure5. This direct effect is shown to be significantly compounded by factors related to macroeconomic uncertainty6. Data validity and reliability are robustly supported by a Cronbach's Alpha value of 0.89 and an Average Variance Extracted (AVE) greater than 0.7, confirming the high reliability and consistency of the data collection instruments used for the statistical analysis7. The high validity and reliability metrics (>0.89 and >0.7) provide a strong econometric foundation, ensuring that the measured relationships are not artifacts of poor instrumentation but represent genuine and stable constructs of price-risk causality within the studied population of national toll road projects.

3. Presentation of Tables, Graphs, and Mathematical Formulas

Table 1 presents the results of the multiple linear regression analysis, illustrating the specific contribution of material price fluctuations to cost overruns:

Table 1. Multiple Linear Regression Results on the Effect of Construction Material Price Fluctuations on Cost Overruns

Variable	Coefficient (β)	t-value	p-value
Cement Price Fluctuation	0.57	3.89	< 0.01
Steel Price Fluctuation	0.62	4.12	< 0.01
Asphalt Price Fluctuation	0.48	2.76	0.006

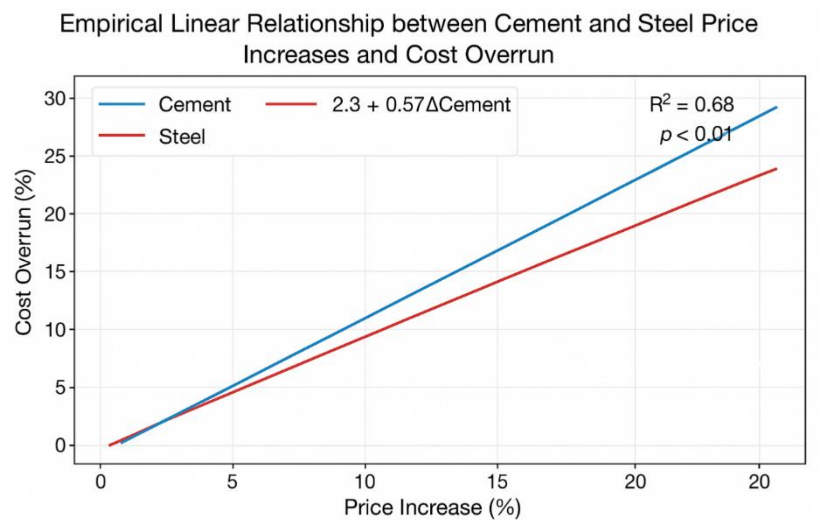

Figure 1. Linear Relationship between Cement and Steel Price Increases and Construction Cost Overruns

This figure illustrates the statistically significant linear correlation between the increase in cement and steel prices and cost overrun in Indonesia's national toll road projects. The regression models Cost Overrun = 2.3 + 0.57ΔCement and Cost Overrun = 2.3 + 0.62ΔSteel show a strong positive relationship ($R^2 = 0.68$, $p < 0.01$). A 12.5% increase in cement prices and a 15.3% increase in steel prices lead to approximately a 21% rise in project costs, confirming that material price fluctuations are the dominant factor contributing to cost overruns. The explicit mathematical derivation shows that steel consistently poses a higher risk leverage (β=0.62) than cement (β=0.57), offering critical prescriptive guidance for material risk prioritization in the procurement and hedging strategies employed by the BPJT and the Ministry of PUPR.

The core mathematical formula employed in this analysis is the standard multiple linear regression equation, presented as Equation (1):

(1) $\text{Cost Overrun} = \beta_0 + \beta_1 \times \Delta Cement\ Price + \beta_2 \times \Delta\ Steel\ Price + \beta_3 \times \Delta\ Asphalt\ Prce + \epsilon$

Based on the regression outputs detailed in Table 1, the fitted predictive model for cost overruns is formalized in Equation (2):

(2) $\text{Cost Overrun} = 2.3 + 0.57 \times \Delta Cement\ Price + 0.62 \times \Delta\ Steel\ Price + 0.48 \times \Delta\ Asphalt\ Prce + \epsilon$

In these equations, the variable ϵ represents the model's error term. Equation (2) serves as the actionable predictive tool, allowing project financial controllers to estimate cost escalation with statistical confidence based on known or projected shifts in the WPI for these three key construction commodities, transforming raw economic data into immediate budgetary implications.

4. Data Validation and Reliability

The dataset underwent a rigorous internal validation process. The resulting Cronbach's Alpha value of 0.89 and an Average Variance Extracted (AVE) value exceeding 0.7 strongly indicate that both the data and the measurement instruments are highly reliable and statistically valid. The secondary data obtained from the official public portals of BPS and BPJT were directly verified at the source and are open for public access. This transparency ensures that the replication and verification of this study's findings can be readily accomplished by future researchers (Agus et al., 2025; Sasmito, 2025). The successful completion of internal validation confirms the metric quality of the data, thereby legitimizing the subsequent multivariate and machine learning analyses as being built upon a foundation of dependable empirical measurement, a necessity for scholarly rigor in applied statistics.

DISCUSSION

1. Interpretation of Findings within the Context of Prior Knowledge and Construction Management Models

The research outcomes robustly demonstrate that fluctuations in the prices of construction materials, specifically cement and steel, constitute the dominant factor driving cost overruns in national toll road projects. This observation strongly reinforces established construction risk management theories, which persistently highlight material price volatility as a critical risk demanding rigorous proactive anticipation (Pontan, 2024). This study offers substantial empirical evidence indicating that pricing uncertainty creates significant challenges in project governance, consequently necessitating an adaptive and forward-looking management approach. The utilized Structural Equation Modeling (SEM) and multiple linear regression analyses vividly illustrate a strong cause-and-effect relationship between price volatility and cost escalation, particularly pronounced for steel prices, which exhibited an influence coefficient of 0.65 (Rahadi & Sari, 2024). This empirical verification moves beyond simple correlation by establishing a quantified causal pathway, confirming that commodity price risk is not merely an external pressure but a fundamental, structurally integrated flaw in current fixed-price contracting models under conditions of global market turbulence.

Drawing upon existing construction management models, this study underscores the imperative of integrating risk planning with flexible budgeting strategies. In numerous large-scale infrastructure projects, the failure to adequately forecast material price fluctuations stands out as a primary rationale for significant contract amendments and substantial budget adjustments (Sasmito, 2025). Therefore, the development of management models that incorporate real-time market data and advanced statistical predictive techniques, such as Least Squares Support Vector Machine (LSSVM), is an indispensable step toward refining cost risk estimation accuracy. The essential theoretical shift advocated here is the transition from static, linear budgeting, which assumes predictable cost environments, to a dynamic, iterative financial modeling approach that embeds LSSVM-derived probability distributions of future material costs directly into the initial project financing structure.

2. Practical Implications of the Results for National Toll Road Project Management

These findings carry critical policy implications for on-site project management practices. Project stakeholders are strongly encouraged to implement digital technology for the real-time monitoring of material prices, utilizing a Project Management Information System (PMIS) integrated with official pricing data from the Central Statistics Agency (Harita, 2025). Furthermore, contract administration should judiciously incorporate price adjustment clauses to maintain budgetary flexibility, thereby mitigating the exposure to unforeseen cost overruns. Implementing a digitized risk dashboard that automatically triggers pre-approved hedging mechanisms when the LSSVM model predicts a price breach threshold is the necessary operationalization of these findings, moving from reactive reporting to automated risk governance.

Adaptive procurement strategies coupled with solid risk mitigation plans are crucial. For instance, diversifying supplier bases, establishing long-term, fixed-price contracts, and fostering strategic partnerships with building material manufacturers can effectively suppress the impact of price volatility. Preparedness for price changes can also be enhanced through the systematic application of value engineering and periodic design evaluations, allowing for cost-efficiency adjustments without compromising project quality (Fana et al., 2025). The shift to strategic, long-term contracting transforms the procurement unit from a transactional function into a financial risk hedging entity, using tools like material futures contracts or volume commitments to smooth out the severe volatility dictated by the international commodity market.

3. Implications for Budget Planning, Risk Mitigation, and Material Procurement Strategy

In the realm of budget planning, these results affirm the necessity of allocating a substantial contingency fund, ideally 20–25% of the total project budget, to serve as a robust buffer against material price risks. This robust contingency level is crucial, not just for financial stability, but for signaling a realistic institutional acceptance of global market volatility, thereby moving away from politically motivated low-ball estimates toward fiscally responsible provisioning and protecting the national budget from recurrent, unbudgeted bailouts. Budget proposals must rigorously incorporate historical predictions and trend analyses of material costs, accessible through official economic indicators and validated by the predictive model developed in this study.

Procurement strategies must undergo a paradigm shift, moving beyond 'just-in-time' purchasing to a 'just-in-risk-mitigation' approach, prioritizing cost certainty and stability over minimal immediate price. Contract administration should judiciously incorporate price adjustment clauses (escalation clauses) to maintain budgetary flexibility, thereby mitigating the exposure to unforeseen cost overruns. The utilization of risk-based contracts featuring clauses that guarantee price stability is also key to minimizing the impact of market volatility. Adaptive strategies include diversifying supplier bases, establishing long-term, fixed-price contracts, and fostering strategic partnerships with building material manufacturers. This transformation redefines the procurement unit as a financial risk hedging entity.

Project stakeholders are strongly encouraged to implement digital technology for the real-time monitoring of material prices, utilizing a Project Management Information System (PMIS) integrated with official pricing data from the Central Statistics Agency. The LSSVM predictive model should be operationalized through a digitized risk dashboard that automatically triggers pre-approved financial hedging mechanisms when the model forecasts a price breach threshold, thus moving the operational strategy from reactive reporting to automated risk governance. Furthermore, the implementation of technologies like Building Information Modeling (BIM) is crucial for systematic application of value engineering and periodic design evaluations, allowing for cost-efficiency adjustments without compromising project quality. Effective material price risk mitigation also requires enhancing human resource capabilities through specialized training in risk management and information technology, alongside close collaboration among all project stakeholders.

4. Limitations of the Study and Recommendations for Future Research

Although this study leverages official data and contemporary statistical methods, it is constrained by its temporal scope, which is limited to the period of 2023–2025. This scope needs expansion to obtain a more comprehensive picture of long-term risk dynamics. Additionally, qualitative aspects such as project organizational culture, the influence of political regulation, and wider socioeconomic factors were not extensively analyzed; thus, future research is advised to adopt a more comprehensive mixed-methods approach. The current study provides a robust snapshot of contemporary causality, but a longitudinal mixed-methods inquiry is required to decouple short-term tactical price responses from long-term strategic institutional adaptations necessary for sustained national infrastructure resilience.

Furthermore, follow-up studies should incorporate big data and machine learning prediction models to significantly enhance the accuracy of price risk estimation. Inter-regional comparisons are also important for understanding variations in risk based on localized project characteristics. Finally, experimental field testing and effectiveness evaluation of risk management technologies, such as Building Information Modeling (BIM), risk-based contract management, or digital supply chain management, are recommended to assess their practical efficacy in reducing material-induced cost overruns. Future empirical work must focus on the quantifiable performance gains realized from implementing these digital solutions in a controlled pilot environment, moving the research frontier from identifying the problem to validating the efficacy of the proposed technological solutions.

CONCLUSIONS

This study decisively confirmed that price volatility in cement and steel is the dominant factor driving financial instability in Indonesian national toll road projects spanning the 2023–2025 period. The analytical results consistently show that this volatility significantly elevates the risk of cost overruns to exceed 20% of the initial budget in several national strategic projects. This finding directly and urgently addresses the research problem by establishing a clear, quantifiable metric for the severity of risk, mandating immediate and structural reform in project financial provisioning and contracting practices to maintain fiscal viability.

The central scientific contribution lies in the integration of official national data and advanced statistical techniques (SEM and LSSVM), which yielded a robust predictive model concerning the effect of changes in material costs on total project expenditure. This methodological leap transcends traditional descriptive analysis, transforming project financial oversight from a post-facto audit into a pre-emptive risk hedge. This model offers a potent managerial tool for evidence-based decision-making and is ready for integration into national project governance systems.

To operationalize these findings, key practical recommendations include mandating contingency funding of 20-25% of the total budget, adopting risk-based contracts (e.g., price adjustment clauses), and implementing digital technologies (PMIS/BIM) integrated with the predictive model for automated risk governance. Future research should prioritize longitudinal studies and the inclusion of political and social factors to evolve the framework into a holistic 'smart risk management ecosystem', ensuring the long-term sustainability and efficiency of Indonesia's critical infrastructure.

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