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Feasibility Analysis of Toll Road Investment Due to the Risk of Construction Cost Increases and Schedule Changes (Patimban Port Access Toll Road)

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ABSTRACT (10PT)

The development of toll road infrastructure as a national priority faces significant challenges in the form of construction cost uncertainties and implementation schedule changes that can affect investment feasibility. This study aims to analyze the impact of construction cost escalation risk and schedule changes on the investment feasibility of the Patimban Access Toll Road. The research was conducted using a quantitative method with sensitivity analysis, utilizing relevant financial data, traffic data, and supporting documents. Financial feasibility analysis employed Net Present Value and Internal Rate of Return indicators complemented by sensitivity analysis to measure the impact of construction cost variations and schedule changes on investment return rates. This research uses a quantitative approach with an integrated financial analysis method. Data collection was conducted through a comprehensive documentation study of the project's financial, technical, and operational data, which was then analyzed using mathematical models and simulations. The project demonstrates good financial feasibility under normal conditions with an NPV of IDR 1,250.35 billion, an IRR of 12.85% and a payback period of 15.5 years. The risk of construction cost increases significantly impacts the project, with a 30% increase from the basic design to the RTA of IDR 734.64 billion. However, Monte Carlo simulations indicate the project still generates a positive NPV of IDR 198.76 billion at a 95% confidence level. The Monte Carlo simulation proved effective in capturing the complexity of risk variable interactions with the highest correlation (0.88) between delay and IDC and (0.78) between delay and land acquisition costs.

1. Introduction

The development of transportation infrastructure plays a strategic role in supporting national economic growth and enhancing Indonesia's competitiveness in the era of global trade. Toll road infrastructure, as the backbone of the national transportation system, makes a significant contribution to logistics efficiency and interregional connectivity. In the context of industrialization and international trade, the need for an efficient and reliable transportation system has become increasingly urgent to ensure the smooth distribution of goods and services. Toll roads constitute a supporting infrastructure for vehicular transportation, enabling faster travel to destinations, with users required to pay a specified toll fee. The Government of Indonesia has allocated substantial infrastructure funding within the State Budget (APBN) to support the development of national toll roads. However, fiscal limitations necessitate alternative financing schemes through cooperation with business entities. This approach aligns with the government's efforts to optimize resource utilization and enhance the effectiveness of infrastructure development. In such partnerships, the government may provide support to business entities while adhering to principles of financial risk management and control within the State Budget [14]. Within the framework of Public-Private Partnerships (PPP), agreements are implemented under a Build-Operate-Transfer (BOT) scheme, whereby the private entity is responsible for financing the construction, operation, and maintenance of the toll road, in exchange for concession rights granted in accordance with the agreement. A toll road concession refers to a specified period granted to the business entity to recover investment costs and obtain a reasonable return on toll road operations (Minister of Public Works Regulation No. 6, 2023). Determining the concession period requires both financial and technical analyses, influenced by several factors such as construction costs, maintenance costs, operational costs, and projected traffic volumes to estimate revenue streams.

Patimban Port holds a strategic position as an international hub port designed to serve industrial areas in West Java and its surrounding regions. As part of efforts to decentralize port activities from Tanjung Priok Port, Patimban Port is expected to reduce the burden on the main port while simultaneously increasing the capacity of national port services. The government plans to enhance connectivity to Patimban Port through the development of the Patimban Access Toll Road, which is included in the National Strategic Projects (PSN) and aims to optimize the distribution of goods for both export and import activities. The development of the Patimban Access Toll Road is implemented through a Public-Private Partnership (PPP) between the Government (Toll Road Regulatory Agency) and PT Jasamarga Akses Patimban. Based on the Business Plan, the total investment amounts to IDR 5.026 trillion. The toll road connects the Cikopo–Palimanan Toll Road to Patimban Port, spanning 37.05 km and located in Subang Regency, West Java Province. The government provides support in the form of partial construction through Viability Gap Funding (VGF) covering 22.94 km, while the Toll Road Business Entity (BUJT) is responsible for constructing the remaining 14.11 km, and illustrated in Figure 1 below.

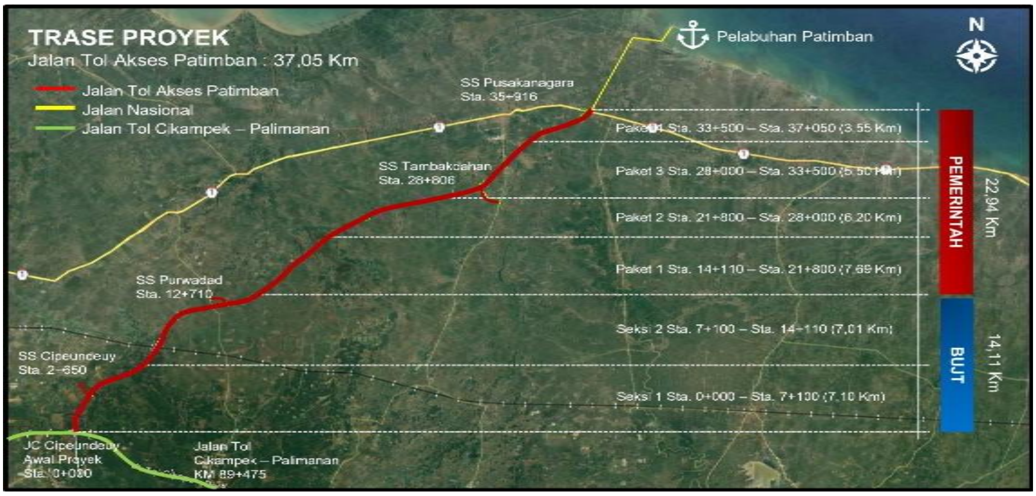

Figure 1. Patimban Access Toll Road Map

The Toll Road Concession Agreement (PPJT) for the Patimban Access Toll Road requires the business entity to undertake the construction and operation of the toll road. This obligation encompasses a range of agreed-upon scopes of work, including the development of non-toll access roads as part of regional connectivity, as well as the construction of Rest and Service Areas (RSAs) to support operational functions and enhance user convenience. These provisions constitute an integral part of the transportation infrastructure management strategy aimed at improving accessibility and fostering economic growth in the surrounding regions. Several risks may affect the feasibility level of toll road operations, such as increased construction costs resulting from the fulfillment of technical requirements and changes in the construction schedule. These technical requirements were identified during the preparation of the Final Engineering Design (FED) documents and must be accommodated, as certain aspects of the Basic Design were found to be inconsistent with actual field conditions. These adjustments occurred in the following construction work items in Tabel 1.

The construction cost in the initial investment amounted to IDR 2,452,549,055,529.81, and the increase in construction costs due to adjustments to technical requirements reached IDR 734,635,842,983. The detailed breakdown of the cost increases by work items is presented in Table 2.

Table 1. Changes In Construction Work Items

No.	Item	Increase (Rp)
1	Changes in structural type from Stations 7+100 to 8+200 (KAI, East Tarum, and high embankments on soft soil).	212.369.400.587,39
2	Addition of Crossing Building.	57.907.801.721,21
3	Junction Structures.	173.953.768.124,83
4	Earthwork.	(154.459.243.057,71)
5	Soft Soil Handling.	444.864.115.607,30
Total		734.635.842.983

Table 2. Increase In Construction Costs

No.	Description	Basic Design	RTA
1	[1] Changes in the structure type from Station 7+100 to Station 8+200.	2 bridges with bridge lengths of 80m and 85m.	1 bridge with a length of 1.1 km.
2	Addition of Crossing Building.	• 2 bridges • 10 overpasses • 1 box underpass	• 3 bridges • 11 overpasses • 2 box underpasses
3	Change in Length of Junction Structure.	The length of the bridge on each ramp is a total of 545m.	The bridge length on each ramp is a total of 701m with ground handling.
4	Reduction in Earthwork Volume due to the addition of bridge structures.	Earthwork volume 2,712,825.554 m3.	Earthwork volume: 2,073,987.799 m3.
5	Soft Soil Handling.	-	Addition of a slab-on-pile structure (bridge) to handle soft soil.

Therefore, this study addresses the issue of the impact of increased construction costs and schedule changes on the development of the Patimban Access Toll Road, which will be further examined. Through this research, the authors aim to fill this gap by conducting a financial feasibility study of a toll road project that considers cost dynamics and construction schedules. This research will utilize the NPV and IRR methods, complemented by sensitivity analysis, to provide a more realistic and in-depth picture for BUJTs in making investment decisions.

2. Method

2.1 Research Type

This study applies financial analysis to toll road investment using an exploratory and descriptive approach. Financial analysis fundamentally involves the evaluation of cash flows, including both inflows and outflows associated with an investment. The exploratory and descriptive methods are employed to understand and identify potential risks occurring during the pre-construction, construction, and operational phases of the Patimban Access Toll Road project.

2.2 Research Framework

This study aims to obtain the results of an investment feasibility analysis of the toll road project in response to the risks of increased construction costs and changes in the construction schedule of the Patimban Access Toll Road.

2.3 Research Data

This study utilizes secondary data to conduct financial analysis aimed at determining the feasibility level of the investment. The data include the following:

a. Financial and cost data:
- Initial Business Plan
- Construction Cost Increase Data Due to Technical Changes

b. Construction Technical Data:
- Basic Design Document
- Final Engineering Plan Document
- Changes in Construction Scope

c. Macroeconomic Data:
- Inflation Rate: Historical data and BI projections
- Interest rates: Risk-free rate and cost of capital
- Economic Growth: Regional and national GDP

d. Land Acquisition Data
- Land Acquisition Planning Document (DPPT)
- Land Acquisition Cost Realization
- Land Acquisition Progress per Section

2.4 Financial Aspect Analysis

The financial analysis is conducted based on the collected investment data of the Patimban Access Toll Road Project. This analysis involves the preparation of projected cash flows, including both cash inflows and outflows. The steps for preparing the financial cash flow analysis during the concession period are as follows:

- Estimating toll road revenue during the concession period;
- Incorporating construction costs, as well as operation and maintenance costs throughout the concession period;
- Calculating depreciation of the toll road infrastructure;
- Determining earnings before interest and taxes (EBIT) by deducting operational, maintenance, and depreciation costs from revenue;
- Calculating interest expenses from obtained loans;
- Determining earnings before tax (EBT) by deducting interest expenses from EBIT;
- Calculating annual income tax during the concession or operational period;
- Constructing financial cash flow by adding net income after tax to depreciation;
- Calculating total cash inflows and outflows for financial analysis;
- Evaluating investment feasibility after completing the cash flow analysis;
- Assessing the investment using parameters such as Payback Period (PP), Net Present Value (NPV), and Internal Rate of Return (IRR);
- Determining project feasibility based on established criteria.

2.5 Sensitivity Analysis and Scenario Analysis

Scenario analysis is a forecasting method in which experts present their views on current and future opportunities, while identifying key trends and challenges [4]. By evaluating various strategic alternatives and testing existing assumptions and practices, integrated scenarios can be developed. In this context, the identification of key factors is conducted to determine the most appropriate scenario for the Patimban Access Toll Road project. This analysis also aims to identify optimal solutions or strategies to improve project feasibility and ensure its implementation, as well as to understand the financial impact of the selected scenario. The scenarios considered are as follows:

- Scenario A: Reduction in construction costs of non-toll access roads;
- Scenario B: Reduction in construction costs of Rest and Service Areas (RSAs);
- Scenario C: Increase in toll tariffs;
- Scenario D: Combination of reductions in construction costs (non-toll access roads and RSAs) and an increase in toll tariffs.

Sensitivity analysis is conducted by systematically varying key economic parameters. These parameters, such as inflation rate, interest rate, and discount rate, are adjusted for each potential business scenario. The financial feasibility parameters for each scenario are calculated using the following equation. Calculating the Net Present Value (NPV) by incorporating the relevant parameters for each scenario.

$$\text{NPV} = \frac{\text{Rt}}{(1+i)t} - R_0 \tag{1}$$

Description:
NPV = Net Present Value
Rt = Net cash flow at time *t*
R0 = Initial investment
i = Discount rate
t = Time period of the cash flow

The Internal Rate of Return (IRR) is defined as the discount rate that makes the NPV equal to zero. The Payback Period (PP) is used to measure the time required to recover the initial investment and to determine **project** feasibility. Through this approach, the extent to which changes in these parameters affect the results of the financial feasibility analysis can be assessed. Comparing these results provides a clearer understanding of the risks faced by the project and assists decision-makers in making more rational investment decisions.

3. Results and Discussion

3.1 Financial Feasibility Considering Risk

The baseline financial feasibility evaluation was conducted as an initial step to understand the fundamental economics of the project under normal conditions, without taking realized risks into account. The Net Present Value (NPV) was calculated using a Weighted Average Cost of Capital (WACC) of 10.26%, reflecting a blended cost from a financing structure of 30% equity and 70% debt. This WACC accounts for the country risk premium, sector risk premium, and project-specific risk premium, in accordance with the characteristics of infrastructure projects in Indonesia. Cash flow projections were developed based on a revenue model considering a 7-year ramp-up period, a 20-year stable period, and a 15-year mature period during the final years of the concession.

The Internal Rate of Return (IRR) was determined using an iterative approach to identify the discount rate that yields an NPV of zero. This calculation includes all project cash flows, from the initial investment to the terminal value at the end of the concession period. The Payback Period (PP) was calculated both as simple (undiscounted) and discounted, providing a comprehensive view of the capital recovery timeline. The Profitability Index (PI) was calculated as the ratio of the present value of future cash flows to the initial investment. This indicator provides information on value creation per unit of investment, which is important for comparison with alternative investments of different scales. The baseline financial feasibility analysis indicates that the Patimban Access Toll Road project is financially viable, in Table 3.

Table 3. Baseline Financial Feasibility Indicators

No	Parameter	value	Feasible criteria	Status
1	NPV	Rp 1.250,35 Billion	> 0	feasible
2	IRR	12,85%	> WACC (10,26%)	feasible
3	Payback Period	15,5 year	< 20 year	feasible
4	PI	1,25	> 1	feasible

Source: Author's Processed Results

These results indicate that, under normal conditions without realized risks, the project generates positive economic value for investors/shareholders. Optimal Financing Structure, the financing structure analysis indicates the optimal composition as follows:

Table 4. Project Financing Structure

No	Component	Value (Rp Billion)	Percentage	*Cost of Capital*
1	Equity	1.518,60	30%	15%
2	Debt	3.543,40	70%	9%
3	Total	5.062,00	100%	WACC: 10,26%
4	PI	1,25	> 1	feasible

This structure reflects a balance between:

- Minimizing the cost of capital through leverage;
- Maintaining a healthy debt service coverage ratio (DSCR);
- Meeting lenders' requirements for the debt-to-equity ratio.

3.2 Risk of Increased Construction Costs

Identification of Cost Increase Sources

A detailed analysis of the changes from the Basic Design to the Final Engineering Design (FED) documents reveals the complexity factors contributing to the increase in construction costs. Based on the evaluation of changes from Basic Design to the FED, the sources of cost increases include:

Table 5. Analysis of Construction Cost Increase Sources

No	Category	Contribution to Increase	The main cause
1	Earthworks	35%	Soil conditions differ from initial assumptions.
2	Bridge Structures	25%	Addition of bridge structure.
3	Pavement	15%	Improved specifications.
4	Drainage	20%	Adaptation to hydrological conditions.
5	Miscellaneous	5%	Additional road equipment.

3.3 Monte Carlo Simulation for Cost Risk

The Monte Carlo Simulation for cost risk analysis was implemented using a robust methodology with careful consideration of probability distributions and correlations among variables. The process began with a historical data analysis of 25 toll road projects in Indonesia from 2015 to 2023 to derive appropriate probability distributions for each cost component. The Monte Carlo Simulation was implemented using Microsoft Excel integrated with simulation tools such as @RISK. Each cost variable was modeled using a normal distribution based on historical data, and correlations among variables were incorporated through a correlation matrix. The simulation was executed with 10,000 iterations, where random values were generated for each parameter and aggregated to estimate total project cost variability. The software enabled statistical analysis of outputs, including probability distributions, confidence intervals, and sensitivity analysis. The Monte Carlo Simulation was conducted using the following parameters:

Table 6. Monte Carlo Simulation Parameters – Cost Risk

No	Parameter	Distribution	Mean	Std Dev	Min	Max
1	Land Cost Increase	Normal	20%	5%	10%	30%
2	Cost Structure Increase	Normal	15%	3%	10%	25%
3	Pavement Cost Increase	Normal	10%	2%	5%	15%
4	Drainage Fee Increase	Normal	20%	4%	12%	28%

The simulation results (10,000 iterations) are as follows:

Table 7. Monte Carlo Simulation Results – NPV

No	Percentile	NPV (Rp Billion)	Probability NPV > 0
1	P10	325,42	92%
2	P25	568,73	-
3	P50	845,28	-
4	P75	1.124,65	-
5	P90	1.356,89	

The simulation results indicate a positive and robust Net Present Value (NPV), with a 92% probability that NPV > 0, suggesting a solid project fundamental that is resilient to cost variations. The median NPV of

IDR 845.28 billion is lower than the deterministic baseline of IDR 1,250.35 billion, reflecting the impact of uncertainty and the right-skewed distribution of cost overruns. The NPV standard deviation of IDR 398.45 billion indicates moderate variability, which remains within an acceptable range for infrastructure projects.

3.4 Value at Risk (VaR) Analysis

The Value at Risk (VaR) analysis provides a directly relevant risk metric for investment decision-making by quantifying potential losses at a specified confidence level. The VaR methodology employed uses a historical simulation approach, which does not require assumptions about return distributions, making it more robust for infrastructure investments with non-normal return patterns. VaR was calculated at multiple confidence levels to accommodate differing risk appetites among stakeholders. For conservative investors (pension funds, insurance companies), the 99% VaR represents a near-worst-case scenario. For moderate-risk investors (infrastructure funds), the 95% VaR is more relevant. For aggressive investors (private equity), 90% VaR is sufficient. Conditional Value at Risk (CVaR), or Expected Shortfall, was also calculated to provide information on the average loss exceeding the VaR threshold. This is particularly important for infrastructure projects where tail risks can be severe. CVaR calculations were based on the empirical distribution derived from Monte Carlo simulation results for accuracy.

Table 8. Value at Risk – Cost Increase

No	Confidence Level	VaR (Rp Billion)	Interpretation
1	90%	325,42	There is a 90% chance that the NPV will be at least IDR 325.42 billion.
2	95%	198,76	There is a 95% chance that the NPV will be at least IDR 198.76 billion.
3	99%	-45,23	There is a 1% chance of negative NPV.

The analysis indicates that even at a 95% confidence level, the project still generates a positive NPV of IDR 198.76 billion. Only in extreme scenarios (1% probability) does the project have the potential to yield a negative NPV. This provides strong assurance to investors regarding the resilience of the project. The 95% Conditional Value at Risk (CVaR) of IDR 87.34 billion indicates that even in the worst 5% of scenarios, the average loss remains limited.

3.5 Component Sensitivity Analysis

A one-way sensitivity analysis was conducted to identify the most critical cost components that require focused management attention. This methodology involves varying each cost component by ±20% from the base value while keeping other variables constant and then measuring the impact on key financial metrics (NPV and IRR). Elasticity calculations provide a standardized measure of sensitivity that can be compared across variables. Elasticity is defined as the percentage change in output divided by the percentage change in input. An elasticity greater than 1 indicates high sensitivity, warranting priority attention in risk management.

Table 9. NPV Sensitivity to Cost Components

No	Component	1% change	NPV Impact (Rp Billion)	Elasticity
1	Construction Costs	1%	-35,24	-2,82%
2	Land Cost	1%	-28,45	-2,28%
3	IDC	1%	-8,76	-0,70%
4	*Contingency*	1%	-4,52	-0,36%

The analysis revealed that construction costs have the highest elasticity of -2.82, meaning that a 1% increase in construction costs resulted in a 2.82% decrease in NPV. This underscores the critical importance of construction cost management. Land acquisition costs also exhibit high elasticity at -2.28, highlighting the need for careful management in the land compensation process. Interest During Construction (IDC) and contingency costs have lower elasticity, indicating that these components are less critical to the overall project economics.

3.6 Risk of Construction Schedule Changes

A comprehensive analysis of delay factors was conducted through an extensive literature review of previous construction studies and project reports, as recommended by [13]. The identified risks were then evaluated using a probability–impact matrix approach in accordance with guidelines from the Project Management Institute [19].

Table 10. Analysis of Risks Related to Construction Schedule Changes

No	Factor	Probability	Impact (month)	Risk Score
1	Land Acquisition	70%	6-12	High
2	Licensing	40%	3-6	Medium
3	Extreme Weather	30%	2-4	Low
4	Design Changes	50%	3-9	High
5	Material Availability	20%	1-3	Low

Risk assessment using a probability–impact matrix indicates that land acquisition and design changes are high-risk items requiring focused mitigation strategies. Weather-related delays, although less probable, can have a cascading effect if they coincide with critical activities. Material availability is generally low risk, except for specialized items such as prestressed concrete girders for bridge elements, which require long lead times.

3.7 Financial Impact of Delays

The financial impact analysis of delays goes beyond simple Interest During Construction (IDC) calculations to capture the full economic consequences. The methodology involves integrated financial modeling that accounts for both direct costs (additional IDC, extend. ed preliminary costs, escalation) and indirect costs (delayed revenue, lost market opportunities, reputational impacts). Interest During Construction (IDC) increases linearly with the duration of the delay, calculated monthly based on the weighted average construction loan interest rate. With an outstanding construction loan of IDR 3,543.4 billion and an annual interest rate of 9%, each month of delay adds IDR 26.58 billion in IDC. However, the actual impact is more complex due to the drawdown schedule and the effect of compound interest.

Extended preliminary costs include ongoing project management, supervision, insurance, and security expenses during the delay period. Project data indicate an average preliminary cost of IDR 8.5 billion per month. These costs are often overlooked in traditional delay analyses but can accumulate significantly for prolonged delays. Revenue delay impacts are calculated using discounted cash flow analysis. Each month of delay pushes the entire revenue stream backward, resulting in a present value loss. With a projected first-year revenue of IDR 341.78 billion and a discount rate of 10.26%, the cost of delayed revenue is approximately IDR 28.5 billion per month of delay. This often exceeds direct IDC costs, highlighting the importance of time-to-market in toll road economics. Escalation effects apply to the remaining construction costs. With an annual inflation rate of 3% and construction cost escalation typically 1.5 times inflation, the remaining work is subject to a 4.5% annual escalation. For 50% of the remaining work, a 9-month delay results in additional escalation costs of IDR 52.8 billion.

Table 11. Impact of Delays on Financial Indicators

No	Delay	NPV (Rp Billion)	IRR (%)	Payback (year)	Additional IDC (Rp Billion)
1	0 month	1.250,35	12,85	15,5	-
2	3 months	1.125,42	12,53	15,9	79,24
3	6 months	998,67	12,18	16,3	158,47
4	9 months	869,34	11,82	16,8	237,71
5	12 months	738,56	11,45	17,3	316,94

3.8 Probabilistic Delay Simulation

Probabilistic schedule analysis using the Program Evaluation and Review Technique (PERT), enhanced with Monte Carlo simulation, provides a more realistic estimate of project duration compared to deterministic CPM. Three-point estimates (optimistic, most likely, pessimistic) were collected for each activity based on expert judgment and historical data. Probability distributions for activity durations were selected based on the characteristics of each activity. Normal distributions were applied to routine activities with well-understood scope. Beta distributions were used for activities with natural bounds and skewness.

Triangular distributions were applied to activities with limited historical data. A correlation matrix was developed to capture dependencies between related activities.

Simulation results from 10,000 iterations indicate an expected project duration of 39.5 months, compared to a deterministic estimate of 36 months. A standard deviation of 2.8 months indicates moderate schedule uncertainty. The P80 duration (80% probability of completion) is 42 months, providing a 6-month buffer suitable for realistic planning. Schedule risk drivers were identified through sensitivity analysis of the simulation results. The top contributors to schedule variance are: (1) Section I land acquisition (35% of variance), (2) Main bridge construction (25%), (3) System integration (15%), (4) Authority approvals (10%), and (5) Weather delays (8%). This provides clear prioritization for risk mitigation efforts.

Table 12. Impact of Work Delays

No	Scenario	Probability	Expected Delay	Expected Impact NPV
1	On Schedule	20%	0 month	-
2	Minor Delay	40%	3-6 months	-Rp 187,93 billion
3	Moderate Delay	30%	7-9 months	-Rp 342,65 billion
4	Major Delay	10%	> 12 months	-Rp 511,79 billion

Expected value calculations indicate a probability-weighted average delay of 5.4 months, with a corresponding NPV impact of -IDR 235.67 billion. This represents a realistic expectation of project outcomes and should be incorporated into investment decisions. Risk-adjusted project returns must reflect the anticipated impact of such delays.

3.9 Integrated Cost and Schedule Risk Analysis

Integrated risk analysis is a comprehensive approach that acknowledges that cost and schedule risks do not operate independently but interact in complex patterns, often amplifying each other's negative effects. A deep understanding of these interactions is critical for developing effective and realistic mitigation strategies. In the context of the Patimban Access Toll Road project, the interaction mechanisms between cost and schedule risks manifest in several ways. First, project execution delays directly increase costs through the accumulation of Interest During Construction (IDC), calculated based on the outstanding loan balance and the duration of the delay. Second, delayed construction activities are exposed to material and labor cost escalation, which typically exceeds general inflation. Third, project duration extensions require extended preliminary costs, such as ongoing project management, supervision, insurance, and security expenses during the delay period. A combined risk matrix was constructed through a systematic analysis testing various combinations of cost increases (0%, 10%, 20%, 30%) against delay durations (0, 6, 9, 12 months). Each cell in the matrix represents a specific scenario, with NPV calculations incorporating the full financial impact of the combined risks. This approach provides a clear visualization of how project economics deteriorate non-linearly when multiple risks materialize simultaneously.

Table 13. Combined Risk Impact Matrix

No	Cost Increase/Delay	0 Month	6 Month	9 Month	12 Month
1	Baseline (0%)	1.250,35	998,67	869,34	738,56
2	+10%	902,35	685,42	578,93	465,78
3	+20%	554,35	372,17	288,52	192,99
4	+30%	206,35	58,92	-1,89	-79,78

Matrix analysis reveals several critical insights. First, the impact of combined risks is super-additive—the losses from combined risks exceed the simple sum of individual impacts. Second, a "cliff effect" occurs where a cost increases greater than 20% combined with a delay exceeding 9 months pushes the project into a negative NPV zone. Third, project resilience declines sharply as risks accumulate, indicated by the accelerated NPV reduction in the lower-right quadrant of the matrix.

3.10 Integrated Monte Carlo Simulation

Integrated Monte Carlo simulation represents the state-of-the-art approach in infrastructure project risk analysis, enabling a comprehensive evaluation that accounts for the full complexity of uncertainty, correlations, and non-linear interactions. Compared to deterministic or simple sensitivity analyses, this approach produces a complete distribution of possible outcomes, providing decision-makers with richer information on the project's risk–return profile. The simulation model architecture was designed with careful attention to mathematical rigor and computational efficiency. A full financial model with 45 years of projected cash flows was coded with flexibility to accept random samples from probability distributions for each uncertain variable. The simulation engine employs Latin Hypercube Sampling, which is more efficient than traditional Monte Carlo methods, achieving convergence with fewer iterations. The model calibration process involved extensive validation to ensure realistic and reliable results. Probability distribution parameters were derived from a combination of historical data analysis and expert elicitation using structured protocols. Back-testing with completed project data confirmed the model's ability to reproduce observed outcomes. Sensitivity analysis of distribution assumptions demonstrated the robustness of results against reasonable variations in input parameters.

Table 14. Integrated Simulation Parameters

No	Variables	Distribution	Parameter	Correlation
1	Total Cost Increase	Lognormal	μ=15%, σ=5%	-
2	Delay	Triangular	Min=0, Mode=6, Max=12	0,42 with fees
3	Inflation	Normal	μ=3%, σ=0,5%	0,25 with fees
4	Traffic Growth	Normal	μ=5%, σ=1%	-0,15 with fees

The simulation execution with 10,000 iterations produced a comprehensive risk profile for the project. Each iteration represents a possible future scenario, with aggregated results providing a probabilistic view of project outcomes. Convergence diagnostics indicate that results stabilize after approximately 7,500 iterations, providing confidence in the reliability of the findings.

Table 15. Integrated Monte Carlo Simulation Results (10,000 iterations)

No	Indicator	Mean	Std Dev	P10	P50	P90
1	NPV (Rp Billion)	652,34	342,56	187,45	634,28	1.145,67
2	IRR (%)	11,34	1,25	9,76	11,28	12,95
3	Payback (year)	17,2	2,3	14,5	17,1	20,2

The interpretation of the integrated simulation results provides valuable insights for investment decision-making. The expected NPV is IDR 652.34 billion, which, although lower than the deterministic baseline, still indicates strong positive value creation. The NPV distribution shows a 90% confidence interval ranging from IDR 187.45 billion to IDR 1,145.67 billion, reflecting substantial upside potential with manageable downside. The moderate standard deviation suggests that the uncertainty, while present, remains within acceptable bounds for infrastructure investment.

3.11 Economic and Social Feasibility Analysis

Economic analysis of public infrastructure projects requires a broader perspective than private financial analysis, incorporating all costs and benefits to society regardless of who bears the costs or receives the benefits. The Economic Internal Rate of Return (EIRR) is a key indicator that measures the project's return from the national economic perspective, providing a basis to evaluate whether allocating scarce resources to this project is justified from a social welfare standpoint. The EIRR calculation methodology follows international guidelines adapted to the Indonesian context. The first step involves converting financial prices to economic prices through shadow price adjustments. Taxes and subsidies, considered transfer payments from a national economic perspective, are excluded. Labor costs are adjusted to reflect opportunity costs, using a factor of 0.85 considering unemployment and underemployment rates. A 10% foreign exchange premium is applied to imported components to reflect the scarcity value of foreign currency.

Identification and quantification of economic benefits require in-depth analysis of various project impacts. Vehicle Operating Cost (VOC) savings are calculated using the HDM-4 model calibrated for Indonesia, accounting for fuel, maintenance, tire wear, and vehicle depreciation due to road improvements. Travel Time Savings (VOT) are estimated from stated preference surveys, differentiating between business travel (valued at average wage rates) and recreational travel (valued at 30% of the wage rate). Accident cost reductions are calculated using a statistical value of life of IDR 2.5 billion, with proportional values for injuries. Environmental benefits include reduced emissions from smoother traffic flow and shorter travel distances. Carbon emission reductions are monetized using a social cost of carbon of USD 50/ton CO_2. Local air pollution reductions ($PM_{2.5}$, NO_x) are valued using a damage-cost approach based on health impact studies. Noise reduction benefits, though harder to quantify, are estimated using hedonic pricing studies reflecting the impact of traffic noise on property values. The EIRR analysis considers these broader economic benefits.

Table 16. Components of Economic Analysis

No	Component	Value	Information
1	Vehicle Operating Cost (VOC) Savings	Rp 125 billion/year	Vehicle Operating Cost savings
2	Time Saving	Rp 85 billion/year	Value of Time savings
3	Accident Reduction	Rp 15 billion/year	Accident cost reduction
4	Environmental Benefits	Rp 10 billion/year	Emission reduction
	Total Economic Benefit	**Rp 235 billion/year**	

EIRR Analysis Results:
EIRR = 15,67%
Economic NPV = Rp 2.845,32 Billion
Economic B/C Ration = 1,82

The analysis results indicate a strong economic case for the project, with an EIRR of 15.67%, significantly exceeding the social discount rate of 10%. The economic NPV, more than double the financial NPV, suggests substantial positive externalities that cannot be captured by private investors. This provides a strong justification for government support through VGF and risk-sharing mechanisms. The economic B/C ratio of 1.82 indicates that every rupiah invested generates nearly twice the economic benefits.

4. Conclusion

Based on a comprehensive analysis of the investment feasibility of the Patimban Access Toll Road, considering construction cost escalation and schedule changes, it can be concluded that the project demonstrates strong financial feasibility under normal conditions, with an NPV of IDR 1,250.35 billion, an IRR of 12.85% (exceeding the WACC of 10.26%), and a payback period of 15.5 years.

Construction cost escalation represents a significant risk, with a 30% increase from the basic design to the RTA amounting to IDR 734.64 billion. Nevertheless, Monte Carlo simulations indicate that the project remains financially viable, yielding a positive NPV of IDR 198.76 billion at a 95% confidence level. Schedule delays have a material impact through increased IDC (IDR 26.58 billion per month) and postponed revenue (IDR 28.5 billion per month), with delays of 9–12 months reducing NPV to IDR 869.34–738.56 billion. The interaction between cost escalation and schedule delay exhibits a super-additive effect, with a "cliff effect" observed when cost increases exceed 20% and delays surpass 9 months, potentially driving the project into negative NPV territory. From a national economic perspective, the project remains highly viable, as indicated by an EIRR of 15.67%, an Economic NPV of IDR 2,845.32 billion, and a B/C ratio of 1.82. The Monte Carlo simulation approach effectively captures the interaction between risk variables, highlighting strong correlations between delays and IDC (0.88) and between delays and land acquisition costs (0.78).

These findings suggest that project stakeholders should prioritize integrated risk management strategies, particularly in controlling land acquisition timelines and construction scheduling. Early intervention in high-risk phases, stricter cost control mechanisms, and proactive mitigation of delays are critical to avoiding the identified "cliff effect." In addition, the results support the adoption of probabilistic planning tools, such as Monte Carlo simulation, in large-scale infrastructure projects to improve decision-making under uncertainty. Policymakers and investors should also consider implementing contingency buffers and adaptive financing schemes to enhance project resilience against combined cost and schedule risks.

Future research should extend this study by incorporating dynamic and real-time data integration, enabling continuous updating of risk profiles throughout the project lifecycle. Further studies could also explore multi-project or network-level risk interactions, particularly for interconnected infrastructure systems. In addition, integrating advanced methods such as machine learning for risk prediction or system dynamics modelling could improve the accuracy of forecasting complex dependencies between variables. Finally, comparative studies across similar toll road projects would help validate the generalizability of the findings and refine risk thresholds such as the identified cost-delay "cliff effect."

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