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Investment Decision on the Serang–Panimbang Toll Road Project, Taking into Account the Phased Operation of the Toll Road

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Abstract

The Serang–Panimbang Toll Road is a National Strategic Project (PSN) developed to support the Tanjung Lesung Special Economic Zone (SEZ) and consists of three sections. Changes in design scope, prolonged approval processes, and delays in land acquisition necessitated a reassessment of the investment under a phased toll road operation scheme. The investment reassessment determines the critical investment decision threshold when the toll road operates in stages. The base case calculation was conducted using Discounted Cash Flow (DCF) with Weighted Average Cost of Capital (WACC) of 13.55% and a 50-year concession period (2019–2069). Net Present Value (NPV) was used as the primary investment decision parameter. Deterministic sensitivity analysis was applied to identify critical turning points, while stochastic sensitivity analysis was conducted using the Monte Carlo method with Crystal Ball through 10,000 trials. The base case yields NPV of IDR 399,084 million, IRR of 13.96%, Discounted Payback Period of 45 years, and Profitability Index of 1.05. Deterministic analysis identifies the most influential variables as toll tariff and construction Capex, with Section 1 operable no later than 2023, Section 2 by 2024, and Section 3 by 2038. The stochastic Monte Carlo simulation reveals an extreme financial risk profile, with a mean NPV of IDR −1,203,368 million and only 468 of 10,000 trials (4.68%) producing NPV ≥ 0. The investment decision probability boundary ranges from 4.20% to 4.68%.

INTRODUCTION

Investment decisions in infrastructure projects are fundamentally strategic economic decisions intended to create productive assets that generate future financial benefits (Caldecott et al., 2026; Hajkowicz, 2025; Mahmood et al., 2025; Moshood et al., 2023; Olanrewaju et al., 2024). The core considerations include the costs incurred, expected return on investment, and associated risks (Piante, 2014). Investment analysis provides the analytical foundation for decision-making, drawing on commercial, technical, environmental, economic, financial, and social dimensions. Yet such analyses are frequently challenged by return-on-investment risks, cost escalation, shifting economic conditions, and regulatory changes (Valencia et al., 2020).

The Serang–Panimbang Toll Road is a National Strategic Project (PSN) under Presidential Regulation No. 3 of 2016 that serves as critical infrastructure to support the Tanjung Lesung Special Economic Zone (KEK Tanjung Lesung), established by Government Regulation No. 26 of 2012. The KEK spans 1,500 hectares in Panimbang District, Pandeglang Regency, Banten Province, and aims to accelerate regional and national economic development through tourism promotion (PP No. 26, 2012). The toll road is operated by PT Wijaya Karya

Serang Panimbang (PT WSP), a consortium comprising PT Wijaya Karya (Persero) Tbk (80%), PT Pembangunan Perumahan (Persero) Tbk (15%), and PT Jababeka Infrastruktur (5%), under the Toll Road Concession Agreement (PPJT) signed in December 2016 (Laporan Monitoring dan Evaluasi, 2024).

The toll road spans 83.677 km and is divided into three sections: Section 1 (Serang–Rangkasbitung, 26.950 km), Section 2 (Rangkasbitung–Bojong, 32.313 km), and Section 3 (Bojong–Panimbang, 24.414 km). The PPJT set a full operation target of 2019. However, significant changes in design scope, delayed design approvals, and land acquisition delays resulted in operational postponement. Section 1 commenced operation in 2022, while Sections 2 and 3 remained under construction. By 2023, Section 1 recorded actual ADT of 11,360 vehicles (61.03% of the initial investment analysis projection).

The original PPJT parameters included: Class I tariff of IDR 1,000/km, initial ADT of 6,823 vehicles/day, total investment of IDR 5.329 trillion, loan interest rate of 10.52%/year, NPV of IDR 531,699 million, IRR of 13.96%, payback period of 17 years, and PI of 1.10, under a 40-year concession from August 2019 (BA Nego PPJT, 2016). Cost overruns due to design changes and cost escalation necessitated comprehensive investment reassessment, with the requirement that the IRR on project must remain unchanged at 13.96%.

This study reassesses the investment decision under the phased operational scheme, with the analysis perspective set at Year 2021 (prior to the revised business plan), applying both deterministic and stochastic (Monte Carlo) sensitivity analyses. The research objectives are: (1) to determine the investment decision thresholds under phased toll road operation; and (2) to identify the sensitivity ranking of investment variables affecting NPV. Such analysis is essential for risk mitigation as NPV is the primary capital budgeting criterion (Sokolov, 2024; Chandra Sekhar, 2026).

The novelty of this research lies in its integrated application of deterministic and Monte Carlo stochastic sensitivity analyses to a specific National Strategic Project under phased operational conditions. Unlike previous studies that have used either deterministic or probabilistic methods in isolation, this research combines both approaches to provide a comprehensive assessment of investment viability. The research also contributes by identifying the probability boundary for investment decisions, expressed as the probability of NPV ≥ 0, which provides a more intuitive risk metric for decision-makers compared to traditional sensitivity analysis.

METHOD

Research Design

This study employed a quantitative, verificative, and evaluative research approach. It is verificative in comparing the initial and revised investment analyses, and evaluative in providing corrective recommendations for the investment conditions. The quantitative approach generates statistical probabilistic data values as investment parameter outputs. Analysis is conducted using Microsoft Excel for capital budgeting computations and Crystal Ball (an Excel add-in) for Monte Carlo stochastic simulation (Parikesit et al., 2025).

Research Object and Data

The research object is the Serang–Panimbang Toll Road investment. Data are sourced from PT WSP as the toll road business entity. Some data use approximation approaches due to the confidential nature of proprietary company data, while maintaining the same directional trends as actual data. The investment analysis assumes Year 2021 conditions before the revised business plan submission when the toll road had not yet fully commenced operations. Technical specifications of the toll road are presented in Table 1.

Table 1. Technical Data of Serang–Panimbang Toll Road

Technical Data	**Description**
Main Road Lanes (Initial)	2 × 2 lanes @ 3.6 m width
Main Road Lanes (Final)	2 × 3 lanes @ 3.6 m width
Outer Shoulder (Main Road)	3.0 m
Inner Shoulder (Main Road)	1.5 m
Median Width	0.8 m
Ramp Lane Width	4.0 m
Lane and Inner Shoulder Pavement Type	Rigid pavement
Outer Shoulder Pavement Type	Flexible pavement

Source: PT WSP Monitoring and Evaluation Report, June 2024

Table 2 presents the investment cost structure, converted from the original hierarchical diagram into tabular form for clarity. Table 3 presents the capital structure, converted from the original flow diagram.

Table 2. Investment Cost Structure of the Serang–Panimbang Toll Road Project (converted from structural diagram)

Cost Category	**Sub-Component**	**Notes**
Land Investment Cost Reimbursement	Reimbursement to Government	IDR 291 billion (2016 value)
Project Cost	Planning Cost (FS, AMDAL, DED)	IDR 81.585 billion
	Construction Cost	Includes road, bridges, toll facilities
	Supervision Cost (incl. PMI)	IDR 90.770 billion
	Equipment & Toll Operation	IDR 127.410 billion (closed system)
	Escalation Cost	CAGR index g = 1.56%
	Upfront Fee + PII + Government Guarantee + Overhead + VAT	Various rates
Financial Cost	Interest During Construction (IDC) + Financial Cost	Loan rate 10.52%/year

Source: Author's analysis

Table 3. Capital Structure of the Serang–Panimbang Toll Road (converted from capital structure diagram)

Source of Capital	**Scheme**	**Proportion / Composition**
Private (PT WSP)	Equity (30%)	WIKA 80% | PP 15% | Jababeka 5%
	Bank Loan / Debt (70%)	Syndicated loan from 6 banks
Government (VGF)	Viability Gap Fund	Construction support along 33 km (Sta 50+677 to Sta 83+677) including Section 3

Source: PT WSP PPJT documents and author's analysis

Research Variables

Research variables comprise investment cost, rate of return, concession period, and cash flows from operations. These variables generate the capital budgeting parameters: NPV, IRR, Discounted Payback Period (DPP), and Profitability Index (PI). Table 4 summarises the variable operationalisations.

Table 4. Research Variable Operationalisations

No.	Variable	Indicator	Scale	Method
1	Operational Revenue	Toll Revenue	Monetary	ADT projection × toll tariff
2	Investment Cost	Design, construction, supervision, land, interest, equipment	Monetary	Estimated cost projection per year
3	Rate of Return	Capital structure & WACC	Percentage	Based on equity and debt costs
4	Investment Period	Concession period	Years	As per PPJT agreement
5	Operational Cost	O&M Cost	Monetary	% of annual revenue

Source: Author's analysis

Discount Rate — Weighted Average Cost of Capital (WACC)

The WACC is calculated using the formula: WACC = (D/D+E)×Kd + (E/D+E)×Ke (Fernandes, 2014), where D = debt, E = equity, Kd = cost of debt, Ke = cost of equity. The capital structure is 30% equity and 70% debt. The WACC calculation is presented in Table 5.

Table 5. WACC Calculation of PT WSP

No.	Capital Source	Proportion	Rate / Margin	Weighted Coeff.	Source
1	Equity — WIKA	80%	14%	11.20%	Subjective
	Equity — PP	15%	14%	2.10%	Subjective
	Equity — Jababeka	5%	13%	0.65%	Subjective
	Ke (Cost of Equity)			**13.95%**	
2	Debt — Bank A	37.74%	10.95%	4.13%	SBDK OJK 2017
	Debt — Banks B–F	62.26%	12–19.26%	9.23%	SBDK OJK 2017
	Kd (Cost of Debt) / WACC	Debt 70%	Equity 30%	**Kd = 13.38%** **WACC = 13.55%**	

Source: Author's analysis; OJK Basic Lending Rates December 2017

Investment Parameter Equation

The primary parameter used to determine investment decision thresholds is Net Present Value (NPV), calculated as: NPV = Σ(Bt − Ct − It)/(1+i)^t, where I = invested capital, B = inflows over concession period, C = outflows over concession period, i = discount rate (WACC), and t = concession period (Sinaga & Risma, 2013). NPV is selected as the primary parameter because it directly represents the absolute economic value created by the project and incorporates the time value of money. The investment decision criterion is NPV ≥ 0 (Sokolov, 2024).

Deterministic Sensitivity Analysis

Deterministic analysis varies each input variable individually across five scenarios (Table 12) while holding all other variables at base case values. The NPV impact is plotted on a spider diagram (laba-laba chart). The critical turning point where NPV = 0 is interpolated from the linear equation of each sensitivity line. Sensitivity ranking is determined by the NPV range (NPV High − NPV Low) for each variable.

Table 6. Deterministic Sensitivity Scenarios

No.	Scenario	Change Applied
1	Very Low (VL)	−30% from Base Case
2	Low (L)	−15% from Base Case
3	Base Case (BC)	0% (reference point)
4	High (H)	+15% from Base Case
5	Very High (VH)	+30% from Base Case

Source: Author's analysis

The 12 input variables analysed are presented in Table 13. Each variable is selected for its direct impact on project cash flows: ADT and tariff affect revenue; operational year affects revenue commencement timing; construction cost and O&M ratio affect expenditure.

Table 7. Input Variables for Sensitivity Analysis

No.	Investment Variable	Cash Flow Position	Relation to NPV
1	Toll Tariff	Cash inflow	Positive — higher tariff → higher NPV
2–4	Initial ADT — Sections 1, 2, 3	Cash inflow	Positive — higher demand → higher NPV
5	Construction Capex	Cash outflow	Negative — higher cost → lower NPV
6	O&M Cost Ratio	Cash outflow	Negative — higher ratio → lower NPV
7–9	ADT Growth Rate — Sections 1, 2, 3	Cash inflow	Positive — higher growth → higher NPV
10–12	Operational Year — Sections 1, 2, 3	Cash inflow	Negative — later operation → lower NPV (delayed revenue)

Source: Author's analysis

Stochastic Monte Carlo Sensitivity Analysis

Monte Carlo simulation uses Crystal Ball with 10,000 trials to simultaneously vary all input variables according to their assigned probability distributions. This enables evaluation of the probability distribution of NPV outcomes and identification of variable sensitivity through a tornado chart. The investment decision boundary in the stochastic approach is expressed as the probability of NPV ≥ 0. Two distribution types were used: Triangular (for continuous variables with limited data, using minimum/most likely/maximum values) and Discrete Uniform (for the operational year variables, which are discrete integer values) (Clemen & Reilly, 2014; Hertz, 1964). The simulation uses 10,000 trials to achieve statistical accuracy on the order of approximately 1% for the Monte Carlo estimator, consistent with Graf & Korn (2020). The confidence level is set at 95% (Oracle, 2017). Table 16 presents the probability distribution assumptions for all 12 input variables.

Table 8. Probability Distribution Assumptions for Crystal Ball Input Variables

No.	Assumption Variable	Distribution	Parameters
1	Toll Tariff	Triangular	Min = IDR 965/km; Most Likely = IDR 1,162/km; Max = IDR 1,618/km
2	Construction Capex	Triangular	Min = 90%; Most Likely = 100%; Max = 110% of Base Case
3	O&M Cost Ratio	Triangular	Min = 20%; Most Likely = 30%; Max = 40% of revenue
4	Initial ADT — Section 1	Triangular	Min = 4,170; Most Likely = 8,339; Max = 10,424 vehicles/day
5	Initial ADT — Section 2	Triangular	Min = 3,221; Most Likely = 6,442; Max = 8,053 vehicles/day
6	Initial ADT — Section 3	Triangular	Min = 2,844; Most Likely = 5,688; Max = 7,110 vehicles/day
7–9	ADT Growth Rate — Sections 1, 2, 3	Triangular	Min = 70%; Most Likely = 85%; Max = 100% of Base Case (per section)
10	Operational Year — Section 1	Discrete Uniform	Min = 2021; Max = 2022
11	Operational Year — Section 2	Discrete Uniform	Min = 2023; Max = 2027
12	Operational Year — Section 3	Discrete Uniform	Min = 2023; Max = 2030

Source: Author's analysis based on project management discussions and consultant reports

RESULTS AND DISCUSSION

Investment Cost (Capital Expenditure — Capex)

Investment cost increased substantially from the original PPJT estimate. The primary driver was the revised construction cost which increased from IDR 3,568,944 million to IDR

5,637,938 million due to scope changes in the DED, route adjustments, and additional structures including 5 interchanges, 1 junction, 51 crossing structures, 18 bridges, and 24 frontage roads. Escalation is computed using CAGR of the Construction Cost Index (IKK) for Banten Province: IKK 2011 = 83.14, IKK 2020 = 97.05, yielding $g = (97.05/83.14)^{(1/10)} - 1 = 1.56\%$. Table 9 presents the full Capex summary.

Table 9. Resume of Investment Cost (Capex) — Base Case vs. PPJT Initial

No.	Description	PPJT 2017 (IDR million)	Base Case (IDR million)	Data Source
1	Planning Cost	81,585	81,585	Project data
2	Construction Cost	3,568,944	5,637,938	Project data
3	Toll Equipment & Facilities	138,270	127,410	Project data
4	Supervision + PMI Cost	50,206	90,770	Project data
5	Escalation Cost	150,319	300,535	Author analysis (CAGR g=1.56%)
6	VAT (10%)	416,216	623,824	Author analysis
7	Project Overhead (4.5% of construction)	172,837	253,707	Project owner (subjective)
8	Upfront Fee	8,100	8,100	Project data
9	Government Guarantee	7,599	7,599	Project data
10	PII Cost	12,050	12,050	Fixed IDR 1.6 billion/year × 15 years
Sub-Total		**4,595,463**	**7,143,518**	
11	Interest During Construction (IDC) — 10.52%/year	630,733	1,105,569	Project data
12	Financial Cost (0.375%)	103,702	39,410	Project data
Total Investment Cost		**5,329,898**	**8,288,497**	

Source: Author's analysis; PT WSP project data

Table 10 presents inflation data for Banten Province used in the calculation of toll tariff escalation. The average inflation rate of 4.67% is used for biennial tariff adjustments throughout the concession period.

Table 10. Banten Province Inflation Data (2009–2020) Used for Tariff Escalation

Year	Inflation Rate	Year	Inflation Rate
2009	2.86%	2015	4.29%
2010	6.10%	2016	2.94%
2011	3.45%	2017	3.98%
2012	4.37%	2018	3.42%
2013	9.65%	2019	3.30%
2014	10.20%	2020	1.45%

Source: Badan Pusat Statistik (BPS) Banten Province Inflation Data 2009–2020

The government guarantee costs to PT WSP under the PPJT, paid through PT Penjaminan Infrastruktur Indonesia (PII), cover risks including land acquisition delays, periodic tariff adjustment delays, legal changes, and project termination. These costs are incorporated into the Capex structure. Table 11 presents the government guarantee fee schedule.

Table 11. Government Guarantee Fee Schedule (per BA Perubahan RUPPJT 2021)

Milestone	Government Guarantee Fee (IDR)
Effective Date	632,000,000
1 Year after Effective Date	1,513,000,000

Milestone	Government Guarantee Fee (IDR)
Commercial Operation Date (COD)	2,040,000,000
1 Year after COD	2,038,000,000
2 Years after COD	2,034,000,000
3 Years after COD	2,032,000,000
4 to 8 Years after COD	2,030,000,000
9 Years after COD	2,027,000,000
10 Years after COD	2,006,000,000
11 Years after COD	1,945,000,000
12 Years after COD	1,852,000,000
13 Years after COD	1,665,000,000
14 Years after COD	1,325,000,000

Source: BA Perubahan RUPPJT (2021)

Traffic Volume and Revenue

Initial ADT projections from the consultant are presented in Table 7. The base tariff for Class I vehicles is IDR 1,162/km, determined to maintain the IRR at 13.96% as required. Class II and III tariffs are set at 1.5× the base rate, while Class IV and V are set at 2×. Tariff adjustments are projected every two years in accordance with Law No. 38/2004 and Government Regulation No. 15/2005, using the average Banten Province inflation rate of 4.67% (2009–2020). ADT growth assumptions are presented in Table 12.

Table 12. Initial ADT Projections at Section Operation Commencement (vehicles/day)

No.	Vehicle Class	Section 1 (2021)	Section 2 (2023)	Section 3 (2023)
1	Class I	6,755	5,218	4,607
2	Class II	1,084	837	739
3	Class III	250	193	171
4	Class IV	167	129	114
5	Class V	83	64	57
Total		**8,339**	**6,442**	**5,688**

Source: PT WSP (2021)

Table 13. ADT Annual Growth Rate Assumptions by Section (condensed)

Year Period	Section 1	Section 2	Section 3
2021	12%	—	—
2022	10%	—	—
2023	9%	12%	12%
2024–2025	8%	9–10%	9–10%
2027–2042	8%	8%	8%
2054–2058	0%	8%	8%
2059–2060	0%	0%	8%
2061–2069	0%	0%	0%

Source: PT WSP (2021)

Total projected toll revenue across all sections is IDR 478,906,277 million (Section 1: IDR 168,332 billion; Section 2: IDR 180,336 billion; Section 3: IDR 130,238 billion). Operating costs (Opex) are estimated at 30% of annual revenue (IDR 143,899,440 million total), consistent with the project owner's operational parameters. Section 3 construction cost is excluded from the investor's Capex as it is financed by the government through VGF.

Investment Variables Summary and Base Case Results

The complete investment variable assumptions are summarised in Table 9. Cash flows are structured using Free Cash Flow to Firm (FCFF) methodology, discounted by the WACC of 13.55%. The concession period is extended to 50 years (2019–2069) as government compensation for land acquisition delays attributable to the government.

Table 14. Investment Variables Summary — Base Case Assumptions

No.	Variable	Value	Notes
1	Capital Expenditure (Capex)	IDR 8,288,497 million	As per Table 6
2	Operating Expenditure (Opex)	IDR 143,899,440 million	30% of annual revenue
3	Land Acquisition	Government guarantee	Covered by VGF
4	Revenue	IDR 478,906,277 million	Tariff IDR 1,162/km (Cl. I); sections op. 2021/2023
5	Concession Period	50 years (2019–2069)	Extended 10 years as government compensation
6	Discount Rate (WACC)	13.55%	Capital structure: 30% equity, 70% debt

Source: Author's analysis

The base case capital budgeting results are presented in Table 15. All four parameters indicate a feasible investment under the base case assumptions.

Table 15. Base Case Capital Budgeting Results

No.	Parameter	Value	Status
1	Net Present Value (NPV)	IDR 399,084 million	Positive — Feasible
2	Internal Rate of Return (IRR)	13.96%	IRR > WACC (13.55%) — Feasible
3	Discounted Payback Period (DPP)	45 years	Before concession end
4	Profitability Index (PI)	1.05	PI > 1 — Feasible

Source: Author's analysis

Compared to the original 2016 PPJT parameters, the base case shows a decreased NPV from IDR 531,699 million to IDR 399,084 million and PI from 1.10 to 1.05, while the IRR is maintained at 13.96% as contractually required. The discounted payback period extended substantially due to the application of discounting. Table 16 presents the comparative analysis.

Table 16. Comparison of Base Case (2021) vs. Initial PPJT (2016) Parameters

No.	Parameter	Base Case (2021)	PPJT Initial (2016)	Change
1	NPV	IDR 399,084 million	IDR 531,699 million	Decreased
2	IRR	13.96%	13.96%	Unchanged (required)
3	DPP	45 years	17 years*	Longer
4	Profitability Index (PI)	1.05	1.10	Decreased

Source: Author's analysis; BA Nego PPJT (2016)

** Note: PPJT 2016 payback period was not discounted (simple payback period).*

Deterministic Sensitivity Analysis Results

Applying the five-scenario framework across all 12 input variables, Table 14 presents the NPV results for the five most influential variables. The complete sensitivity ranking is shown in Table 17.

Table 17. Deterministic NPV Results for Five Most Influential Variables (IDR million)

Variable	VL Scenario NPV	L Scenario NPV	BC Scenario NPV	H Scenario NPV	VH Scenario NPV
Toll Tariff	(1,102,067)	(339,228)	399,084	1,132,837	1,869,815
Capex Construction	(880,966)	(240,700)	399,084	1,034,675	1,667,287
ADT Growth S1	(310,347)	(2,655)	399,084	926,169	1,621,215

Variable	VL Scenario NPV	L Scenario NPV	BC Scenario NPV	H Scenario NPV	VH Scenario NPV
ADT Growth S2	(219,493)	46,756	399,084	868,811	1,498,755
Op. Year Section 2	(666,379)	(175,458)	399,084	782,663	806,007
Others (7 variables)	Range	of (16,851)	to	399,084	See full table

Source: Author's analysis

Table 18 presents the critical investment decision turning points derived from interpolation of the spider chart lines at NPV = 0. The table is ordered from most to least sensitive variable.

Table 18. Critical Investment Decision Turning Points — Deterministic Analysis

Rank	Investment Variable	Critical Threshold (NPV = 0)
1	Minimum Toll Tariff	IDR 1,068/km
2	Maximum Construction Capex	IDR 6,165,664 million (109.4% of Base Case)
3	Minimum ADT Growth Rate — Section 1	84% of Base Case
4	Minimum ADT Growth Rate — Section 2	82% of Base Case
5	Latest Operational Year — Section 2	2024
6	Maximum O&M Cost Ratio	36% of revenue
7	Minimum Initial ADT — Section 1	6,696 vehicles/day
8	Minimum ADT Growth Rate — Section 3	71% of Base Case
9	Minimum Initial ADT — Section 2	4,959 vehicles/day
10	Minimum Initial ADT — Section 3	3,741 vehicles/day
11	Latest Operational Year — Section 1	2023
12	Latest Operational Year — Section 3	2038

Source: Author's analysis

The deterministic analysis reveals that toll tariff and construction Capex are the dominant investment variables, accounting for the largest NPV ranges of IDR 2,971,882 million and IDR 2,548,253 million respectively. Regarding phased operation, Section 2 operational year (rank 5, range IDR 1,472,386 million) is more sensitive than Section 1 (rank 11) and Section 3 (rank 12). Section 3's low sensitivity is attributable to its shorter remaining concession period relative to its operational commencement year. More than 50% of the deterministic simulation lines lie above the NPV = 0 decision boundary, indicating reasonably strong investment viability under single-variable variation. However, deterministic analysis assumes all other variables remain at base case a condition that does not reflect real-world uncertainty. This necessitates the stochastic analysis.

Monte Carlo Stochastic Sensitivity Analysis Results

Table 19 presents the Crystal Ball simulation configuration. The 10,000-trial simulation with 12 simultaneously varied input variables reflects the real-world interdependence of investment uncertainties.

Table 19. Crystal Ball Simulation Configuration

No.	Setting	Value / Configuration
1	Number of Trials	10,000
2	Input Variables	12 assumption variables (Table 16)
3	Output / Forecast Variable	NPV (Net Present Value)
4	Confidence Level	95%
5	Output	Forecast histogram, statistical data, tornado chart, spider chart

Source: Author's analysis

Table 20 presents the complete statistical summary of the Monte Carlo simulation output for NPV, IRR, and PI. The Mean Std. Error-to-Mean ratio of 0.57% confirms simulation stability.

Table 20. Monte Carlo Simulation Output Statistics (NPV in IDR million)

No.	Statistic	NPV	IRR	PI
1	Trials	10,000	10,000	10,000
2	Base Case	399,084	13.96%	1.05
3	Mean	(1,203,368)	12.06%	0.85
4	Median	(1,244,962)	12.05%	0.85
5	Standard Deviation	687,674	0.89%	0.08
6	Skewness	0.3413	0.0667	0.4116
7	Minimum	(3,257,947)	8.78%	0.61
8	Maximum	1,866,187	15.43%	1.24
9	Trials with NPV ≥ 0 (Probability)	**468 / 10,000 = 4.68%**	—	—

Source: Author's analysis via Crystal Ball

The stochastic analysis produces a strikingly different picture from the deterministic base case. The mean NPV of IDR −1,203,368 million and only 4.68% of trials producing NPV ≥ 0 demonstrate extreme financial risk when all variables are simultaneously uncertain. The skewness value of 0.3413 indicates a near-normal distribution with slight right skew, confirming validity of the simulation output (Hair et al., 2022). The investment decision probability boundary of 4.20–4.68% reflects the narrow margin of feasibility under multi-variable uncertainty. Table 19 presents the P5–P95 ranges for each input variable within the 468 trials that produced NPV ≥ 0.

Table 21. Stochastic Input Variable Bounds for NPV ≥ 0 Scenarios (468 trials, P5–P95 range)

No.	Variable	Lower Bound (P5)	Upper Bound (P95)	Probability
1	Capex Construction (% of BC)	91.85%	104.92%	4.20%
2	Initial ADT — Section 1 (veh/day)	6,695	9,977	4.20%
3	Initial ADT — Section 2 (veh/day)	4,894	7,668	4.20%
4	Initial ADT — Section 3 (veh/day)	4,145	6,749	4.20%
5	ADT Growth S1 (% of BC)	77.02%	97.23%	4.20%
6	ADT Growth S2 (% of BC)	76.69%	97.13%	4.20%
7	ADT Growth S3 (% of BC)	75.34%	95.74%	4.20%
8	O&M Cost Ratio	21.76%	33.34%	4.20%
9	Operational Year — Section 1	2021	2022	4.68%
10	Operational Year — Section 2	2023	2026	4.60%
11	Operational Year — Section 3	2023	2030	4.68%
12	Toll Tariff (IDR/km)	1,221	1,570	4.20%

Source: Author's analysis

Regarding the operational year variables, the stochastic results show that Section 2's operational year (2023–2026) has the highest probability of all phased operation variables (4.60%), confirming its critical role in investment decision sensitivity. Section 3's operational year extends to 2030 at the upper bound, while still maintaining a 4.68% probability, reflecting its lower sensitivity to NPV due to its shorter remaining concession duration.

Tornado Chart: Stochastic Variable Sensitivity Rankings

Table 22 presents the complete tornado chart sensitivity analysis, ranking all 12 input variables by their NPV range in the stochastic simulation. The top five variables account for over 80% of NPV variance (cumulative explained variation of 80.93% at rank 5).

Table 22. Tornado Chart — Stochastic Sensitivity Ranking by NPV Range (IDR million)

Rank	Variable Input	NPV Downside	NPV Upside	Range	Cumul. Expl. Var.
1	Toll Tariff	(1,667,717)	(339,288)	1,328,429	33.93%
2	Initial ADT — Section 1	(1,659,521)	(699,062)	960,459	51.66%
3	Operational Year — Section 2	(702,809)	(1,453,852)	751,044	62.51%
4	O&M Cost Ratio	(741,454)	(1,466,253)	724,799	72.61%
5	Initial ADT — Section 2	(1,479,282)	(821,601)	657,682	80.93%
6	Capex Construction	(791,253)	(1,412,946)	621,693	88.36%
7	ADT Growth Rate — Section 1	(1,324,249)	(836,361)	487,888	92.93%
8	Initial ADT — Section 3	(1,344,097)	(922,153)	421,944	96.36%
9	ADT Growth Rate — Section 2	(1,245,876)	(930,152)	315,724	98.27%
10	ADT Growth Rate — Section 3	(1,200,743)	(983,259)	217,484	99.18%
11	Operational Year — Section 1	(1,102,099)	(1,258,710)	156,611	99.65%
12	Operational Year — Section 3	(1,071,387)	(1,205,746)	134,359	100.00%

Source: Author's analysis via Crystal Ball

The stochastic results differ from the deterministic ranking in several aspects. Toll tariff remains the most sensitive variable in both approaches. However, initial ADT of Section 1 rises to rank 2 in the stochastic analysis (versus rank 7 in deterministic), while Section 2 operational year is rank 3 stochastically (rank 5 deterministically). The O&M cost ratio emerges as rank 4 stochastically. These differences arise because the stochastic analysis captures the interaction effects among variables, revealing that demand-side variables (ADT) have greater aggregate impact when their uncertainty is simultaneously considered alongside pricing and cost variables. The combined first five variables explain 80.93% of NPV variance, providing a clear focus for management risk mitigation efforts.

Managerial Implications

The combined deterministic and stochastic results provide actionable insights. Toll tariff policy requires careful balance between investor financial requirements (minimum IDR 1,068/km deterministically; IDR 1,221–1,570/km stochastically for viable scenarios) and user affordability, with mandatory biennial adjustments. Traffic projection accuracy demands regular validation using updated historical data, land use development patterns, and network connectivity studies. Section 2 must be prioritised for operational scheduling, as it represents the phased operation variable with the greatest sensitivity impact. The stochastic probability boundary of 4.20–4.68% underscores the necessity of coordinated risk mitigation across all five high-sensitivity variables simultaneously, rather than managing each in isolation.

CONCLUSION

This study reassessed the investment decision of the Serang–Panimbang Toll Road Project under a phased operational scheme, applying both deterministic and Monte Carlo stochastic sensitivity analyses to identify critical investment decision thresholds. The base case analysis using a 50-year concession period and WACC of 13.55% yielded a positive NPV of IDR 399,084 million, IRR of 13.96%, Discounted Payback Period of 45 years, and Profitability Index of 1.05, confirming investment feasibility under assumed conditions. The deterministic analysis identified toll tariff and construction Capex as the most sensitive variables, with minimum tolerable tariff at IDR 1,068/km and maximum Capex at 109.4% of base case. Regarding phased operation, Section 1 must operate no later than 2023, Section 2 by 2024, and Section 3 by 2038. The Monte Carlo stochastic simulation using 10,000 trials produced a mean NPV of IDR −1,203,368 million, with only 468 trials (4.68%) generating NPV ≥ 0, confirming extreme financial risk under simultaneous variable uncertainty and yielding an investment decision probability boundary of 4.20–4.68%. The five most sensitive variables from the tornado chart toll tariff, Section 1 initial ADT, Section 2 operational year, O&M cost ratio, and Section 2 initial ADT account for over 80% of NPV variance. Managerial implications require: (1) careful toll tariff policy balancing investor returns and user affordability, with biennial adjustments as stipulated; (2) regular validation of traffic projections incorporating updated historical data, land use development, and network connectivity analysis; and (3) treating Section 2 operational scheduling as the highest-priority risk mitigation target among phased sections, since its delay significantly impacts investment viability. Coordination with the government and Tanjung Lesung SEZ management is essential to accelerate land acquisition resolution for Section 2. Future research should explore the integration of land acquisition risk modelling, interest rate volatility, and macroeconomic scenario analysis to further enhance the robustness of investment decision frameworks for toll road infrastructure projects in Indonesia.

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