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Decision-Making Model for Prioritizing Toll Road Investment Projects in Sumatra Using Analytic Hierarchy Process (AHP)

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Abstract

The Trans-Sumatra Toll Road (Jalan Tol Trans Sumatera [JTTS]) is a national strategic infrastructure project spanning approximately 2,800 km and designed to enhance connectivity and promote economic growth across Sumatra. However, investment prioritization among its 25 segments remains inconsistent because of subjective judgments, policy and regulatory changes, and the absence of a structured multicriteria evaluation framework. This study developed a decision-making model for prioritizing toll road investments by integrating Strengths, Weaknesses, Opportunities, and Threats (SWOT)–Threats, Opportunities, Weaknesses, and Strengths (TOWS) analysis with the Analytic Hierarchy Process (AHP) to address identified limitations in existing prioritization practices. A mixed-methods approach combining qualitative SWOT–TOWS analysis and quantitative AHP was employed, involving 34 expert respondents representing toll road stakeholders. An initial set of 75 indicators was screened using a grand mean threshold of 3.70, and the selected indicators were subsequently synthesized into 10 evaluation criteria for pairwise comparison and consistency assessment. Transportation Network Integration and Connectivity emerged as the highest-weighted criterion (0.166), followed by Technical and Geometric Conditions (0.147) and Economic Impact and Regional Distribution (0.116). The consistency ratio (CR) of 0.04 indicated an acceptable level of consistency in the pairwise comparison judgments. The integrated SWOT–TOWS–AHP framework provides a structured, transparent, and replicable decision-support approach for strengthening infrastructure investment governance and aligning toll road investment priorities with national development objectives.

INTRODUCTION

Transportation infrastructure serves as a vital catalyst for national economic growth and regional equity in developing countries (Law No. 38/2004; Law No. 2/2022). Although Indonesia's road network has expanded significantly to more than 545,000 kilometers (Ministry of PUPR, 2023), the World Bank (2020) notes that network quality and connectivity remain insufficient to support efficient mobility. These limitations contribute to high national logistics costs, estimated at between 22% and 27% of GDP, substantially exceeding those of neighboring ASEAN countries such as Thailand (15%), Vietnam (16%), and Malaysia (13%) (World Bank, 2021; PwC Indonesia, 2023).

The financial underperformance of several accelerated Trans-Sumatra Toll Road (Jalan Tol Trans Sumatera [JTTS]) segments provides evidence of the need for a structured investment prioritization framework. Operational data from the Toll Road Regulatory Agency (Badan Pengatur Jalan Tol [BPJT]) as of May 2025 indicate that segments such as Sigli–Banda Aceh and Taba Penanjung–Bengkulu, which were designated for accelerated development under Presidential Regulation (Peraturan Presiden [Perpres]) No. 42/2024, recorded average daily traffic (Lalu Lintas Harian Rata-Rata [LHR]) substantially below their business-plan projections, potentially resulting in negative cash flows and operating losses. The transition from financing supported by State Capital Participation (Penyertaan Modal Negara [PMN]) toward greater commercial self-reliance has intensified these challenges, as Toll Road Business Entities (Badan Usaha Jalan Tol [BUJT]) may have less capacity to rely on state equity injections to offset losses from underperforming segments. Historically, PMN support reduced financing pressures and improved the financial feasibility of projects with relatively low traffic volumes. Without comparable financial support, premature project development driven by non-economic considerations rather than systematic evaluation may adversely affect the financial sustainability of the JTTS program and weaken investor confidence in future toll road investments.

The strategic importance of addressing this prioritization gap extends beyond the performance of individual segments to the broader institutional credibility of Indonesia's infrastructure governance. International investors and multilateral development institutions, including the World Bank and the Asian Development Bank, increasingly emphasize evidence-based infrastructure planning and transparent decision-making as important considerations in infrastructure and development financing (Asian Development Bank, 2023). The absence of a systematic multicriteria prioritization framework may increase the risk of inefficient allocation of limited fiscal resources while signaling institutional weaknesses that could discourage private-sector participation and international development support for subsequent phases of the JTTS program.

Table 1. Key Regulatory Changes Across Presidential Regulations Governing JTTS

Aspect	Perpres 100/2014	Perpres 117/2015	Perpres 42/2024
Objective	Initial acceleration of JTTS construction	Amendment due to financing adjustments	Reaffirmation with restructured sections
Concession Assignment	PT Hutama Karya (initial)	PT Hutama Karya (expanded scope)	PT Hutama Karya (updated corridors)
Corridor Scope	7 initial corridors	Expanded to 24 segments with phased sequencing	Added new corridors, removed low-feasibility ones
Financing Scheme	SOE financing with state support	Expanded instruments and state equity participation	Strengthened fiscal support and restructured mechanisms
Political Context	Initiated under SBY administration	Revised under Jokowi's first term	Re-amended to accelerate completion before term end

Source: Perpres 100/2014, Perpres 117/2015, Perpres 42/2024

PT Hutama Karya (Persero), the state-owned enterprise assigned as the primary developer of the Trans-Sumatra Toll Road (Jalan Tol Trans Sumatera [JTTS]), operates within a complex stakeholder ecosystem that influences investment prioritization decisions. As a state-owned enterprise (Badan Usaha Milik Negara [BUMN]) established in 1961, the company has undergone a strategic transformation toward becoming a sustainable infrastructure enterprise, guided by the AKHLAK core values established by the Ministry of State-Owned Enterprises. The company's organizational structure encompasses three core toll road functions: planning, construction, and operations and maintenance, each of which contributes a distinct perspective to the prioritization process. Beyond the Toll Road Business Entity (Badan Usaha Jalan Tol [BUJT]), multiple stakeholders participate in the decision-making process. Design and environmental consultants conduct feasibility studies and regulatory compliance assessments, while expert teams provide analytical support, including multicriteria decision-making methods. This multistakeholder environment reinforces the need for a structured, transparent, and quantitative prioritization framework capable of integrating diverse perspectives into a coherent investment strategy (Hong et al., 2026; Mohamad et al., 2026; Mukhtar & Bahormoz, 2022; Wang et al., 2025).

Within this broader infrastructure context, toll road investment represents a complex decision-making problem because projects typically involve substantial capital requirements, long concession periods, uncertain traffic demand, and multiple stakeholder interests. The Trans-Sumatra Toll Road (Jalan Tol Trans Sumatera [JTTS]) is one of Indonesia's largest strategic infrastructure projects, extending approximately 2,800 km from Banda Aceh to Bandar Lampung and intended to strengthen connectivity and promote economic development across Sumatra. The project was designated as a National Strategic Project through Presidential Regulation No. 100/2014 and was subsequently revised through Presidential Regulation No. 117/2015 and Presidential Regulation No. 42/2024 in response to changes in financing mechanisms, project scope, and development priorities. Nevertheless, JTTS implementation has encountered challenges related to investment prioritization, financing sustainability, and discrepancies between projected and actual traffic performance. Several segments, including Sigli–Banda Aceh and Taba Penanjung–Bengkulu, have recorded traffic volumes below business-plan projections, raising concerns regarding operating losses and long-term financial sustainability. These challenges demonstrate the need for a structured evaluation model capable of determining investment priorities using comprehensive and measurable criteria.

Previous studies have demonstrated that multicriteria decision-making (MCDM) methods, particularly the Analytic Hierarchy Process (AHP), have been widely applied to complex infrastructure prioritization problems. Amankwah-Nkyi et al. (2025) applied AHP to assess transportation asset criticality by incorporating stakeholder perspectives, highlighting the importance of systematic evaluation in transportation management. Similarly, Baric and Zeljko (2021) employed AHP to evaluate road transportation alternatives, demonstrating the applicability of hierarchical decision-making approaches to transportation assessments. Quadros and Nassi (2015) applied AHP to transportation infrastructure investment decisions and identified economic impact as an important criterion influencing project prioritization. Shirazi et al. (2024) further demonstrated that technical parameters, construction complexity, and project characteristics influence road project outcomes through AHP-based evaluation. Collectively, these studies indicate that AHP provides a structured approach to infrastructure decision-making problems involving multiple criteria and stakeholder judgments.

Although previous research has contributed significantly to transportation decision-making, several limitations remain. Most existing studies have primarily applied AHP as a quantitative prioritization method without integrating broader strategic analysis to identify contextual factors influencing investment decisions. In addition, previous infrastructure prioritization models have generally evaluated transportation projects from technical or economic perspectives, with limited attention to the institutional and strategic challenges faced by toll road operators under changing financing conditions. In the context of JTTS, the transition from government-supported financing mechanisms toward greater commercial sustainability creates additional complexity because toll road developers must balance national connectivity objectives with financial feasibility. Existing regulatory guidelines, including technical assessment procedures and project evaluation standards, establish administrative and technical requirements but do not necessarily provide a comprehensive multicriteria framework specifically designed for toll road investment prioritization. Therefore, a research gap remains in developing an integrated decision-support model that combines strategic assessment with quantitative prioritization.

Addressing this research gap is particularly important because infrastructure investment decisions influence not only financial performance but also broader national development outcomes. Inadequate prioritization may result in inefficient capital allocation, underutilized infrastructure assets, increased financial burdens, and reduced investor confidence. International development institutions, including the World Bank and the Asian Development Bank, emphasize transparent and evidence-based infrastructure planning as an important component of effective infrastructure governance and investment mobilization. In the case of JTTS, a systematic prioritization framework is needed to assess whether proposed toll road segments contribute effectively to transportation connectivity, regional economic development, and sustainable infrastructure outcomes. Furthermore, JTTS involves stakeholders with different objectives, including government institutions pursuing national connectivity, business entities seeking financial sustainability, regional governments promoting economic development, and communities expecting socioeconomic benefits. Consequently, an effective decision-making model should accommodate these diverse perspectives while maintaining analytical consistency.

This study introduces an integrated approach combining Strengths, Weaknesses, Opportunities, and Threats (SWOT)–Threats, Opportunities, Weaknesses, and Strengths (TOWS) analysis with the Analytic Hierarchy Process (AHP) to develop a comprehensive toll road investment prioritization framework. Unlike conventional AHP applications that assign weights directly to predetermined criteria, this study employs SWOT–TOWS analysis as an initial strategic assessment to identify internal strengths and weaknesses and external opportunities and threats affecting JTTS investment decisions. Relevant indicators are subsequently screened through expert assessment before being incorporated into the AHP hierarchy. This methodological integration provides a more systematic basis for criterion selection because the evaluation variables are informed not only by the researchers' conceptual assessment but also by stakeholder judgments. The resulting integrated SWOT–TOWS–AHP framework is intended to provide a transparent and replicable decision-support approach for strengthening infrastructure governance and aligning investment priorities with national development objectives.

The objective of this research is to develop a structured decision-making model for prioritizing toll road investment projects within the Trans-Sumatra Toll Road development program. Specifically, the study aims to identify limitations in existing prioritization procedures, determine influential evaluation criteria through expert-based assessment, and formulate an integrated prioritization framework using SWOT–TOWS analysis and AHP. The study employs a mixed-methods approach combining qualitative strategic analysis with quantitative multicriteria evaluation. Through this approach, the proposed decision-support model integrates technical feasibility, economic contribution, financial sustainability, operational performance, environmental considerations, and institutional factors into a unified evaluation framework. The study also seeks to reduce subjectivity in infrastructure investment decisions by establishing measurable criterion weights and systematic prioritization mechanisms.

This research offers both theoretical and practical contributions. From a theoretical perspective, the study extends the infrastructure decision-making literature by integrating strategic management analysis with a multicriteria decision-making approach. The combination of SWOT–TOWS and AHP provides a broader analytical framework than the independent application of either approach. From a practical perspective, the proposed framework offers policymakers, infrastructure authorities, and toll road operators a structured and transparent instrument for evaluating investment proposals. The model may support PT Hutama Karya, the Toll Road Regulatory Agency (Badan Pengatur Jalan Tol [BPJT]), and relevant government institutions in developing evidence-based investment strategies. By identifying and weighting criteria such as transportation network integration and connectivity, technical and geometric conditions, economic impact, and financial feasibility, the framework may assist decision-makers in allocating resources to projects with greater strategic value.

Ultimately, this research is expected to contribute to improved infrastructure governance, investment efficiency, and sustainable transportation development in Indonesia. The proposed prioritization model provides a structured mechanism for moving from fragmented and potentially subjective evaluation processes toward more systematic, transparent, and accountable investment planning. Beyond the JTTS context, the framework may provide a methodological reference for other large-scale infrastructure projects in developing countries facing similar challenges related to financing constraints, stakeholder complexity, and uncertainty in project performance. By integrating qualitative strategic analysis with quantitative multicriteria decision-making, this study contributes to the development of evidence-based infrastructure planning and supports long-term national connectivity and economic development objectives.

METHOD

The conceptual framework established a systematic flow from the identification of existing prioritization challenges to analytical intervention and expected outcomes. Three primary issues were identified: subjective and inconsistent prioritization, limited application of structured decision-making tools within existing regulatory procedures, and investment decisions with limited quantitative justification and stakeholder consensus. To address these issues, the study employed a sequential analytical approach comprising SWOT–TOWS strategic analysis, stakeholder-based indicator screening, and AHP weighting to determine investment priorities. The resulting priorities were subsequently adjusted by considering practical constraints and applicable regulatory requirements.

This study employed a mixed-methods approach integrating qualitative strategic analysis with quantitative multicriteria decision-making. The methodology consisted of two sequential phases: SWOT–TOWS analysis to identify strategic factors influencing toll road investment decisions, followed by the Analytic Hierarchy Process (AHP) to determine criterion weights through expert-based pairwise comparisons and consistency assessment. This integration enabled strategic factors identified through qualitative analysis to be incorporated into a structured quantitative prioritization model.

The SWOT–TOWS analysis was conducted through a systematic review of relevant regulatory and project documents, including Presidential Regulations (Peraturan Presiden [Perpres]) No. 100/2014, No. 117/2015, and No. 42/2024; project feasibility studies; Technical Guidelines (Petunjuk Teknis [Juknis]) No. 12/SE/Db/2017; the Program Proposal Assessment Procedure (SOP/UPM/DJBM-104); Government Regulation (Peraturan Pemerintah [PP]) No. 23/2024; and relevant reports from PT Hutama Karya (Persero). The identified variables were classified as internal factors (strengths and weaknesses) and external factors (opportunities and threats) across financial, technical, social, and policy dimensions. A TOWS matrix was then developed to formulate Strength–Opportunity (SO), Strength–Threat (ST), Weakness–Opportunity (WO), and Weakness–Threat (WT) strategies. The resulting strategic factors were subsequently translated into evaluation criteria for the AHP model.

Primary data were collected through structured questionnaires administered to 34 purposively selected respondents representing relevant toll road development stakeholders within PT Hutama Karya (Persero), including personnel at the analyst, manager, and expert levels. Respondents were selected based on their professional experience, organizational responsibilities, and involvement in toll road planning, evaluation, or investment decision-making. These criteria were used to ensure that respondents possessed sufficient technical knowledge and practical experience to evaluate the factors influencing toll road investment priorities.

Respondents represented different levels of professional and organizational responsibility, including analysts or specialists, managers or consultants, and experts. This multilevel respondent structure was designed to capture perspectives from both analytical and strategic decision-making functions within the toll road development process. The resulting expert judgments were used in the AHP pairwise comparisons to determine the relative importance of the evaluation criteria and support the development of the investment prioritization model.

Table 3. Respondent Profile Structure and Competency Mapping

Competency Level	Bloom's Level	KKNI Level	Experience	Number of Respondents
Analyst/Specialist	C4: Analyzing	Level 4-6	3-5 years	12
Manager/Consultant	C5: Evaluating	Level 6-8	> 5 years	14
Expert/Pakar	C6: Creating	Level 8-9	> 8 years	8
Total				34

Source: Research data, 2025

The data collection process was conducted in two rounds. The first questionnaire employed a 5-point Likert scale (Sugiyono, 2016) to assess the relevance and importance of 75 initial indicators derived from the document review. Indicator screening was performed using a data-centered cutoff based on the grand mean of all indicators (Bacon, 2003), which yielded a threshold of 3.70. Indicators with mean scores equal to or greater than 3.70 were retained for subsequent analysis and used to develop the AHP evaluation criteria.

The AHP analysis was conducted through pairwise comparisons of the selected criteria. Priority weights were derived using the principal eigenvector method, and the consistency of the pairwise judgments was assessed using the Consistency Index (CI) and Consistency Ratio (CR). For the 10-criterion comparison matrix, a Random Index (RI) value of 1.49 was applied, and a CR below 0.10 was considered to indicate an acceptable level of consistency (Saaty, 1980).

The first-round questionnaire comprised 75 indicators covering technical, economic, financial, social, environmental, policy, and SWOT-related factors. The second-round questionnaire consisted of 45 pairwise comparisons among the 10 selected evaluation criteria. Respondents assessed the relative importance of each criterion using Saaty's 1–9 fundamental scale and its reciprocal values. All 34 respondents completed both rounds of data collection, and their judgments were subsequently used to determine the relative weights of the evaluation criteria.

The methodological approach differed from previous studies by integrating strategic analysis, empirical indicator screening, and quantitative prioritization. Rifqi and Siallagan (2025) applied AHP to prioritize Phase II segments of the Trans-Sumatra Toll Road, primarily using quantitative pairwise comparisons. In contrast, this study employed SWOT–TOWS analysis before AHP to identify strategic factors relevant to investment prioritization. Furthermore, while Raharjo (2024) proposed a sequential TOWS–AHP approach for national infrastructure projects, the present study incorporated a data-centered indicator-screening procedure based on the grand mean threshold before constructing the AHP hierarchy. This process provided an empirical basis for selecting the indicators included in the subsequent multicriteria evaluation.

The second-round questionnaire employed Saaty's (1980) fundamental 1–9 pairwise comparison scale to assess the relative importance of the selected criteria. The AHP procedure included constructing the decision hierarchy and pairwise comparison matrices, deriving criterion weights using the principal eigenvector method, and assessing judgment consistency using the Consistency Index (CI) and Consistency Ratio (CR). A CR value below 0.10 was used as the criterion for acceptable consistency. Expert judgments were aggregated across respondents to determine the final criterion weights. Respondent confidentiality was maintained throughout the data collection and analysis processes.

RESULTS AND DISCUSSION

This section presents the findings from both the SWOT-TOWS analysis and the AHP-based prioritization model. The results are organized sequentially: the SWOT analysis findings, the variable screening process, the AHP weighting results, followed by a comprehensive discussion integrating AHP outcomes with TOWS strategic analysis, theoretical implications, and practical recommendations.

Before presenting the detailed findings, it is important to note the analytical structure employed in this section. The results are presented in three progressive stages: first, the SWOT analysis provides the qualitative strategic landscape that identifies the key internal and external factors influencing toll road investment decisions; second, the variable screening process demonstrates how the initial pool of 75 indicators was systematically reduced to the most relevant evaluation criteria through empirical stakeholder assessment; and third, the AHP weighting results present the quantitative priority rankings derived from expert pairwise comparisons. The subsequent discussion section integrates these results with the TOWS strategic matrix and relevant theoretical frameworks to generate actionable insights for improving JTTS investment prioritization. This sequential presentation ensures methodological transparency and enables readers to trace the analytical progression from raw data to final strategic recommendations.

SWOT Analysis

The SWOT analysis systematically identified 25 strategic factors organized across internal and external dimensions relevant to JTTS investment prioritization. Among the internal factors, seven strengths were identified, including the JTTS project's superior advantage over other infrastructure in corridor areas (St1), ideal geometric conditions for construction efficiency (St2), well-planned integration with existing road networks (St3), strong functionality as JAP/JKP-1 connecting super nodes (St4), guaranteed connectivity to national transportation nodes (St5), solid government support through PSN and fiscal mechanisms (St6), and strong technical capabilities in project implementation (St7). These strengths collectively reflect the institutional and technical foundation supporting JTTS development.

Six weaknesses were identified that significantly constrain the current prioritization process. These include significant operational risks affecting project performance on certain sections (W1), high risks in land acquisition cost estimation (W2), substantial funding and cash flow challenges (W3), delays in land acquisition critically affecting prioritization decisions (W4), risks of compensation for buildings on planned routes (W5), and unclear asset ownership status during the concession period (W6). These weaknesses highlight the persistent challenges that undermine investment sustainability and require strategic mitigation within any prioritization framework.

Among external factors, six opportunities emerged, including benefits from surrounding industrial and port area development (O1), significant upward trends in logistics and traffic flows along toll corridors (O2), the role of JTTS in developing National Strategic Tourism Areas (O3) and Special Economic Zones (O4), supportive government policies accelerating development (O5), and substantial social benefits for surrounding communities (O6). Conversely, six threats were identified: reduced future road user demand (Th1), disruptive regulatory changes (Th2), environmental risks to conservation areas (Th3), potential cessation of government funding mechanisms (Th4), negative consequences for national defense strategies (Th5), and high seismic risks in certain corridors (Th6).

Table 4. SWOT Analysis of JTTS Investment Prioritization

Category	Code	SWOT Factors
Strengths	St1	JTTS has greatest advantage over other infrastructure in corridor
	St2	Ideal geometric conditions for construction efficiency
	St3	Well-planned integration with existing road network
	St4	Strong function as JAP/JKP-1 connecting super nodes
	St5	Guaranteed connectivity to national transportation nodes
	St6	Solid government support (PSN/Fiscal)
	St7	Very good technical capabilities and implementation
Weaknesses	W1	Operational risks significantly impact project performance
	W2	High risk in land acquisition cost estimation
	W3	Significant funding/cash flow challenges on certain sections
	W4	Land acquisition delays affect project prioritization
	W5	High risk of building compensation on planned routes
	W6	Unclear asset ownership during concession period
Opportunities	O1	Benefits from surrounding industrial/port area development
	O2	Significant upward trend in logistics/traffic flows
	O3	Major role in developing KSPN (tourism areas)
	O4	Major role in supporting KEK (economic zones)
	O5	Supportive government policies accelerating development
	O6	Enormous social benefits to surrounding communities
Threats	Th1	External risks reducing future road user demand
	Th2	Sudden regulatory/policy changes disrupting priorities
	Th3	Risk of damaging conservation/protected forest areas
	Th4	Risk of government funding cessation (VGF)
	Th5	Negative consequences for defense/security strategies
	Th6	High seismic potential in road corridors

Source: Document review and expert validation, 2025

Variable Screening and Selection

From the initial pool of 75 indicators derived from Technical Guidelines, SOP procedures, PP 23/2024, and feasibility studies spanning technical (14 indicators), economic (10 indicators), financial (8 indicators), social (5 indicators), environmental (6 indicators), and policy (7 indicators) dimensions, plus 25 SWOT factors, a systematic screening process was conducted using responses from all 34 expert respondents. Each indicator was evaluated on a 5-point Likert scale, and the data-centered cutoff approach yielded a grand mean threshold of 3.70. This empirical threshold was preferred over a fixed theoretical value because the large number of indicators (75 total) risked retaining too many variables if a conventional cutoff of 3.40 were applied. Indicators meeting or exceeding the grand mean were retained, and the selected variables were synthesized through expert consultation into ten main evaluation criteria that comprehensively represent the multidimensional aspects of toll road investment decision-making.

The grand mean calculation revealed distinct patterns across the six indicator dimensions. Technical indicators exhibited the highest average relevance scores, with indicators related to network connectivity (T10: mean 4.32), road integration (T5: mean 4.18), and super node connectivity (T9: mean 4.09) consistently rated above the grand mean threshold. Financial indicators, particularly projected income analysis (F1: mean 4.26) and financial feasibility analysis (F2: mean 4.21), also demonstrated high expert consensus on their importance. In contrast, certain environmental indicators, such as impacts on cultural heritage sites (En5: mean 3.15) and river border areas (En6: mean 3.09), fell below the grand mean and were excluded from the AHP model. This systematic screening ensured that the final set of evaluation criteria reflected genuine expert consensus rather than an exhaustive but unfocused compilation of all possible factors.

The synthesis of selected indicators into ten evaluation criteria was conducted through iterative expert consultation to ensure that related indicators were meaningfully grouped while maintaining analytical distinctiveness. For example, the criterion 'Transportation Network Integration and Connectivity' synthesized indicators T5 (road network integration), T9 (super node connectivity), T10 (national transportation node connectivity), and related SWOT factors St3 (well-planned integration), St4 (JAP/JKP-1 function), and St5 (guaranteed connectivity). Similarly, 'Financial Feasibility and Financing Structure' consolidated financial indicators F1 through F5 with SWOT weakness factors W3 (cash flow challenges) and W6 (asset ownership uncertainty). This synthesis approach balanced comprehensiveness with parsimony, producing a manageable number of criteria (n=10) that falls within the cognitive processing limits recommended for AHP applications (Cowan, 2001; Saaty, 2008).

AHP Weighting Results

The pairwise comparison matrix was constructed from aggregated responses of 34 expert respondents using Saaty's 1-9 scale. The normalized eigenvector computation yielded the final priority weights for each criterion. The maximum eigenvalue obtained was 10.47, producing a Consistency Index (CI) of 0.05 and a Consistency Ratio (CR) of 0.04, which is well within the acceptable threshold of CR < 0.10 established by Saaty (1980), confirming that the expert judgments are sufficiently consistent and reliable. The final criteria weights, ranked in descending order of priority, are presented in Table 5.

Table 5. AHP Weighting of Evaluation Criteria (Ranked in Descending Order)

No	Criteria	Weight	%	TOWS Analysis
1	Transportation Network Integration and Connectivity	0.166	16.6%	SO1, SO4, SO5, WO5
2	Technical and Geometric Conditions of the Road Corridor	0.147	14.7%	SO2, SO5, ST3, ST5
3	Economic Impact and Regional Distribution	0.116	11.6%	SO4, SO5, WO3, ST4
4	Financial Feasibility and Financing Structure	0.108	10.8%	WO1, WO3, WO4, ST3, WT1, WT2, WT4
5	Operational Impact on Traffic Performance	0.104	10.4%	SO2, WO5, ST1, ST5, WT1
6	Traffic Demand Projection and Economic Feasibility	0.094	9.4%	SO2, WO1, WO5, ST1, WT1, WT4
7	Spatial Planning and Regional Development Compatibility	0.081	8.1%	SO1, SO4, SO5, WO1, WO4
8	Environmental and Protected Area Impacts	0.066	6.6%	SO4, WT5

9	Business Model and Operational Phasing	0.064	6.4%	SO3, WO4, ST3, WT2, WT5
10	Policy, Regulatory, and Institutional Aspects	0.055	5.5%	SO3, WO2, ST2, ST4, WT3, WT4, WT5

Source: Primary data analysis, 2025

The AHP results reveal a clear hierarchy of priorities reflecting expert consensus on the most critical factors for toll road investment decision-making in the Trans-Sumatra context. Transportation Network Integration and Connectivity emerged as the highest-weighted criterion with a weight of 0.166, indicating that experts consider the ability of a toll road project to strengthen regional connectivity and improve network integration as the most determinant factor in investment prioritization. This finding aligns with the strategic positioning of JTTS as a national connectivity project and is consistent with Amankwah-Nkyi et al. (2025), who identified network connectivity and system redundancy as primary considerations in transportation asset prioritization. The strong association between this criterion and Strength-Opportunity (SO) strategies, specifically SO1, SO4, and SO5, underscores the importance of accelerating development in toll road sections connected to industrial zones, ports, Special Economic Zones (KEK), and National Strategic Tourism Areas (KSPN). These strategies are designed to maximize the strategic advantages of JTTS while capturing opportunities arising from regional economic expansion and increasing logistics demand.

Technical and Geometric Conditions of the Road Corridor ranked second with a weight of 0.147, confirming that technical readiness and engineering feasibility remain critical determinants in investment prioritization decisions. This result supports the findings of Shirazi et al. (2024), who demonstrated through AHP analysis with Expert Choice software that design parameters, construction complexity, and terrain conditions significantly influence road project success and should receive prioritized attention in project planning. In the JTTS context, segments with favorable geometric conditions, accessible terrain, and manageable engineering complexity are logically prioritized to ensure efficient implementation, cost management, and timely completion. The criterion's strong linkage to strategies SO2 and SO5 emphasizes utilizing favorable technical conditions and strong institutional capabilities to improve construction efficiency and corridor competitiveness.

Economic Impact and Regional Distribution, weighted at 0.116 and ranked third, reinforces the importance of evaluating toll road investments beyond direct financial returns to encompass broader economic multiplier effects. This finding corroborates Quadros and Nassi (2015), who established economic impact, including transportation cost reduction and regional economic stimulation, as a priority criterion in infrastructure investment decisions using AHP. The JTTS macroeconomic data from CORE Indonesia (2023) substantiates this criterion, demonstrating that operational toll roads have generated regional GDP output of IDR 924.39 trillion, cumulative household income increases of IDR 182.33 trillion, and employment for 4.46 million workers. The criterion's association with strategies SO4, SO5, WO3, and ST4 emphasizes maximizing regional benefits through improved accessibility, reduced logistics costs, and enhanced connectivity between production centers and markets.

Financial Feasibility and Financing Structure, ranked fourth with a weight of 0.108, reflects the critical importance of ensuring project financial viability in the post-PMN environment. This criterion is directly associated with multiple TOWS strategies spanning defensive (WT1, WT2, WT4) and corrective (WO1, WO3, WO4) quadrants, indicating that financial challenges represent both significant weaknesses and opportunities for strategic intervention. The result is consistent with Jin et al. (2018), who validated financial feasibility indicators such as NPV, IRR, and payback period as core determinants in investment prioritization using AHP methodology. The relatively high weight reflects the practical reality that BUJT must now independently bear financial risks without state subsidies, making rigorous financial assessment essential before committing to new segment development. Innovative financing mechanisms, including public-private partnerships, capital market instruments, and collaboration with industrial estates and port operators, emerge as essential strategies for ensuring financial sustainability.

The remaining six criteria collectively constitute approximately 47% of the total weight, representing essential complementary factors for comprehensive evaluation. Operational Impact on Traffic Performance (0.104) and Traffic Demand Projection and Economic Feasibility (0.094) address operational efficiency and demand reliability, reflecting concerns about traffic volume uncertainty and revenue sustainability. Spatial Planning and Regional Development Compatibility (0.081) ensures alignment with national and regional development plans. Environmental and Protected Area Impacts (0.066) addresses ecological stewardship requirements. Business Model and Operational Phasing (0.064) concerns concession management and project sequencing. Notably, Policy, Regulatory, and Institutional Aspects received the lowest weight (0.055), suggesting that while regulatory compliance is necessary, experts view it as a supporting condition rather than a primary driver of investment decisions. This finding contrasts sharply with the current practice where political and regulatory considerations have disproportionately influenced JTTS prioritization, often overriding technical and financial assessments through successive presidential regulation amendments.

The weighting distribution across the ten criteria reveals important insights about expert perceptions of investment priorities. The top three criteria (Network Integration, Technical Conditions, and Economic Impact) collectively account for 42.9% of the total weight, indicating a strong expert consensus that connectivity, technical readiness, and economic contribution are the primary determinants of toll road investment value. The middle tier of criteria (Financial Feasibility, Operational Impact, and Traffic Demand) accounts for 30.6%, reflecting the importance of financial sustainability and operational viability as enabling conditions for investment success. The lower tier (Spatial Planning, Environmental Impacts, Business Model, and Policy Aspects) accounts for 26.6%, representing contextual and regulatory factors that, while necessary for project implementation, are not considered primary drivers of investment priority. This three-tier structure provides a useful heuristic for decision-makers: prioritize sections that maximize connectivity and economic impact, ensure financial and operational viability, and verify compliance with spatial, environmental, and regulatory requirements.

A closer examination of the middle-tier criteria provides additional insights into the investment decision landscape. Operational Impact on Traffic Performance (0.104) reflects expert concern about the real-world operational consequences of toll road development, including travel time savings, volume-to-capacity ratios, and network stability effects on existing roads. This criterion draws directly from the SOP/UPM/DJBM-104 indicators related to traffic flow impacts and is associated with both aggressive (SO2, ST5) and defensive (WT1) strategies. The weight suggests that experts view operational performance as a critical validation mechanism: a toll road segment should not only demonstrate connectivity value and financial viability but must also deliver measurable improvements to the transportation network's operational efficiency.

Traffic Demand Projection and Economic Feasibility (0.094) addresses the fundamental challenge of accurately forecasting future traffic volumes and ensuring that revenue projections are realistic and achievable. The JTTS experience has demonstrated that demand overestimation is a significant risk, with several operational segments recording LHR substantially below business plan assumptions. This criterion's association with strategies WO1, ST1, and WT4 underscores the need for conservative demand modeling, sensitivity analysis, and contingency planning for scenarios where actual traffic falls short of projections. The relatively moderate weight suggests that while demand analysis is important, experts recognize that demand is partly a function of network connectivity and regional economic development, which are captured by higher-weighted criteria.

Spatial Planning and Regional Development Compatibility (0.081) ensures that toll road investments align with national spatial plans (RTRW), support suburban area development, and contribute to balanced regional growth. This criterion connects the infrastructure investment decision to broader territorial planning objectives, reflecting the interdisciplinary character of toll road development that extends beyond transportation engineering into regional economics and urban planning. Environmental and Protected Area Impacts (0.066) addresses the ecological and conservation dimensions of toll road construction, including impacts on protected forests, conservation areas, air quality, and land use. While receiving a relatively lower weight, this criterion remains essential for ensuring regulatory compliance with environmental legislation (UU No. 41/1999) and international sustainability standards.

Business Model and Operational Phasing (0.064) concerns the strategic structuring of concession agreements, operational timelines, and phased development approaches that determine the long-term commercial viability of toll road segments. This criterion is linked to strategies SO3, WO4, ST3, WT2, and WT5, reflecting its cross-cutting relevance to both growth-oriented and risk-mitigation objectives. The weight indicates that experts recognize the importance of flexible and adaptive business models that can accommodate changing market conditions, regulatory environments, and traffic demand patterns. In the JTTS context, where some segments may require decades to achieve full financial breakeven, the design of appropriate concession structures, revenue-sharing mechanisms, and operational phasing strategies becomes critical for attracting private sector investment and ensuring long-term institutional sustainability. The relatively modest weight suggests that business model considerations, while important, are viewed as implementation-level decisions that should follow rather than drive strategic investment prioritization.

A noteworthy finding is the relatively low weight assigned to Policy, Regulatory, and Institutional Aspects (0.055), which stands in stark contrast to the current practice where political and regulatory considerations have been the dominant force shaping JTTS development priorities. The successive amendments to presidential regulations, often driven by political legacy-building objectives and regional lobbying rather than systematic technical analysis, have resulted in the premature acceleration of segments with weak financial fundamentals. The expert consensus reflected in the AHP results effectively challenges this status quo by demonstrating that practitioners with deep domain expertise view policy alignment as a necessary but not sufficient condition for investment prioritization. This finding suggests that future JTTS governance should shift toward a model where technical and financial assessments drive prioritization decisions, with policy and regulatory frameworks serving as enabling conditions rather than primary determinants.

The integration of AHP results with the TOWS matrix reveals that the investment prioritization framework is predominantly positioned within the Strength-Opportunity (SO) quadrant, suggesting an aggressive growth-oriented strategic direction. The highest-weighted criteria are strongly aligned with strategies that capitalize on existing institutional strengths, favorable technical conditions, and emerging economic opportunities. This integrated perspective provides decision-makers with a dual-layered framework: quantitative priority weights from AHP determine the relative importance of evaluation criteria, while TOWS strategic directions guide the formulation of actionable investment strategies. The framework demonstrates that future JTTS investment priorities should focus on toll road sections providing the greatest contribution to transportation network integration, regional connectivity, and economic development, while simultaneously maintaining financial sustainability and managing operational risks through appropriate defensive (WT) and corrective (WO) strategies.

The TOWS strategic analysis generated 20 strategic alternatives organized across four quadrants. The Strength-Opportunity (SO) strategies include: SO1 - accelerating development of sections connected to industrial zones and ports; SO2 - utilizing favorable geometric conditions and strong technical capabilities; SO3 - leveraging government support to secure diversified funding; SO4 - maximizing economic benefits through connectivity to KEK and KSPN; and SO5 - strengthening network integration with national transportation nodes. The Weakness-Opportunity (WO) strategies address: WO1 - securing alternative financing to overcome cash flow constraints; WO2 - aligning with supportive policies to mitigate regulatory uncertainty; WO3 - leveraging economic growth to improve financial feasibility; WO4 - reforming concession frameworks to clarify asset ownership; and WO5 - improving operational efficiency through technological integration.

The Strength-Threat (ST) strategies include: ST1 - utilizing technical advantages to maintain competitiveness despite demand uncertainty; ST2 - strengthening institutional resilience against regulatory disruption; ST3 - managing construction risks through phased implementation; ST4 - advocating evidence-based policy frameworks; and ST5 - building operational redundancy for seismic-prone corridors. The Weakness-Threat (WT) strategies focus on: WT1 - developing contingency plans for revenue shortfalls; WT2 - establishing risk-sharing mechanisms with private partners; WT3 - creating adaptive regulatory frameworks; WT4 - implementing conservative financial modeling for vulnerable sections; and WT5 - integrating environmental safeguards and climate resilience measures. This comprehensive strategic mapping demonstrates that the AHP criteria weights are not isolated numerical outputs but are embedded within a broader strategic context that informs both prioritization decisions and implementation strategies.

Table 6. TOWS Strategic Matrix for JTTS Investment Prioritization

Quadrant	Strategic Direction
SO Strategies	SO1: Accelerate development of sections connected to industrial zones and ports to maximize economic corridors
	SO2: Utilize favorable geometric and technical conditions to improve construction efficiency and timely completion
	SO3: Leverage strong government support (PSN) to secure diversified financing and maintain development momentum
	SO4: Maximize connectivity to KEK and KSPN to generate economic multiplier effects across regions
	SO5: Strengthen network integration with national transportation super nodes for long-term competitiveness
WO Strategies	WO1: Secure alternative financing mechanisms (PPP, capital markets) to overcome cash flow constraints
	WO3: Leverage regional economic growth trends to improve financial feasibility of underperforming segments
	WO4: Reform concession frameworks to clarify asset ownership and attract private sector participation
	WO5: Improve operational efficiency through digital technology and traffic management integration
ST Strategies	ST1: Utilize technical advantages and established capabilities to maintain viability despite demand uncertainty
	ST2: Strengthen institutional resilience and governance frameworks against sudden regulatory disruptions
	ST3: Implement phased construction approaches to manage financial and construction risks systematically
	ST4: Advocate for evidence-based policy frameworks that integrate multi-criteria analysis into regulation
WT Strategies	WT1: Develop contingency plans and conservative financial models for segments with revenue shortfall risks
	WT2: Establish risk-sharing mechanisms with private partners to distribute financial exposure
	WT3: Create adaptive regulatory frameworks that accommodate changing economic and environmental conditions
	WT4: Implement strict financial monitoring and early warning systems for vulnerable toll road sections
	WT5: Integrate environmental safeguards and climate resilience measures into project planning cycles

Source: SWOT-TOWS analysis, 2025

From an international perspective, the proposed framework contributes to the broader discourse on infrastructure investment governance in developing economies. The integration of SWOT-TOWS strategic analysis with AHP quantitative weighting addresses the common challenge of balancing political imperatives with technical rationality in public infrastructure decisions. While Petrillo et al. (2023) proposed extending AHP with BOCR (Benefits, Opportunities, Costs, Risks) analysis for sustainable infrastructure, the present study demonstrates that combining SWOT-TOWS with classical AHP provides a more accessible and equally rigorous alternative that is particularly suitable for organizational contexts with limited access to advanced decision-support technologies. The findings may be applicable to similar large-scale toll road programs in other developing countries facing comparable challenges of political interference, fiscal constraints, and multi-stakeholder complexity.

The international relevance of this study extends to the growing body of literature on infrastructure investment governance in emerging economies. Comparable challenges of politically influenced infrastructure prioritization have been documented in countries across Southeast Asia, Sub-Saharan Africa, and Latin America, where large-scale transportation projects frequently face similar tensions between political expediency and technical rationality. The proposed framework's combination of accessible analytical tools (SWOT-TOWS and classical AHP) with rigorous validation procedures (consistency ratio verification) makes it particularly transferable to institutional contexts where advanced computational decision-support systems may not be readily available. The framework can be adapted for application to other types of infrastructure investments, including railways, ports, airports, and energy facilities, by modifying the evaluation criteria and SWOT factors to reflect sector-specific considerations while maintaining the underlying methodological architecture of integrated qualitative-quantitative analysis.

The study also contributes to the theoretical discourse on the relationship between multi-criteria decision-making and strategic management in public infrastructure contexts. While MCDM methods like AHP have been extensively applied to operational and tactical decisions in transportation engineering (Vaidya and Kumar, 2006), their integration with strategic analysis frameworks such as SWOT-TOWS for investment-level decisions remains relatively underexplored. This study demonstrates that the sequential combination of qualitative strategic diagnosis and quantitative priority weighting produces richer and more actionable outcomes than either approach applied independently. The SWOT-TOWS analysis provides contextual depth and strategic directionality that purely numerical AHP outputs cannot capture, while the AHP quantification provides the rigor and reproducibility that qualitative strategic analysis alone cannot deliver. This complementary relationship suggests that future research on infrastructure investment decision-making should consider hybrid methodological designs that bridge the qualitative-quantitative divide.

The practical implications of this study extend beyond academic contribution to directly inform infrastructure governance and investment planning. For PT Hutama Karya and BPJT, the proposed framework provides a systematic basis for evaluating new toll road segment proposals by establishing quantifiable criteria weights that can be applied to individual segment assessments. The dominance of connectivity and technical factors (combined weight: 0.313) over policy factors (0.055) suggests that institutional decision-making should reorient toward technical and network considerations rather than political or administrative convenience. For the Ministry of PUPR, the framework offers a transparent basis for justifying investment decisions to multiple stakeholders, including parliament, investors, and the public, thereby strengthening institutional accountability and reducing the perception of politically motivated project prioritization.

Furthermore, the framework's integration of SWOT-TOWS strategic analysis provides a mechanism for anticipating and responding to changing environmental conditions. The identification of critical weaknesses (land acquisition delays, cash flow constraints) and threats (demand uncertainty, funding cessation) enables proactive risk management rather than reactive crisis response. The periodic application of this framework, incorporating updated data on traffic volumes, economic conditions, and regulatory developments, would support adaptive investment planning that maintains strategic coherence while accommodating evolving circumstances. This dynamic capability represents a significant advancement over the current static and fragmented prioritization approach that has characterized JTTS investment decision-making to date.

The present study's findings align with and extend the growing body of literature emphasizing the necessity for evidence-based infrastructure governance in developing countries. The World Bank (2021) has consistently advocated for transparent, multi-criteria evaluation frameworks in infrastructure investment decision-making, arguing that politically motivated project selection leads to resource misallocation and undermines long-term development outcomes. The AHP-SWOT/TOWS framework developed in this study operationalizes this recommendation by providing a concrete, implementable tool that transforms abstract governance principles into measurable decision criteria. The framework's emphasis on network integration, technical conditions, and economic impact as primary determinants directly responds to the World Bank's call for infrastructure decisions that prioritize connectivity, efficiency, and development impact over political expedience.

Moreover, the findings carry significant implications for the broader agenda of infrastructure reform in Indonesia. The government's commitment to accelerating infrastructure development, as articulated through the National Strategic Project (PSN) framework and successive presidential regulations, requires complementary institutional mechanisms that ensure investment quality alongside investment quantity. The proposed framework addresses this need by introducing systematic quality assurance into the prioritization process, ensuring that accelerated development does not come at the cost of financial sustainability or operational effectiveness. The periodic application of the framework, incorporating updated traffic data, economic indicators, and stakeholder assessments, would support a dynamic and adaptive approach to infrastructure planning that maintains strategic coherence while responding to evolving conditions. This adaptive capacity is particularly important in the post-pandemic economic environment where traditional demand forecasting models may require recalibration to account for structural changes in mobility patterns, remote work adoption, and evolving logistics networks across Sumatra.

In the context of Indonesia's long-term development vision, the effective prioritization of JTTS investments has implications beyond the toll road sector itself. The Trans-Sumatra corridor serves as a backbone for regional integration, supporting the development of industrial corridors, agricultural supply chains, tourism circuits, and cross-border trade linkages. Misaligned investment priorities in toll road development can create cascading effects across these interconnected economic systems, either by failing to provide timely connectivity where economic potential is greatest or by overinvesting in corridors where demand remains insufficient to justify the infrastructure expenditure. The AHP-SWOT/TOWS framework provides a mechanism for anticipating and managing these systemic interdependencies by incorporating economic impact, spatial planning compatibility, and regional development considerations alongside traditional technical and financial criteria.

This study acknowledges several limitations that should be considered in interpreting the results. First, the AHP model was developed at the criteria level without being applied to rank specific JTTS segments, which would require additional segment-level data and assessments. Second, the respondent pool was limited to BUJT-affiliated experts within PT Hutama Karya, potentially introducing institutional perspective bias that may not fully represent the views of regional governments, local communities, or private investors. Third, the study employed classical AHP without incorporating uncertainty quantification methods such as Fuzzy AHP (Ishizaka & Labib, 2011), which could provide more nuanced results in contexts with inherent judgment ambiguity. These limitations present opportunities for future research to extend and refine the proposed framework.

CONCLUSION

This study developed an integrated decision-making model for prioritizing investment projects within the Trans-Sumatra Toll Road (Jalan Tol Trans Sumatera [JTTS]) program by combining SWOT–TOWS analysis with the Analytic Hierarchy Process (AHP). The findings identified several weaknesses in the existing prioritization process, including operational risks, funding and cash flow constraints, land acquisition delays, and insufficient consideration of network integration, economic impact, and financial sustainability. Based on judgments provided by 34 expert respondents, the AHP results identified Transportation Network Integration and Connectivity as the highest-priority criterion, followed by Technical and Geometric Conditions, Economic Impact and Regional Distribution, and Financial Feasibility. The resulting consistency ratio (CR) of 0.04 indicated an acceptable level of consistency in the pairwise comparison judgments. The SWOT–TOWS results indicated that future JTTS investments should prioritize projects that strengthen network connectivity, regional development, logistics efficiency, and financial sustainability while incorporating appropriate financing strategies and risk management measures. Theoretically, this study contributes an integrated qualitative–quantitative framework for infrastructure investment prioritization. Practically, it provides a structured, transparent, and replicable decision-support framework for relevant stakeholders, including the Ministry of Public Works, the Toll Road Regulatory Agency (Badan Pengatur Jalan Tol [BPJT]), and PT Hutama Karya (Persero). Future implementation should incorporate institutionalized multicriteria evaluation procedures, standardized scoring mechanisms, transparent technical justification in investment and policy documents, and broader expert participation. Future research could further extend the model by integrating Geographic Information Systems (GIS), real-time data, Fuzzy AHP, the Analytic Network Process (ANP), and sustainability indicators to enhance infrastructure investment prioritization and decision-making.

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