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Critical Analysis of Toll Road Investment Through a Systematic Literature Review Approach: Trends, Challenges, and Opportunities

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ABSTRACT

Toll Road Investment is a key strategy in transportation infrastructure development aimed at improving connectivity, logistics efficiency, and economic growth. However, financing complexity, regulatory uncertainty, and socio-political risk dynamics make this investment face serious challenges. Twenty scientific articles published in Q1–Q3 between 2019–2024 were evaluated based on their study focus, key findings, geographic context, and journal rankings. The research results indicate that toll road investment trends are undergoing a significant transformation, marked by the dominance of Public–Private Partnership (PPP) schemes, the integration of digital technology, and a lifecycle-based management approach. Meanwhile, the key challenges identified include a weak regulatory framework, financial risks, limited government capacity, and minimal stakeholder involvement. Conversely, opportunities can be leveraged through strengthening project governance, utilizing innovative contract models, and adopting risk- and sustainability-based performance evaluation systems. These findings are expected to provide theoretical and practical contributions to academics, policymakers, and investors in designing more adaptive and sustainable toll road investment strategies in the future

KEYWORDS *Toll Road Investment; Public-Private Partnership; Infrastructure Risk; SLR; Transportation Policy.*

INTRODUCTION

Investment in toll road infrastructure has become a strategic element of economic development in various countries, including Indonesia. Toll roads not only serve as high-speed transportation routes but also act as drivers of regional growth by improving connectivity, logistics efficiency, and inter-regional accessibility. In the context of national development, toll roads play a crucial role in reducing distribution costs, encouraging population mobility, and opening access to new economic centers that were previously geographically isolated. Therefore, toll road development is a top priority in sustainable infrastructure policies.

However, the implementation of toll road projects is not without complex, multidimensional challenges. Large financing requirements, slow land acquisition processes that risk triggering social conflict, and the potential for technical failures during construction and operational phases are often major obstacles. Furthermore, limited government fiscal capacity and regulatory uncertainty add another layer of challenges that hinder the realization of toll road projects on a national scale (Fauzan, Kuswanto, & Utomo, 2023).

Investment in toll road projects, therefore, requires a financing approach that is more adaptive to long-term risks, cash flow volatility, and political and institutional dynamics. One approach that has seen significant growth is the Public–Private Partnership (PPP), where the government and the private sector share responsibilities, risks, and benefits within a single

contractual framework. Through this scheme, the government can alleviate budgetary pressures, while private investors gain participation in public infrastructure development. As the demand for toll road investment increases, project financing and governance models are also undergoing transformation. A bibliometric study by Azarian et al. (2024) noted a surge in scholarly interest in infrastructure investment issues within the PPP context, particularly those related to regulation, risk management, and sustainability.

Various studies have shown that the success of toll road investment through PPPs is largely determined by institutional design and flexible financing structures. Castelblanco et al. (2024) developed a dynamic, project lifecycle-based model to manage financial aspects more responsively. Endo et al. (2021) emphasized that achieving financial close in toll road projects is significantly influenced by legal certainty, institutional support, and government guarantees. Meanwhile, Fatima et al. (2024) proposed a risk-based approach to assess and manage the overall performance of PPP projects.

Although PPPs are seen as capable of accelerating infrastructure development, various challenges remain in practice. Inequality in risk sharing (Li et al., 2024), political interference leading to premature contract termination (Tang et al., 2023), and a lack of transparency in procurement processes (Oliveros-Romero et al., 2023) are recurring issues. In the Indonesian context, the main problems lie in weak public sector governance, limited institutional capacity, and ineffective inter-agency coordination (Rohman et al., 2021; Winata et al., 2023). Failure to fully engage stakeholders at every stage of the project is also a serious obstacle (Uddin et al., 2023).

On the other hand, the complexity of toll road projects in the modern era demands innovation in management systems. Recent literature proposes the integration of digital technology and information systems based on the infrastructure lifecycle. Huang et al. (2024) developed a digital framework for toll road asset management that can improve decision-making. The transformation to an electronic toll system is also considered crucial for strengthening efficiency and accountability, as explained by Shahrier et al. (2023). From an environmental perspective, green tollway strategies are beginning to be developed to address the challenges of reducing emissions and achieving sustainability targets (Shang et al., 2024).

Although numerous studies have addressed various aspects of PPP-based toll road investment, most remain sector-specific and have not comprehensively integrated the three main dimensions—trends, challenges, and opportunities. Most available analyses focus on technical or financial aspects in isolation, without fully considering policy and institutional dynamics. This gap underpins the development of this study. Using a Systematic Literature Review (SLR) approach, this article offers a critical analysis of the dynamics of toll road investment over the past five years (2019–2024), presenting a thematic synthesis based on empirical evidence and cross-disciplinary conceptual reflection.

This research aims to identify and analyze current trends in toll road investment based on scientific literature published in the past five years; to examine and classify the main challenges faced in its implementation, spanning regulatory, financial, and institutional aspects; and to explore and evaluate emerging strategic opportunities within toll road investment schemes, including the roles of technology, financial innovation, and policy reform. By integrating these three critical dimensions through a systematic review, this study is expected to provide significant theoretical and practical contributions. It offers academics a

synthesized, cross-disciplinary understanding of the field's evolution, while equipping policymakers and investors with an evidence-based framework to design more adaptive, sustainable, and risk-informed investment strategies. Ultimately, this work addresses a notable literature gap by moving beyond isolated, sector-specific analyses toward a holistic view essential for navigating the complex future of transportation infrastructure development.

METHOD

This study uses a Systematic Literature Review (SLR) approach as the primary method to identify, critically assess, and synthesize relevant scientific literature on toll road investment. SLR was chosen because it provides a structured, transparent, and replicable methodological framework, enabling comprehensive, evidence-based conclusions to be drawn. This method is relevant because the theme of toll road investment is multidimensional—encompassing policy, financial, technical, and social aspects—and is spread across various cross-disciplinary studies.

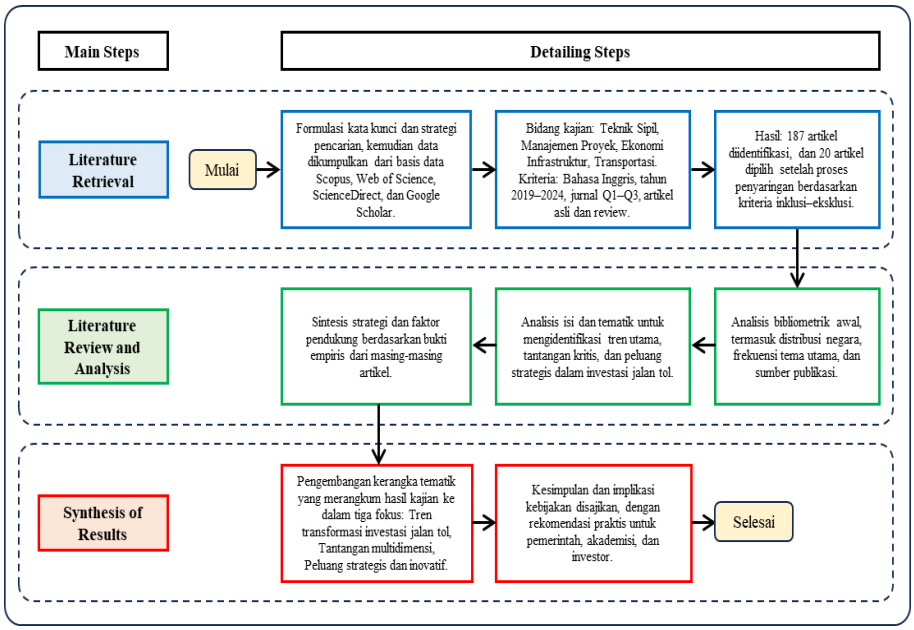

Figure 1. Research Method Flowchart
Source: Author's analysis (2025)

Research Protocol and Search Strategy

Before beginning the data collection and analysis process, the author developed a research protocol that served as the primary guideline for this SLR. This protocol included the study objectives, primary research questions, literature search strategy, and inclusion and exclusion criteria for article selection. The protocol was designed to ensure a systematic literature review process free from selection bias. The primary objective of this study is to provide a comprehensive overview of development trends, critical challenges, and strategic opportunities in toll road investment based on academic findings from the past five years.
The primary research question that underpinned the development and screening of the literature is as follows:

"What are the main trends, challenges, and opportunities in toll road investment as reflected in the scientific literature indexed in Q1–Q4 over the past five years?"

Based on this question, the search strategy focused on accommodating various perspectives in the literature, including empirical, theoretical, and conceptual studies. The literature was collected through exploration of four credible international scientific databases: Scopus, Web of Science (WoS), ScienceDirect, and Google Scholar. These four databases were selected for their multidisciplinary coverage, accessibility to reputable journals, and ease of reference management. The search process was conducted between March and April 2025.

Search keywords were determined through internal discussions and a pilot search. The keywords used were a combination of technical and practical terms reflecting the three main focuses of the study: trends, challenges, and opportunities. These keywords included: toll road investment, highway investment, infrastructure finance, project finance, public–private partnership, infrastructure development, transportation infrastructure, investment challenges, investment opportunities, emerging trends, and risk management. Boolean operators such as AND, OR, and NOT were used to broaden or narrow the scope of search results. For example, combinations such as "PPP" AND "toll road" AND "risk management" were used to identify literature focusing on risk management in public–private partnership-based toll road projects.

Study Inclusion and Exclusion Criteria

To ensure that the literature obtained was relevant to the study's focus and objectives, strict inclusion and exclusion criteria were established. These criteria served as the basis for the initial and final selection of all articles identified. The criteria are listed in Table 1 below:

Table 1. Inclusion and Exclusion Criteria

Criteria	Information	
Inclusion	Published in 2019–2024	According to the scope of the study of the last five years
	Peer-reviewed scientific journal	Minimum indexed by Scopus Q1–Q3
	Focus on toll road investment or PPP schemes for transportation infrastructure	Must have a main discussion about the toll road project, both financial, institutional and technical aspects.
	Available in English	To ensure consistency and appropriateness of the analysis
	Fully accessible in PDF format	For the purposes of data extraction and thematic analysis
Exclusion	The article is only an abstract	Does not allow for in-depth analysis
	Non-scientific reports, news, or conference proceedings	Does not meet SLR academic standards
	The study is not related to the toll road/transportation infrastructure sector.	Out of scope of research theme
	Redundancy or duplication of articles	The same article was published in two places

Source: Developed by the author based on the SLR protocol (2025)

Literature Selection Process The literature selection process is carried out in the following stages:

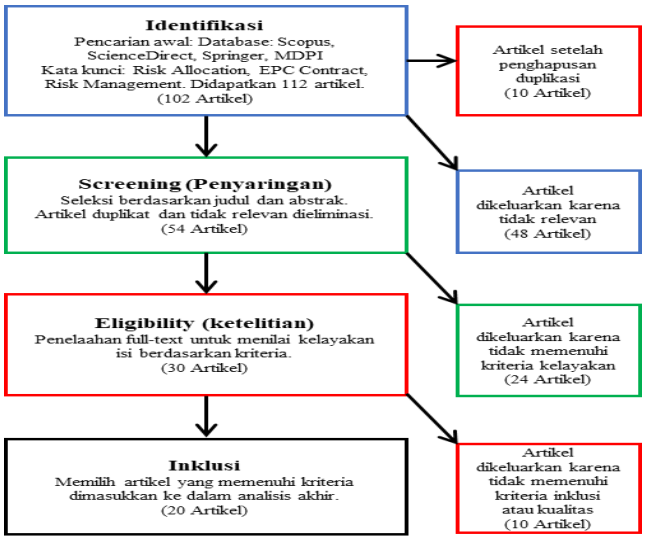

Figure 2. PRISMA process flow diagram literature sampling

Source: Adapted from the PRISMA 2020 guidelines by the author (2025)

The process details are as follows

a. Initial Identification

The search was conducted in four major academic databases: Scopus, Web of Science, ScienceDirect, and Google Scholar. Using a combination of relevant keywords, 112 initially relevant scientific articles were identified.

b. Duplicate Filtering

Duplicate articles between databases were removed, resulting in 102 unique documents for further selection.

c. Title and Abstract Selection

An evaluation of titles and abstracts was conducted to assess their relevance to the study's main topic, namely toll road investment in the context of public–private partnerships and risk management. This stage resulted in 54 articles deemed relevant.

d. Full-text Review

Next, a comprehensive review of the full content of the articles was conducted to assess methodological completeness, argument quality, and topic relevance. From this stage, 30 articles were selected for final evaluation.

e. Final Evaluation (Eligibility Check)

Based on predetermined inclusion–exclusion criteria, such as publication period (2019–2024), journal classification (Q1–Q3), and substance suitability, 20 scientific articles that were most relevant and met high-quality requirements were selected for analysis in this study.

Data Analysis After the selected articles were collected, a data extraction process was conducted, covering the following elements: author name and year of publication, article title, main focus of the study, main findings, geographic context, and journal ranking. All data were compiled in a thematic synthesis table format (see Table 2 in the results section). Next,

narrative synthesis and thematic analysis were conducted to group the findings into three main themes: a. Trends: general patterns or changes in investment and project management approaches, b. Challenges: recurring structural and technical barriers, c. Opportunities: potential for future development based on best practices or current innovations. This analysis aims to reveal the contribution of each study to the development of knowledge and practice in the field of toll road investment, while also explaining the relationships between variables that frequently appear in the literature.

RESULT AND DISCUSSION

Based on the synthesis results of 20 scientific journals analyzed, several important findings were identified, which can generally be grouped into three broad categories: (1) trends in toll road investment practices and approaches, (2) key challenges faced in their implementation, and (3) strategic opportunities that can be optimized in the future. Each category was analyzed thematically based on the study focus of each article.

Trends in Toll Road Investment

Global trends in toll road investment indicate a paradigm shift from traditional financing that relies on the state budget toward a more flexible and risk-oriented Public–Private Partnership (PPP) scheme. Several journals emphasize that PPPs enable time and cost efficiencies (Winata & Gultom, 2023) and expand private participation in long-term infrastructure management (Castelblanco et al., 2024). Furthermore, studies by Esperilla-Niño-de-Guzmán et al. (2023) and Azarian et al. (2024) show that the evolution of PPPs is influenced by institutional factors, regulatory developments, and the adoption of sustainability principles.

Another important trend is the adoption of digitalization and smart technology in toll road asset management. Huang et al. (2024) and Li et al. (2024) demonstrate that digitalization of the infrastructure lifecycle and the use of multi-objective evaluation systems for smart highways are becoming the new norm in project development. A shift toward greater use of life-cycle financing models and adaptive contracts such as SBOT and DBFOM has also been identified, as discussed by Castelblanco (2024) and Winata & Gultom (2023). These contracts are considered more responsive to operational uncertainty and traffic dynamics.

Challenges in Toll Road Investment

Despite significant progress, toll road investment through PPP schemes continues to face substantial systemic and multidimensional challenges. Studies by Nguyen & Tung (2023) and Endo et al. (2021) revealed that regulatory uncertainty, weak government institutional capacity, and disintegrated decision-making processes are key obstacles to smooth project implementation. Financial close issues resulting from low project credibility and suboptimal risk mitigation schemes are also common—particularly in developing countries such as Indonesia. This is confirmed by findings from Endo, Gianoli & Edelenbos (2021) and Rohman et al. (2021), which highlight the lack of institutional support and limited government monitoring mechanisms.

Additionally, studies by Wibowo et al. (2012) and Fatima et al. (2024) identify financial, political, and legal risks as major barriers in BOT and DBFOM projects. Structural political risks, such as public pressure and central government intervention, may even lead to premature termination of PPP contracts (Tang et al., 2023). Another persistent challenge is uneven stakeholder involvement and lack of community participation. Uddin et al. (2023) show that

differences in stakeholder network structures across public, private, and PPP projects can affect the quality of project outcomes.

Opportunities in Toll Road Investment

Despite the high complexity of toll road projects, the reviewed literature also reveals several strategic opportunities that can enhance investment effectiveness and sustainability. First, strengthening institutional frameworks and project governance has emerged as essential for success. Research by Winata & Gultom (2023) and Guevara et al. (2022) suggests that establishing a collaborative sponsorship network (SPV) and a clear incentive mechanism can increase investor confidence and project sustainability.

Second, there is significant potential in implementing a risk-based approach and integrated performance measurement. Fatima et al. (2024) developed a PPP performance assessment framework based on 16 performance indicators and 10 key risk types, providing a practical guide for objective and comprehensive infrastructure evaluation.

Third, innovations based on digital technology—such as electronic toll collection, real-time sensor systems, and digital twins for asset maintenance—offer opportunities to achieve high efficiency in the operation and maintenance phases (Shahrier et al., 2023; Huang et al., 2024).

Fourth, toll road projects can also contribute to decarbonization and environmental efficiency targets. Shang et al. (2024) introduced the concept of a green tollway based on the government's post-BOT operational strategy, which considers carbon emissions as an efficiency parameter. Finally, evaluative approaches that integrate social and spatial dimensions require further development. Oliveros-Romero & Aibinu (2023) emphasize the importance of ex-post evaluation from multiple stakeholder perspectives, particularly in assessing socio-economic impacts such as urban segregation and tariff equity.

Critical Discussion

Findings from the 20 journals analyzed indicate that toll road investment through Public–Private Partnership (PPP) schemes is a promising approach—though still fraught with challenges. The literature generally agrees that digitalization, lifecycle-based financial models, and heightened awareness of sustainability represent leading trends in toll road infrastructure development. However, the adoption of these trends remains uneven, as many countries face institutional constraints, regulatory uncertainty, and high political and social risks.

A major criticism evident in the literature is the unequal geographical distribution of studies. Most research focuses on developing countries in Asia and Latin America, such as Indonesia, Vietnam, Colombia, and China. Meanwhile, regions such as Sub-Saharan Africa, Eastern Europe, and small Pacific nations are virtually absent from the global discourse, suggesting a significant geographic gap.

Methodologically, the studies analyzed employ diverse approaches—ranging from qualitative analyses and mathematical modeling to bibliometric reviews. This diversity enriches perspectives but also poses challenges in generating cross-country generalizations due to the absence of a uniform analytical framework. Thematically, while many studies emphasize financial and political risks (Wibowo et al., 2012; Tang et al., 2023), few explicitly address social and environmental risks, such as resistance to land acquisition or post-construction spatial impacts (Oliveros-Romero & Aibinu, 2023). This indicates that the socio-ecological

dimensions of toll road investment remain underexplored, despite their critical importance for long-term sustainability.

The implications of these findings underscore the need for a cross-sectoral and multi-actor approach in toll road project planning. Governments, investors, and communities should be engaged in more participatory and adaptive forms of governance. Furthermore, performance-based evaluation systems—such as the model proposed by Fatima et al. (2024)—are essential to ensure that project success is measured not only in financial terms but also through social and environmental outcomes.

Theoretically, this synthesis enriches understanding of the dynamics of infrastructure investment in developing countries and promotes the development of a more inclusive and risk-responsive theory of PPP governance. Practically, the results of this study can inform policymakers and investors in designing investment policies that are more contextual and adaptable to global challenges.

Study Synthesis Table

The following table summarizes the 20 scientific articles reviewed in this study, including author details, main focus, and the contribution of the findings to a comprehensive understanding of the toll road investment landscape..

Table 2. Study Synthesis Table

No.	Author (Year)	Original Title of Article	Study Focus	Key Findings	Country /Context	Q
1	Soria-Lara *et al* . (2021)	*Environmental Impact Assessment for Transport Projects: A Review of Technical and Process-Related Issues*	Environmental Impact	Technical and procedural challenges of EIA; the importance of transparency, public participation, and integration of EIA from the outset of the project	Global	Q1
2	Esperilla-Niño-de-Guzmán *et al* . (2023)	*Public–Private Partnerships in Road Infrastructure Projects: A Review of Evolution, Approaches, and Prospects*	Toll Road PPP	Review of PPP evolution and approaches; the importance of institutional, financial and sustainability frameworks in toll road projects	Global	Q1
3	Shahrier *et al* . (2023)	*Towards Intelligent Transportation Systems: A Comprehensive Review of Electronic Toll Collection Systems*	Digital Technology (ETC)	Interoperability and security are key issues in ETC development	Global	Q2

No.	Author (Year)	Original Title of Article	Study Focus	Key Findings	Country /Context	Q
4	Endo, Gianoli & Edelenbos (2021)	*Coming to Financial Close in PPPs: Identifying Critical Factors in the Case of Toll Road Projects in Indonesia*	Financial Close PPP	The main factors for the success of financial close: *political will* , institutional support, regulatory clarity, and project credibility.	Indonesia	Q1
5	Wibowo *et al* . (2012)	*Ranking Risks of BOT Toll Road Investment Projects Using the Delphi Method and Fuzzy AHP*	Investment Risk	The most dominant financial, political and legal risks in toll road BOT projects	Indonesia–Taiwan	Q2
6	Nguyen & Tung (2023)	*Failure of PPP Mechanism: A Cross-Country Analysis of Unique Issues in Road Sector in Southeast Asian Markets*	Regulation & PPP Failure	PPP failure is caused by weak institutions, regulatory inconsistencies, and limited government capacity.	Southeast Asia	Q1
7	Castelblanco *et al* . (2024)	*Financial System Dynamics Model for Multidimensional Flexibility in Toll Road PPPs: A Life-Cycle Analysis*	Financial Model	Multidimensional flexibility is needed in the financial model so that toll road PPPs can adapt to the uncertainty of the project life cycle.	Global	Q1
8	Rohman *et al* . (2021)	*Assessment of the Government's Role Performance in Public-Private Partnership (PPP) Toll Road Projects in Indonesia*	Role of Government	The government's performance is considered to be lacking in terms of monitoring and regulatory support.	Indonesia	Q3
9	Huang *et al* . (2024)	*A Framework of Life-Cycle Infrastructure Digitalization for Highway Asset Management*	Toll Road Digitalization	There is a need for comprehensive digitization of road infrastructure data, with interoperable systems across the lifecycle to support efficient and sustainable	China	Q2

No.	Author (Year)	Original Title of Article	Study Focus	Key Findings	Country /Context	Q
				asset management.		
10	Shang *et al* . (2024)	*Green Tollways: Strategizing Carbon-Emissions-Based Government-Owned Public Toll Road Operations in China*	Toll Road Operations & Carbon Emissions	After the BOT ends, the road will continue to be tolled by the government for efficiency; the study analyzed operational costs including carbon emissions and suggested sustainability-based management strategies.	China	Q2
11	Castelblanco *et al* . (2023)	Environmental Impact Assessment Effectiveness in Public–Private Partnerships: Study on the Colombian Toll Road Program	Effectiveness of Amdal in Toll Road PPP Projects	The effectiveness of an EIA depends on a combination of consultant skills, project characteristics, and community participation. No single combination of conditions guarantees multidimensional effectiveness.	Colombia	Q1
12	Winata & Gultom (2023)	*The Effects of Governance on Performance: The Case of Public–Private Partnership (PPP) Toll Roads in Indonesia*	Contract Model & Project Performance	SBOT and DBFOM contracts have proven to be more efficient than BOT in terms of cost and completion time due to better incentive structures and upfront management.	Indonesia	Q2
13	Fatima *et al* . (2024)	*Risk-based Integrated Performance Assessment Framework for Public–Private Partnership*	Risk and Performance Management	Develop a risk-based performance assessment framework with 16 performance indicators and 10	Pakistan, Global	Q2

No.	Author (Year)	Original Title of Article	Study Focus	Key Findings	Country /Context	Q
		Infrastructure Projects		key risks (financial, legal, operational, environmental, etc.), to improve PPP project evaluation and outcomes.		
14	Azarian *et al* . (2024)	*Public-Private Partnership: A Bibliometric Analysis and Historical Evolution*	Bibliometric Analysis & Concept Evolution	PPP has experienced significant development across various disciplines. Key elements of PPP research trends include *sustainability* , technology, and *smart infrastructure.*	Global (Bibliometric *review* since 1979)	Q2
15	Uddin, Ong & Matous (2023)	*Stakeholder engagement variability across public, private and public-private partnership projects: A data-driven network-based analysis*	Stakeholder Engagement	There are significant differences in the structure of stakeholder networks between public, private, and PPP projects; this involvement influences project outcomes.	Australia	Q1
16	Tang, Wang & Yang (2023)	*Political Influences of Stakeholders on Early Termination of Public-Private Partnerships: A Study on China's Toll Road Projects*	Political Risk	Political pressure from the central government and the public as well as political relations influenced the early termination of PPP projects.	China	Q1
17	Guevara, Herrera-Castro & Salazar (2022)	*Interorganizational Sponsor Networks in Road and Social Infrastructure PPP Equity Markets*	Sponsor / SPV Collaboration	Sponsors form a *self-organizing network* in the formation of SPVs, demonstrating the important role of dominant actors in the sustainability of PPPs.	Six European countries:,	Q1

No.	Author (Year)	Original Title of Article	Study Focus	Key Findings	Country /Context	Q
18	Oliveros-Romero & Aibinu (2023)	*Ex-post impact evaluation of PPP projects from multiple stakeholder perspectives: a toll road case*	Project Impact Evaluation (Ex-post)	Developing an ex-post impact evaluation method based on the *Project Success Evaluation Pyramid* (PSEPM) model to measure the success of PPP projects from multiple stakeholder perspectives. A case study of Chilean toll roads reveals issues of urban segregation, weak business models, and ineffective pricing strategies.	Chile	Q1
19	Mengzhuo Li, Xincheng Wu, Xiying Yue, Xiaomin Dai (2024)	*Investment Risk Assessment and Countermeasure Strategies for Highway PPP Projects in Western China*	Investment Risk	Highest risk at O&M stage; dynamic modeling approach reveals risk accumulation pathways and mitigation solutions	China (Western Region)	Q1
20	Li Li, Yixin Long, Chongmei Peng (2024)	*A Multi-Objective Evaluation Method for Smart Highway Operation and Management*	Smart Toll Road Operational Evaluation	Smart highway management requires technology-based multi-objective evaluation methods and expert participation to improve system efficiency.	China	Q1

Source: Author's synthesis of data from 20 selected articles (2019–2024)

This synthesis not only serves as a foundation for understanding toll road investment trends, challenges, and opportunities, but also serves as a basis for strategic decision-making in the transportation infrastructure sector. These systematically reviewed findings are expected to provide a useful reference for policymakers, investors, and practitioners in formulating sustainable and adaptive toll road development strategies to address global dynamics. Furthermore, this synthesis can also serve as a starting point for further empirical and more

contextual studies, particularly those focusing on cross-country comparative approaches, public policy evaluations, or the development of risk- and sustainability-based investment performance measurement frameworks.

CONCLUSION

Thematic analysis of the literature shows a clear shift in toll road investment toward collaborative, cost-efficient, sustainable, and digitally enabled models, with PPPs increasingly dominant for flexible financing and management. This trend is accompanied by technology-based evaluation systems and end-to-end lifecycle digitalization that enhance operational efficiency. However, material constraints persist—regulatory frictions, institutional capacity gaps, political uncertainty, suboptimal stakeholder engagement, and significant financial or legal risks that impede financial close and long-term viability. These challenges are compounded by uneven risk allocation and weak public oversight, signaling the need for institutional reform and policy harmonization.

Even so, actionable opportunities remain through stronger project governance, lifecycle contract structures such as DBFOM and SBOT, and performance evaluation systems tightly integrated with risk management—further amplified by advancing technologies and rising sustainability expectations. Accordingly, future research and practice should widen geographic coverage beyond Asia and Latin America to include underexplored regions (e.g., Sub-Saharan Africa and parts of Eastern Europe) through comparative, cross-country studies. Scholars should also deepen inquiry into social–environmental dimensions—long-term social impacts, spatial equity, and community resistance—using multidisciplinary methods. There is a need to develop integrated, risk- and sustainability-based evaluation frameworks with indicators spanning economic, social, and environmental outcomes, multidimensional risks, and long-term public value. Moreover, public–private–civil society collaboration must be operationalized under transparent, stable policy regimes while scaling digital capabilities—such as real-time evaluation, digital twins for maintenance, and AI-driven tariffing—to improve efficiency, reduce costs, and extend asset life. Overall, success depends less on the financing scheme itself and more on the coherent alignment of institutions, regulation, technology, and stakeholder commitment so that strategies remain effective, sustainable, and responsive to evolving global dynamics.

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