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STRATEGIC RISK MANAGEMENT THROUGH LEAN CONSTRUCTION–ENHANCED MITIGATION: THE SITINJAU LAUIK FLYOVER PROJECT, INDONESIA

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ABSTRACT

The Sitinjau Lauik Flyover Project is a strategic infrastructure initiative in West Sumatra designed to address severe geometric constraints and safety risks along a critical logistics corridor. Delivered under a Design–Build–Finance–Operate–Maintain–Transfer (DBFOM) Public–Private Partnership (PPP) scheme with an investment value of IDR 2.793 trillion (approximately USD 175 million), the project operates within a complex planning environment characterized by geotechnical instability, environmental constraints, and an aggressive construction timeline. These conditions require robust risk mitigation planning at an early project stage. This study adopts a scenario-based comparative approach to examine how Lean Construction can enhance risk mitigation planning compared to conventional practices. Using a project risk register as the primary data source, inherent and residual risk profiles are compared under two mitigation scenarios: conventional mitigation and Lean Construction–enhanced mitigation. Residual risk values are assessed through scenario-based estimation to support comparative analysis rather than predict actual performance outcomes.

The results indicate that Lean Construction enhances mitigation robustness by reducing risk probability and exposure through improved planning reliability, early alignment, and constraint management. The findings suggest that Lean Construction can function as a planning-level risk mitigation enhancer, complementing conventional controls in complex infrastructure PPP projects.

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KEYWORDS

Risk management, lean construction, PPP, infrastructure project, risk mitigation.

INTRODUCTION

Infrastructure development in West Sumatra is strongly influenced by complex mountainous topography that constrains connectivity between coastal commercial centers and inland regions (Akmelliona & Arif, 2024). The Sitinjau Lauik route serves as a critical logistics corridor linking Padang City and Solok City; however, steep slopes reaching 70°–80° make the corridor highly susceptible to landslides and recurrent disruptions, undermining safety, logistics reliability, and regional economic competitiveness (Akmelliona & Arif, 2024; Nurhayati & Febrian, 2025).

To address these challenges, the Sitinjau Lauik Flyover has been proposed as a strategic infrastructure intervention aimed at improving route reliability and resilience within the national logistics system (Rinjayadi & Utomo, 2025). The project is delivered under a Design–Build–Finance–Operate–Maintain–Transfer (DBFOM) Public–Private Partnership (PPP) scheme, in which lifecycle risks are transferred to the private sector and revenue is governed by an availability payment mechanism (Winata & Gultom, 2024; Ministry of Public Works, 2026). Under this arrangement, construction readiness and schedule discipline are critical, as delays defer revenue while financing costs continue to accrue (Hutama Karya, 2025).

Despite the high-risk planning environment, risk mitigation in infrastructure projects has traditionally relied on conventional approaches. These approaches emphasize rigid scheduling, fragmented production logic, and reactive contractual controls such as penalties and liquidated damages (Salem et al., 2006; Sari et al., 2025). In complex terrains such as Sitinjau Lauik, reactive measures may intensify congestion, increase safety exposure, and generate diminishing returns, while empirical evidence indicates persistent inefficiencies driven by poor coordination (Salem et al., 2006; Sari et al., 2025).

Lean Construction offers a contrasting, process-oriented framework that emphasizes planning reliability, workflow stability, and waste reduction. Rooted in the Toyota Production System, Lean Construction conceptualizes construction as a value-generating flow rather than a sequence of isolated activities, addressing variability and misalignment at the planning stage (Salem et al., 2006).

While prior studies have examined strategic risk management in PPPs and the operational benefits of Lean Construction, these domains are rarely integrated at the planning stage. PPP risk management literature primarily focuses on contractual governance and financial safeguards, whereas Lean Construction research emphasizes execution-phase improvements. Consequently, limited attention has been given to Lean Construction as a planning-level risk mitigation enhancer in high-risk PPP projects.

This study adopts a scenario-based comparative analysis at the planning stage to examine differences between conventional mitigation and Lean Construction–enhanced mitigation. Using project risk registers and planning documents, the study compares inherent and residual risk profiles under both scenarios to assess how Lean Construction may enhance mitigation robustness.

LITERATURE REVIEW

Strategic risk management in infrastructure Public–Private Partnerships (PPPs) has evolved from static risk lists toward integrated, lifecycle-oriented frameworks due to the long-term horizons and multi-stakeholder nature of such projects (Ahmadabadi & Heravi, 2019). In Design–Build–Finance–Operate–Maintain (DBFOM) schemes, risks are consolidated across project phases, creating strong interdependencies in which early-stage planning failures may

propagate into significant financial and operational consequences during the operational period (Ahmadabadi & Heravi, 2019). Consequently, effective risk mitigation planning at the early stages is critical to maintaining value-for-money and long-term project viability.

Prior studies emphasize structured and multi-level risk identification approaches to capture interactions between political, regulatory, technical, and operational risks across the project lifecycle (Xu et al., 2010). Within PPP contexts, strategic risk management is also closely linked to risk allocation principles, whereby risks should be assigned to parties best positioned to manage them. However, empirical evidence shows that risks related to land acquisition, permitting, and environmental constraints often fall into governance "grey areas," requiring coordinated mitigation rather than contractual risk transfer alone (Carbonara et al., 2015; Wang et al., 2023). From a financial perspective, inadequate management of such planning-stage risks may delay revenue commencement under Availability Payment schemes and erode project bankability (Winata & Gultom, 2024).

Lean Construction (LC) offers a process-oriented perspective that contrasts with conventional Business as Usual (BAU) approaches embedded in PPP risk management practice. Rooted in the Transformation–Flow–Value (TFV) framework, LC emphasizes planning reliability, workflow stability, and value generation rather than reactive control of downstream impacts (Salem et al., 2006). Prior research suggests that planning-oriented lean practices can reduce variability and coordination failures that commonly originate at the early stages of complex infrastructure projects (Ballard & Pennanen, 2013; Ibrahim et al., 2025). Empirical studies in Indonesia further indicate that lean-based planning improves coordination and reduces systemic inefficiencies frequently observed under BAU approaches (Sari et al., 2025).

METHODOLOGY

This study adopts a scenario-based comparative case study approach conducted at the planning stage of the Sitinjau Lauik Flyover Public–Private Partnership (PPP) Project. The objective is to compare how different mitigation logics influence expected risk profiles, rather than to evaluate realized project performance. The overall research flow is illustrated in Figure 1.

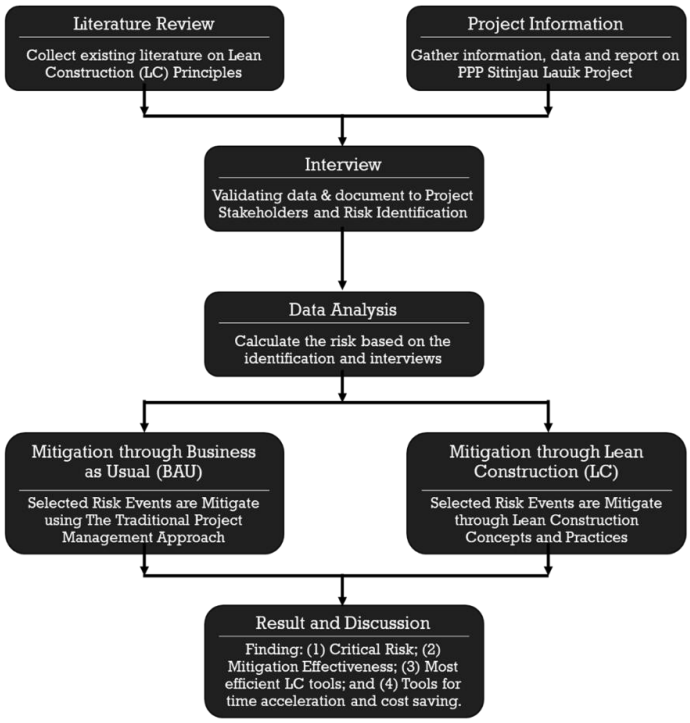

Figure 1: Methodological flow

RESEARCH DESIGN

This study adopts a mixed qualitative–quantitative comparative framework using structured risk scenarios. Two mitigation scenarios are defined for the same set of risks: (1) mitigation based on conventional project practices, and (2) mitigation enhanced with Lean Construction principles. The unit of analysis is the planning-stage mitigation strategy, focusing on how mitigation logic influences risk probability, impact, and exposure.

DATA SOURCES

The analysis is based on project-specific documentation and supporting literature. The primary data source is the **Sitinjau Lauik Flyover Risk Identification Register**, which contains fourteen identified risks, including probability–impact assessments and documented mitigation plans. These mitigation plans serve as the baseline representation of conventional mitigation practices.

Lean Construction–enhanced mitigation is developed by interpreting how relevant Lean principles—such as planning reliability, constraint management, early alignment, and workflow stabilization—can strengthen the existing mitigation strategies. These interpretations are grounded in Lean Construction literature, particularly from IGLC proceedings and peer-reviewed studies, and are adapted to the project context.

For each identified risk, two mitigation scenarios are therefore defined: a **conventional mitigation scenario**, directly derived from the project risk register, and a **Lean Construction–enhanced scenario**, representing a planning-oriented improvement of the same mitigation logic. Together, these sources enable a structured, scenario-based comparison of expected risk behaviour under alternative mitigation approaches.

RISK IDENTIFICATION AND PRIORITIZATION

Risk identification follows the structure defined in the project risk register and is aligned with a Risk Breakdown Structure (RBS), which classifies risks into macro (regulatory and environmental), meso (project and procurement), and micro (technical and operational) levels (Xu et al., 2010). Each risk is assessed using an inherent risk score calculated as:

Inherent Risk = Probability × Impact …… (Xu et al., 2010**)**

A 5×5 risk matrix is applied to identify high-scale risks. To maintain analytical focus, a subset of critical risks is selected based on their risk magnitude and relevance to planning-stage decision-making. This prioritization ensures that the analysis concentrates on risks with the greatest potential influence on project viability.

COMPARATIVE RISK MITIGATION ANALYSIS

The core analysis compares conventional mitigation and Lean Construction–enhanced mitigation by examining their influence on expected risk probability, impact, and exposure. Conventional mitigation is characterized by monitoring, coordination, contingency measures, and reactive adjustments. In contrast, Lean Construction–enhanced mitigation emphasizes planning-stage interventions, including early constraint identification, improved stakeholder alignment, and workflow stabilization. The comparison focuses on differences in mitigation logic rather than implementation performance. The analysis is qualitative in nature but supported by **scenario-based, illustrative risk scoring** to indicate expected directional changes in residual risk.

RESIDUAL RISK ASSESSMENT

Residual risk is estimated by reassessing probability and impact under each mitigation scenario. The difference between inherent and residual risk scores is used to illustrate the relative effectiveness of conventional and Lean Construction–enhanced mitigation approaches. These

residual risk values are **scenario-based and illustrative**, derived to support comparative analysis rather than to predict actual project outcomes. Therefore, the results should be interpreted as **analytical insights into mitigation logic rather than empirical validation of project performance**. Lean Construction–enhanced mitigation is positioned as a complementary planning approach. It does not eliminate externally driven risks such as regulatory constraints or force majeure events, but may influence their probability and exposure through improved planning preparedness

RESULT

The residual risk values presented in this section are derived from scenario-based assessment using the project risk register and do not represent actual project performance. The analysis aims to compare mitigation logic rather than predict realized outcomes. The project risk register contains 14 identified risks categorized across compliance, design, procurement, and operational domains. From this dataset, a subset of high-scale risks is selected to enable focused comparative analysis across different categories.

RISK SELECTION AND CATEGORY REPRESENTATION

Table 1: Screening and Selection of Representative Risks from the Risk Register (n = 14)

Risk Category	Total Risks	High-Scale Risks	Selected for Analysis	Rationale
Compliance	1	1	1	Strong dependency on early approvals and regulatory alignment
Design	1	1	1	High impact if design assumptions fail during execution
Procurement	1	1	1	Supply readiness directly affects planning reliability
Operational	8	5	2	Represents workflow variability and site constraints
QHSSE	2	1	0	Important but less sensitive to planning-stage mitigation
Finance	1	0	0	Limited leverage through planning-stage interventions
Total	**14**	**9**	**5**	Cross-category, planning-sensitive representation

Table 1 presents the screening and selection of risks from the fourteen-risk register. The selection of risks is based on inherent risk scores calculated using a probability–impact matrix. Only high-scale risks are included in the analysis to ensure focus on risks with the greatest potential influence on project performance. The selected risks represent different categories, including compliance, design, procurement, and operational risks, allowing cross-functional analysis of mitigation strategies at the planning stage.

Table 2: Selected risks for comparative analysis

Risk No	Risk Description	Category	Inherent Risk Score	Risk Level
R1	Delay in land acquisition and permits in protected forest areas	Compliance	25	Extreme
R2	Design assumptions incompatible with actual geotechnical conditions	Design	16	High
R3	Delay in critical material procurement affecting work readiness	Procurement	15	High
R4	Force majeure events (landslide, extreme rainfall, earthquake)	Operational	25	Extreme
R5	Site access and work area limitations affecting construction flow	Operational	20	High

Table 2 further details the selected risks, their descriptions, and categories. The selected set represents key planning-stage uncertainties related to regulatory approval, design reliability, supply readiness, force majeure exposure, and site constraints. Together, these risks capture diverse mechanisms through which planning quality may influence residual risk outcomes.

CONVENTIONAL MITIGATION PROFILE

Table 3: Conventional Mitigation Measures (Aligned with Project Risk Register)

Risk No	Risk Category	Conventional Mitigation Plan
R1	Compliance	Early coordination with government agencies and continuous monitoring of permit progress
R2	Design	Strict change-order procedures and penalties for design revisions
R3	Procurement	Monitoring supplier performance and accelerating procurement if delays occur
R4	Operational	Insurance coverage and implementation of emergency response procedures
R5	Operational	Work rescheduling and additional resources to recover delays

The Conventional mitigation plans documented in the project risk register are summarized in Table 3. Conventional mitigation strategies are derived directly from the project risk register and reflect standard project practices such as monitoring, coordination, contingency allocation, and corrective actions. Under this mitigation approach, residual risk levels are reduced primarily through impact control and reactive response mechanisms. However, several risks remain at medium to high levels, indicating limited influence on reducing risk probability during the planning stage.

Table 4: Residual Risk Profile under Conventional Mitigation

Risk No	Residual Probability	Residual Impact	Residual Risk Score	Risk Level
R1	4	4	16	High
R2	3	4	12	Medium
R3	3	4	12	Medium
R4	3	5	15	High
R5	3	3	9	Medium

The effectiveness of conventional mitigation is reflected in the residual risk profile presented in Table 4. While residual risk scores are reduced compared to inherent risk levels, two risk remains at a high level, and the remaining risks are largely classified as medium. This indicates that conventional mitigation tends to reduce impact severity but offers limited control over the probability of occurrence at the planning stage.

LEAN CONSTRUCTION–INTEGRATED MITIGATION PROFILE

Table 5: Lean construction mitigation measures (as documented)

Risk No	Risk Category	Lean Construction Mitigation
R1	Compliance	Target Value Delivery (TVD): integrating permit constraints and stakeholder requirements early into planning
R2	Design	Set-Based Design: developing multiple design alternatives and delaying final commitment
R3	Procurement	Pull-based procurement planning aligned with work readiness
R4	Operational	Last Planner System (LPS): improving planning reliability and constraint removal
R5	Operational	First Run Studies (FRS): optimizing construction methods before execution

Lean Construction mitigation measures extracted from the risk register are presented in Table 5. Lean Construction–enhanced mitigation strategies are developed by integrating planning-stage principles such as constraint management, early alignment, and workflow stabilization into the existing mitigation approach. These strategies aim to reduce variability and improve planning reliability, thereby influencing risk probability and exposure before execution begins. The resulting residual risk profiles indicate lower risk scores compared to conventional mitigation, particularly due to reductions in probability rather than impact severity.

Table 6: Residual Risk Profile under Lean Construction Mitigation

Risk No	Residual Probability	Residual Impact	Residual Risk Score	Risk Level
R1	2	4	8	Medium
R2	2	2	4	Low
R3	2	3	6	Medium
R4	2	3	6	Medium
R5	2	2	4	Low

The resulting residual risk profile under LC mitigation is shown in Table 6. Compared with the conventional scenario, residual risk scores under LC mitigation are consistently lower across all selected risks. Reductions are primarily driven by decreases in probability rather than impact, reflecting the influence of improved planning reliability and early constraint resolution.

COMPARATIVE RESIDUAL RISK ANALYSIS

Table 7: Comparison of Conventional and Lean Residual Risk Profiles

Risk No	Inherent Risk Level	Conventional Residual	LC Residual	Reduction Eff (%) inherent - LC	Reduction Eff (%) Convent - LC
R1	(25) Extreme	(16) High	(8) Medium	68%	50%
R2	(16) High	(12) Medium	(4) Low	75%	67%
R3	(15) High	(12) Medium	(6) Medium	60%	50%
R4	(25) Extreme	(15) High	(6) Medium	76%	60%
R5	(20) High	(9) Medium	(4) Low	80%	55%

A direct comparison between conventional and LC residual risk profiles is presented in Table 7. The comparison between conventional and Lean Construction–enhanced mitigation shows that Lean-based approaches provide more favourable residual risk profiles across the selected risks. The most significant improvements are observed in design and procurement risks, where early planning decisions play a critical role in reducing uncertainty. For compliance-related risks, improvements are more limited due to external dependencies. Similarly, for operational risks such as force majeure, Lean Construction reduces exposure but does not eliminate the underlying risk.

Table 8: Summary of Conventional versus Lean Mitigation Effects

Aspect	Conventional Mitigation	Lean-Integrated Mitigation
Dominant mitigation logic	Reactive and corrective	Proactive and preventive
Primary risk component addressed	Impact	Probability and exposure
Planning robustness	Moderate	Enhanced
Cross-category effectiveness	Limited	Strong

Table 8 synthesizes the comparative findings by summarizing the dominant mitigation logic and overall planning robustness under each scenario. While conventional mitigation relies on reactive and corrective mechanisms, LC-integrated mitigation enhances planning robustness by addressing uncertainty, coordination, and workflow variability at the source.

RESULTS SUMMARY

Overall, the analysis indicates that Lean Construction–enhanced mitigation provides a more robust planning approach compared to conventional mitigation. While conventional mitigation focuses on controlling the consequences of risk events, Lean Construction enhances mitigation effectiveness by addressing sources of variability and improving planning reliability. This results in lower residual risk profiles, particularly through reductions in probability and exposure. These findings should be interpreted within the context of scenario-based analysis. The results do not represent actual project performance but provide insights into how different mitigation logics may influence risk outcomes at the planning stage.

DISCUSSION

This section discusses the implications of the results by interpreting how different mitigation logics influence residual risk profiles at the planning stage.

The results indicate that conventional mitigation primarily operates through reactive mechanisms, focusing on monitoring, corrective actions, and recovery strategies after deviations occur. As reflected in Table 4, this approach reduces residual risk mainly by controlling impact severity, while probability levels remain relatively high for several risks. This suggests that conventional mitigation has limited influence on reducing planning-stage uncertainty.

In contrast, Lean Construction–enhanced mitigation introduces a more proactive planning logic. As shown in Tables 5 and 6, Lean-based measures emphasize early alignment, constraint management, and workflow stabilization. These mechanisms contribute to lower residual risk scores, particularly through reductions in probability rather than impact. This indicates that Lean Construction influences how risks emerge, rather than only how their consequences are managed.

Across risk categories, the effectiveness of Lean Construction–enhanced mitigation varies. The most significant improvements are observed in design and procurement risks, where early planning decisions, coordination, and information alignment play a critical role in reducing uncertainty. For compliance-related risks, improvements are more limited due to strong dependence on external regulatory processes. Similarly, for operational risks such as force majeure and site constraints, Lean Construction does not eliminate the underlying hazards but may reduce exposure and improve preparedness through more reliable planning.

From a theoretical perspective, these findings contribute to bridging the gap between PPP risk management and Lean Construction literature. While PPP risk management studies primarily focus on contractual governance and financial safeguards, they often overlook production-related uncertainties arising from planning variability. Conversely, Lean Construction research has largely emphasized execution-phase improvements. This study extends the discussion by positioning Lean Construction as a planning-level risk mitigation enhancer that complements conventional approaches.

Several limitations should be acknowledged. First, the analysis is based on scenario-based assessment rather than empirical implementation data; therefore, the findings should be interpreted as indicative of mitigation logic rather than validated performance outcomes. Second, Lean Construction has limited influence over externally driven risks such as permitting, regulatory constraints, and force majeure events. Third, its implementation requires strong coordination, stakeholder alignment, and disciplined planning practices, which may be challenging in PPP environments that emphasize risk transfer over collaboration.

Despite these limitations, the findings suggest that integrating Lean Construction into early-stage planning can enhance the robustness of risk mitigation and support more informed decision-making in complex infrastructure PPP projects.

CONCLUSION

This study examined the role of Lean Construction as a planning-level risk mitigation enhancer through a scenario-based comparative analysis of the Sitinjau Lauik Flyover Public–Private Partnership (PPP) Project. Using a project risk register containing fourteen identified risks, a cross-category subset of high-scale risks was selected to compare residual risk profiles under conventional and Lean Construction–enhanced mitigation scenarios.

The results indicate that conventional mitigation primarily reduces the consequences of risk events through monitoring, corrective actions, and recovery mechanisms, with limited influence on planning-stage uncertainty and risk probability. In contrast, Lean Construction–enhanced mitigation provides more favourable residual risk profiles by reducing probability and exposure through improved planning reliability, early alignment, and constraint management. These improvements are most evident in design and procurement risks, while operational risks show more moderate but meaningful reductions in exposure.

While the findings are based on scenario-based analysis rather than empirical implementation data, they provide useful insights into how mitigation logic influences risk outcomes at the planning stage. Lean Construction should therefore be positioned not as a replacement for conventional mitigation, but as a complementary approach that enhances the robustness of risk mitigation planning.

For complex infrastructure PPP projects operating in high-risk environments, integrating Lean Construction principles into early-stage planning may improve project readiness and support more reliable decision-making. Future research may extend this approach by incorporating empirical implementation data or applying the framework across multiple projects to further validate its applicability.

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