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Study of Risk Mitigation Strategies in the PPP Flyover Project Sitinjau Lauik 1 (Bina Marga – PT. Hutama Panorama Sitinjau Lauik)

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ABSTRACT

Infrastructure projects implemented under the *Public–Private Partnership (PPP)* scheme have a high level of risk complexity due to the long-term division of technical, operational, and occupational safety responsibilities. The *Sitinjau Lauik 1 Flyover* project is characterized by extreme topography, landslide potential, and heavy equipment mobilization, all of which increase the likelihood of construction and occupational safety risks. This study aims to analyze the influence of risk mitigation strategies on construction risk control in PPP projects. The research method employs a descriptive quantitative approach based on the frameworks of ISO 31000 and SMK3, as well as *Failure Mode and Effects Analysis (FMEA)*, using severity, occurrence, and detection parameters to obtain the *Risk Priority Number (RPN)*. The results indicate that there are 31 primary risks, with the highest priority levels originating from technical aspects in the field, such as heavy equipment accidents, potential landslides, inconsistencies in construction methods, and risks associated with working at elevation. The mitigation strategies implemented—including improvements in work methods, periodic inspections, enhancement of workforce competence, and strengthening of the supervision system—have been proven to reduce risk levels from high to medium and low categories. The study concludes that the systematic implementation of risk mitigation strategies has a significant effect on reducing construction risk levels and improving the safety and performance of PPP projects.

INTRODUCTION

Infrastructure development is a global issue and a top priority in encouraging economic growth, improving regional connectivity, and strengthening a country's competitiveness (Ahmed, 2024; Ibrahimov et al., 2023; Mahmood et al., 2025; Setyawati et al., 2024; Tariq, 2024; Vîrjan et al., 2023). Many countries have begun to adopt the Public–Private Partnership (PPP) scheme as a solution to overcome limitations in public budgets for infrastructure financing. This scheme allows for risk-sharing between the government and the private sector so that projects can be implemented more efficiently and sustainably. However, PPP-based projects have a higher level of risk complexity than conventional projects due to their long-term responsibilities, which include the design, construction, financing, operation, and

maintenance stages. Therefore, risk management is a key factor in the success of PPP projects, especially in infrastructure projects with complex technical characteristics and high levels of uncertainty (National Standards Agency, 2018; PMI, 2017).

Risk issues in construction projects are generally influenced by various factors, both technical and non-technical. Technical factors include geotechnical conditions, topography, construction methods, heavy equipment utilization, and the suitability of design with field conditions. Meanwhile, non-technical factors include the quality of human resources, coordination among stakeholders, occupational safety management, and environmental conditions such as extreme weather. In flyover or bridge projects, field conditions such as steep slopes, soil stability, and access for heavy equipment mobilization are dominant factors affecting the emergence of operational risks. Previous research has shown that difficult geographical conditions and limited site access can increase the likelihood of project delays, reduced productivity, and a higher risk of workplace accidents (Aswanto and Wibowo, 2022; Rahmawati and Tenriajeng, 2020; PMI, 2017).

These risk factors have the potential to cause various negative impacts on project performance if not managed systematically. The impacts may include delays in project timelines, cost overruns, decreased quality of work, and workplace accidents that can disrupt project sustainability. In addition, under PPP schemes, operational and occupational safety risks can also affect lifecycle costs, as private entities are responsible for the operation and maintenance phases. This means that failures in risk management impact not only the construction phase but also the long-term sustainability of infrastructure services. Therefore, the implementation of structured risk management is essential to ensuring the success of PPP projects (National Standards Agency, 2018; Directorate General of Highways, 2022).

In the context of this study, the main variables examined are risk mitigation strategies as independent variables and construction risks—which include operational risks as well as occupational safety and health risks—as dependent variables. Construction risk can be defined as uncertainty that has the potential to affect the achievement of project objectives in terms of cost, time, quality, and safety. Meanwhile, risk mitigation refers to a series of measures designed to reduce the likelihood of risks occurring or to minimize their negative impacts if they are unavoidable. In project management practice, risk mitigation can be implemented through various approaches, such as improving work methods, enhancing quality control, increasing workforce competence, and implementing an integrated occupational safety system (National Standards Agency, 2018; PMI, 2021).

The novelty of this study lies in the integration of the quantitative approach of Failure Mode and Effects Analysis (FMEA) within the ISO 31000 risk management framework to determine risk mitigation priorities in PPP projects with extreme geographical characteristics. Most previous studies have focused on qualitative risk identification or risk mapping without providing a numerical basis for prioritizing risk control. In addition, research that specifically examines the integration of operational risks and occupational safety risks in PPP projects with extreme topographical conditions remains limited. Therefore, this study contributes by presenting a quantitative approach using the Risk Priority Number (RPN) to determine risk priorities and formulate mitigation strategies that are more practical and based on actual project conditions (Stamatis, 2003; Hudoyo et al., 2025).

The urgency of this research is heightened by the characteristics of the Sitinjau Lauik 1 PPP Flyover Project, which has a high level of risk due to steep topographical conditions, landslide potential, intensive heavy equipment mobilization, and the predominance of elevated work. These conditions increase the likelihood of operational disruptions and workplace accidents if not anticipated with appropriate mitigation strategies. Furthermore, projects that are still in the early stages of implementation provide an opportunity to identify and mitigate risks proactively before they occur. This approach aligns with modern risk management principles that emphasize early risk control during the planning stage to minimize potential future losses (Agusman et al., 2021; Aven, 2016).

The purpose of this study is to identify potential operational and occupational safety risks in the Sitinjau Lauik 1 PPP Flyover Project, analyze risk priority levels using the Failure Mode and Effects Analysis (FMEA) method, and formulate effective risk mitigation strategies based on the principles of ISO 31000 and the Occupational Safety and Health Management System (SMK3). Thus, this research is expected to produce measurable risk mapping and practical recommendations for mitigation strategies applicable to PPP project management (National Standards Agency, 2018).

The benefits of this research are expected to contribute both theoretically and practically. Theoretically, this study can enrich the field of construction risk management, particularly in integrating FMEA and ISO 31000 approaches in PPP projects. Practically, this research is expected to serve as a reference for project stakeholders, such as the government and private entities, in formulating more effective risk control strategies. In addition, the results of this study may serve as a reference for future research on risk management in highly complex infrastructure projects and support the implementation of best practices in construction risk management in Indonesia.

METHOD

This study used a qualitative approach with a descriptive method to systematically describe potential operational risks as well as occupational safety and health risks in the Sitinjau Lauik 1 PPP Flyover Project. The research was conducted in 2025, with the object of the study focused on the construction stage of the project, which had high-risk characteristics due to challenging geographical conditions and the complexity of construction work. This research was ex ante, as it was oriented toward identifying potential risks as a preventive measure to minimize their impact on project success.

The research population included parties directly involved in the project, such as the project management team, technical personnel, and field supervisors. The sample was determined purposively based on the respondents' experience and competence in understanding project risks. The research data consisted of primary data obtained through questionnaires and interviews, as well as secondary data derived from project documents, scientific literature, and relevant regulations. The research instruments took the form of risk identification questionnaires and interview guidelines, which were developed based on risk management standards and previous studies to ensure the validity of the information obtained.

The research stages were carried out through the processes of risk identification, risk classification, risk level assessment, and the development of risk mitigation strategies. The aspects examined included project operational risks, occupational safety risks, and technical

factors affecting construction implementation. The results of the study were expected to produce priority risk mapping and mitigation recommendations that could serve as a basis for decision-making in improving the effectiveness of PPP project risk management and as a reference for future research in the field of construction risk management.

RESULT AND DISCUSSION

This research was conducted on the Government and Business Entity Cooperation Project (PPP) Sitinjau Lauik 1 Flyover which is located in the Sitinjau Lauik area, Padang City, West Sumatra Province. This project has a handling length of about 2.77 km with details of 1.77 km parallel to the existing road and about 1.00 km in the form of elevated structures. The characteristics of the research location have a high level of risk because it is located in a hilly area with extreme slopes, the potential for landslides, rapidly changing weather conditions, and limited access to construction mobilization. Conceptually, this project uses a Design–Build–Finance–Operate–Maintain–Transfer (DBFOMT) scheme which causes the complexity of risk to be higher than conventional projects due to the division of responsibilities between the government and business entities in the long term. This complexity has implications for the need for a more comprehensive risk management system, especially in operational risk control and occupational safety which has the potential to affect the success of the project in terms of cost, quality, time, and service sustainability.

This research focuses on identifying, analyzing, and mitigating operational risks as well as occupational safety and health (K3) risks that have the potential to arise during the construction stage. The analysis is carried out ex ante because the project is still in the implementation stage, so the risks studied are potential risks based on technical conditions, project documents, and the results of interviews with related parties. The main variables in this study consist of operational risk as an independent variable and the level of construction risk and occupational safety risk as bound variables. Operational risks in this study include risks related to work methods, human resources, heavy equipment, materials, project coordination, and work environment conditions. Meanwhile, K3 risks include potential work accidents, failure of safety procedures, and risks arising from work behavior and project environmental conditions. The results of the study show that the risk characteristics in this project are greatly influenced by the geographical and technical conditions of the field. Steep topography, unstable soil conditions, and high rainfall are the dominant factors that affect the emergence of operational risks. In addition, the coordination factor between stakeholders and the consistency of the implementation of procedures are also important determinants in the project risk profile.

In addition to technical factors, the study also found that labor behavior factors also affect the level of occupational safety risks. Workers' resistance to the application of personal protective equipment and weak safety culture are indicators that the risk of OHCHR is not only influenced by technical aspects but also organizational aspects and work culture. The research data consists of primary data and secondary data. Primary data was obtained through the distribution of questionnaires to respondents directly involved in the project such as project management, technical personnel, and field supervisors. In addition, interviews were also conducted to strengthen the results of risk identification.

Secondary data were obtained from project documents, scientific literature, and regulations related to occupational risk management and safety. The data obtained was then

analyzed using the Failure Mode and Effect Analysis (FMEA) method through severity, occurrence, and detection assessments to obtain a Risk Priority Number (RPN) value. The RPN value is used to determine the priority level of risks that require immediate mitigation. The results of the analysis showed that there were 31 main risks identified in this study with a range of RPN values ranging from 78.00 to 353.36. The risks with the highest RPN values are dominated by field technical risks, while administrative risks tend to have lower priority values.

Table 1. Results of identification of operational risks of the Sitinjau Lauik 1 flyover PPP project

Yes	Operational Risk	Risk Description	Main Causes
1	Slope Landslides	Potential slope collapse at ±25 m *cut* & *fill work* that interferes with project activities	Hilly topography, low soil stability, high rainfall
2	Extreme Weather	Heavy rain, fog, and strong winds that hinder the execution of work	Geographical conditions of mountains and rapid weather changes
3	Worker Unpreparedness	Unsafe actions and work mistakes due to workers not understanding the conditions of the field	Mobilization of new workers, differences in experience levels
4	Material Delay	Material distribution is disrupted due to congestion and public road obstructions	Congested distribution lines and limited access
5	Internal Supply Disruption	Material supply constraints due to the project's internal operational conditions	High rainfall and internal logistical constraints
6	Heavy Equipment Mobilization	Difficulty mobilizing heavy equipment to the job site	Steep terrain and limited access
7	Secure Access Difficulties	Slippery, steep work paths and risk of movement of personnel and tools	Limited access infrastructure
8	Implementation Deviation	The work does not conform to technical specifications and design	Weak field supervision
9	Decreased Productivity	Delay in drilling and casting work	Weather disturbances (rain, fog)
10	Construction Quality Risk	The occurrence of *cold joints* during concrete casting	Mixer truck delays and distribution disruptions
11	Stakeholder Coordination	Conflict of interest and insynchronization of decisions between parties	Many parties are involved in the project

Based on Table 1, the characteristics of the project located in extreme topographic areas and complex environmental conditions contribute significantly to the emergence of various operational risks. These risks are not only related to the technical aspects of construction implementation, but also include aspects of logistics, human resources, organizational coordination, and quality of work. These findings indicate that operational risks in infrastructure projects are not single, but *multidimensional* and interrelated between factors as also described in the risk management study (Aven, 2016).

The risk of slope landslides and extreme weather emerged as the dominant risks influenced by local geographical and climatic conditions. These two risks have a direct impact on the smooth running of construction activities and the safety of personnel in the field. This is in line with the findings Sandhyavitri dan Zulfiqar, (2014). Ardiansyah et al. (2022) also states that external environmental factors are the main determinants in the risk management of construction projects in Indonesia.

In addition to environmental factors, risks derived from the internal aspects of the project also show significant intensity. Worker unpreparedness, implementation deviations, and

decreased productivity reflect that the quality of operational management and field control greatly determine the success of project implementation, as is the case with the Sudarni et al. (2023), This condition emphasizes the importance of implementing a disciplined project management system, starting from the implementation of *safety induction*, continuous technical supervision, to periodic evaluation of operational performance.

Risks related to logistics and supply chains, such as material delays and internal supply disruptions, also demonstrate that limited access and complexity of material distribution at project sites can trigger disruptions to implementation schedules. This corroborates the findings Agusman et al. (2021) which explains that logistics management needs to be positioned as a strategic part of operational risk management and becomes a major operational risk, not just a supporting function.

Furthermore, the risk of *stakeholder coordination* confirms that the complexity of the project's organizational structure, especially those involving many parties, has the potential to lead to conflicts of interest and insynchronization of decisions. The same thing was also stated by Adebayo (2024), that weak coordination between parties leads to one of the main sources of risk in project management. These findings reinforce that governance and communication aspects between parties have a major contribution to the operational stability of the project. Thus, the existence of a routine coordination forum and the use of *an integrated risk register* are important instruments in maintaining consistency in decision-making and the effectiveness of risk control.

Overall, the results of this operational risk identification show that risks are not only derived from technical factors, but also influenced by human, organizational, and external environmental factors. Therefore, a comprehensive, adaptive and integrated risk management approach as recommended in ISO 31000 (Badan Standar Nasional, 2018), and management framework PMI (2017). Thus, an adaptive and systematic risk management approach is the main need to support the successful implementation of infrastructure projects.

The Urgency of Operational Risk Research and K3 Risk in PPP Projects

This research departs from the real need for more systematic risk management in infrastructure projects with the Government and Business Entity Cooperation (PPP) scheme, especially in projects with high technical complexity such as the Sitinjau Lauik 1 Flyover. This complexity arises because PPP schemes not only focus on the success of construction, but also the long-term operational sustainability of the infrastructure, so operational risks are crucial to control from the beginning of the project.

Based on the results of the study, operational risks and K3 risks that arise are not only related to technical construction factors, but are also influenced by organizational factors, the environment, and the characteristics of the PPP scheme itself. This strengthens the argument that PPP projects have a different risk structure than conventional projects due to the long-term risk allocation to implementing business entities.

The urgency of this research is even stronger because the research is carried out at the ex ante stage, which is when the project is still in the early stages of implementation. This approach allows risk identification to be carried out preventively before the risk develops into a real problem that can interfere with the success of the project. When compared to previous research, most construction risk studies are conducted at the project stage or after the project

is completed. Thus, this study makes a different contribution because it seeks to identify risks at an early stage so that mitigation can be designed more strategically and proactively.

Analysis of the Causes of Project Operational Risks

Based on the results of the study, the main causes of operational risks in the Sitinjau Lauik 1 Flyover project can be grouped into three main factors, namely technical factors, human resource factors, and environmental factors.

Technical factors are the dominant cause of project risks. Complex geotechnical conditions, extreme slope slopes, and predominance of elevation structure work increase the likelihood of construction disturbances. This finding is in line with research by Aswanto and Wibowo (2022) who stated that unstable topographic and soil conditions are the dominant factors for operational risks of infrastructure projects.

In addition, work method errors and design incompatibility with field conditions are also causes of construction risks. This suggests that technical risks often arise due to imperfections in advance planning or a lack of comprehensive field data. This condition is also reinforced by research by Debataraja et al. (2020) who stated that design errors and working methods are common causes of construction project delays.

Human resource factors also play an important role in shaping the project's risk profile. Research shows that lack of labor competence, work fatigue, and poor technical coordination can increase the likelihood of work errors. This is in line with research by Panggabean et al. (2024) which shows that the quality of human resources has a great influence on productivity and job quality risks.

In addition to internal factors, environmental factors are also important causes of risks. Extreme weather conditions, potential landslides, and limited access to work indicate that geographical factors have a significant contribution to project operational risks. These findings are consistent with the research of Rahmawati and Tenriajeng (2020) who stated that the characteristics of the project environment greatly affect the level of occupational safety risks.

Occupational Safety and Health Risk Analysis (K3)

The results of the study show that the risk of K3 in the project comes not only from technical hazards, but also from aspects of worker behavior and work safety culture. This shows that the occupational safety system does not rely solely on formal procedures but also requires organizational commitment.

The findings regarding workers' resistance to the use of personal protective equipment show that behavioral factors are the main challenges in the implementation of SMK3. This condition shows that the success of the K3 system is greatly influenced by the safety culture and safety leadership in the project organization.

In addition, the risk of accidents due to the use of heavy equipment in extreme terrain indicates that integration between technical management and safety systems is indispensable. This risk has the highest RPN value which indicates that the risk of work accidents is still a top priority in project management. When compared to previous research, most K3 research only focuses on hazard identification without linking it to PPP schemes. This study shows that in PPP schemes, K3 risks have wider implications because they can affect long-term operational costs and performance of infrastructure services.

Thus, this study strengthens the argument that K3 risk should be viewed as an integral part of operational risk management, rather than as a separate aspect.

The Effectiveness of the FMEA Method in Determining Risk Priorities

One of the important findings of this study is the effectiveness of the FMEA method in determining risk priorities based on the Risk Priority Number (RPN) value. This method provides a more measurable approach than the qualitative methods commonly used in construction risk research.

The use of severity, occurrence, and detection parameters allows risk assessment to be carried out more objectively and systematically. This provides a quantitative basis for determining which risks should be prioritized in mitigation. When compared to previous studies that used a risk matrix or descriptive approach, the FMEA method provides an advantage because it is able to produce numerical risk rankings. This strengthens the results of Hudoyo et al.'s (2025) research which states that FMEA is effective in supporting construction risk mitigation decision-making.

In addition, the use of FMEA in PPP projects is still relatively rare, so this study makes a methodological contribution to the development of construction risk analysis based on a semi-quantitative approach.

Risk Mitigation Strategy as a Solution to Project Problems

Based on the results of the study, the main solution in controlling project risk is through the implementation of a structured risk mitigation strategy based on the principles of ISO 31000, namely risk avoidance, risk reduction, risk transfer, and risk acceptance.

The mitigation strategies produced by this study show that most of the risks can be controlled through risk reduction approaches such as improving work methods, technical supervision, workforce training, and regular heavy equipment inspections.

In addition, the implementation of the permit to work system is also an important solution in controlling the risk of dangerous work. This system ensures that any high-risk work has gone through a hazard identification and risk control process before the work is carried out.

The research also shows the importance of monitoring geotechnical and weather conditions as part of mitigation strategies. This shows that project risk mitigation must be dynamic and adaptive to changing field conditions. When compared to previous studies, most studies only stop at the risk identification stage without formulating an operational mitigation strategy. Therefore, this research makes a practical contribution by producing mitigation strategies that are applicable to project managers.

The Impact of Risk Management Implementation on Project Performance

The results show that the implementation of good risk management can have a significant impact on project performance. Risks that are successfully controlled will reduce the potential for project delays, cost overruns, and work accidents.

In addition, risk mitigation also has an impact on increasing labor productivity because the work environment becomes safer and more controlled. This shows that investment in risk management systems not only impacts safety but also on project efficiency.

In the context of PPP, operational risk control also has an impact on the sustainability of infrastructure services because uncontrolled construction risks can lead to higher maintenance costs in the operational phase.

Thus, this study shows that risk management is not only a hazard control tool but also a strategic instrument in increasing the success of infrastructure projects.

Comparison of Research Results with Previous Research (Novelty)

When compared to previous research, this study has some novelties.

First, this study integrates operational risk analysis and K3 risk in one analytical framework. Most previous studies have only addressed one of these aspects separately.

Second, this research was conducted on PPP projects with extreme geographical conditions that have not been widely studied in previous research. This makes an empirical contribution to the construction risk literature on high-risk infrastructure projects.

Third, this study uses an ex ante approach that is different from most studies that use an ex post approach. This approach provides added value because mitigation can be designed before risk occurs. Fourth, the use of FMEA in the context of PPP projects is also a methodological contribution because this method is still rarely used in PPP research.

Thus, this study not only replicates previous research but also provides the development of a more comprehensive risk analysis approach.

Theoretical and Practical Implications of Research

Theoretically, this study reinforces the concept that operational risk and K3 risk are the dominant factors in the success of high-risk construction projects. This research also shows that the integration of ISO 31000, SMK3, and FMEA can be an effective risk management model. Practically, the results of this research can be a reference for PPP project managers in designing a more systematic risk control system. In addition, this research can also be a reference for the government in developing PPP project risk management policies.

Another implication is the importance of strengthening an occupational safety culture as part of a risk mitigation strategy. This shows that risk management is not only technical but also managerial and organizational in nature.

Based on the overall discussion, it can be concluded that this study has succeeded in answering the urgency of research, namely the need for a more measurable risk management approach in PPP projects with high risk. The main causes of risk come from technical, human resources, and environmental factors. The main solution is the implementation of integrated risk management based on FMEA and ISO 31000. The impact of the implementation of risk mitigation is increased work safety, project efficiency, and infrastructure sustainability.

Thus, this study reinforces that good risk management is a key factor in the success of modern infrastructure projects, especially in PPP schemes that have a higher risk complexity than conventional projects.

CONCLUSION

The conclusion of this study confirms that the main objectives of the study, namely identifying operational risks and occupational safety and health (K3) risks, analyzing the risk priority level, and formulating risk mitigation strategies for the Sitinjau Lauik 1 PPP Flyover Project have been achieved through an ISO 31000-based risk management approach and the Failure Mode and Effect Analysis (FMEA) method. The results of the study show that the characteristics of projects located on steep topography with high complexity of construction work contribute to the emergence of various potential risks that can affect project performance in terms of cost, time, quality, and work safety. Thus, this study succeeded in providing a systematic overview of the project risk profile as the basis for more structured risk control. The main findings of the study show that there are 31 main risks with different priority levels based

on the Risk Priority Number (RPN) value, where the risks with the highest priority are dominated by field technical aspects such as heavy equipment accidents in extreme terrain, potential landslides, incompatibility of construction methods with soil conditions, and work risks at elevation. Meanwhile, administrative risks have a relatively lower level of priority. The mitigation strategy formulated emphasizes the risk reduction approach through improving work methods, strengthening technical supervision, improving labor competence, and optimizing the implementation of the occupational safety system. This study also shows that the integration of FMEA in the risk management framework is able to provide a quantitative basis in determining risk mitigation priorities in high-risk construction projects. The contribution of this research lies in strengthening the literature related to the application of integrated risk management in PPP projects, especially in combining the ISO 31000, SMK3, and FMEA approaches in the context of infrastructure projects with specific risk characteristics. However, this study has limitations because the analysis is carried out ex ante based on the 2025 project conditions and is limited to operational and K3 risks without discussing other financial and external risks. Therefore, further research is recommended to examine project risks more comprehensively by including financial and contractual risk aspects, as well as conducting ex post evaluations after the project is completed in order to obtain a more comprehensive picture of risks and validate the effectiveness of the mitigation strategies that have been formulated.

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