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Project Cost Risk Analysis on National Road Preservation in Bali Province Using FMEA Method

Ni Kadek Dessy Antari*, Anak Agung Gde Agung Yana, Dewa Ketut Sudarsana
Universitas Udayana, Indonesia
Email: dessyantari8@gmail.com*, agungyana@unud.ac.id, dksudarsana@unud.ac.id

KEYWORDS	ABSTRACT
Risk Analysis, Road Preservation, FMEA, Project Costs, Bali Province, National Road Infrastructure	National roads, which have larger sizes and capacities than provincial or district roads to accommodate high volumes of vehicles, make national road projects more susceptible to greater cost risks. Failure Mode and Effect Analysis (FMEA) can identify and prioritize risks by generating a Risk Priority Number (RPN), which determines the priority of risks that need to be addressed first. The results of the study identified 55 risk indicators, including material risks, geographical risks, technical risks, human resource risks, environmental risks, and cost risks. From the FMEA results, 2 low-level risks, 8 medium-level risks, 24 high-level risks, and 21 very high-level risks were obtained. High- and very high-level risks are priority risks because they have relatively large RPN values, so they have the potential to significantly impact project costs and smooth execution (Mascia et al., 2020). The risk with the highest RPN value is the increased cost of mobilizing tools and labor due to rising fuel prices during the project, with an RPN of 360. The risks identified through FMEA have a direct impact on additional project costs. It is recommended that adaptive time management strategies for weather conditions and strengthened coordination among stakeholders be implemented to reduce the risk of cost overruns.
DOI:	

Corresponding Author: Ni Kadek Dessy Antari*
Email: dessyantari8@gmail.com

INTRODUCTION

Population growth and increased community activities require adequate road infrastructure to support social and economic activities (Suganda and Rosyad, 2023). Based on Law Number 2 of 2022, roads are classified into national, provincial, regency/city, and village roads. In Bali Province, national roads play an important role in improving connectivity and supporting the tourism sector and the economy (Wang et al., 2021; Wijaya & Astana, 2022; Zhao et al., 2019). The management of national road sections is carried out by the National Road Implementation Task Force Region II of Bali Province under the East Java-Bali National Road Implementation Center (Suparsa et al., 2019; Taroun, 2020; Taylan et al., 2020).

Socio-cultural factors of local communities, weather conditions, and coordination between stakeholders are significant sources of risk in road construction projects (Wedagama and Suryanti, 2024; Ahmad and Kamaludin, 2022). These risks can lead to cost overruns, schedule delays, and compromised project quality if not properly managed. Therefore, risk management is an essential aspect of controlling potential project losses (Fatimah et al., 2021; Osei-Kyei et al., 2022).

This study examines project cost as the dependent variable, which represents the total financial expenditure required to complete national road preservation projects in Bali Province. The independent variables consist of various risk factors categorized into six main groups: material risks (e.g., quality deterioration, delivery delays), geographical risks (e.g., accessibility challenges, weather conditions), technical risks (e.g., equipment failure, specification errors), human resource risks (e.g., labor competency, safety compliance), environmental risks (e.g., climate conditions, natural obstacles), and cost risks (e.g., fuel price fluctuations, regulatory changes). These independent variables are hypothesized to significantly influence the magnitude of project costs through their impact on project implementation efficiency and resource utilization (Adenan et al., 2020; Alaghbari et al., 2019; Aminbakhsh et al., 2021).

Several studies have investigated risk management in road construction projects using various methodologies. Ahmad and Kamaludin (2022) identified risk management in district road preservation work in Banggai Regency, Central Sulawesi, highlighting geographical and logistical challenges as primary risk sources. Their study emphasized the importance of proactive risk identification in remote areas but did not quantify risk priorities using systematic scoring methods. Wedagama and Suryanti (2024) analyzed risk management in urban road improvement projects and their environmental impacts, demonstrating that inadequate risk assessment can lead to both cost escalation and environmental degradation. However, their focus was primarily on urban contexts rather than inter-regional national road networks. Fatimah et al. (2021) conducted risk identification in building construction projects in Aceh Province, establishing a comprehensive framework for categorizing construction risks (Khalilzadeh & Shakeri, 2019; Liu et al., 2021; Serpella et al., 2021). Nevertheless, their study focused on vertical construction rather than road infrastructure, which presents distinct risk profiles due to linear project characteristics and geographical dispersion. Osei-Kyei et al. (2022) performed a scientometric analysis of risk management studies in construction projects globally, revealing that while risk identification has been extensively studied, the application of quantitative prioritization methods like Failure Mode and Effects Analysis (*Project Cost Risk Analysis on National Road Preservation in Bali Province Using FMEA Method*) remains limited, particularly in developing country contexts and specifically in road preservation projects (Arif & Egbu, 2020; Firmansyah & Amin, 2021; Gündüz & Başbug, 2018).

Despite extensive research on construction risk management, there remains a significant gap in the systematic quantification and prioritization of cost-related risks in national road preservation projects, particularly in geographically challenging regions like Bali Province. Previous studies have predominantly focused on risk identification without providing a structured prioritization framework based on Risk Priority Numbers (RPN). Furthermore, limited research has specifically addressed the unique challenges of national road preservation in island provinces, where material transportation, weather conditions, and geographical constraints create distinct risk profiles (Hwang et al., 2020; Islam et al., 2021; Kerzner & Kerzner, 2017). The integration of Failure Mode and Effects Analysis (FMEA) methodology to systematically assess severity, occurrence, and detection of risks in road preservation contexts remains underexplored in Indonesian road infrastructure literature.

This research contributes novel insights by: (1) applying the FMEA methodology specifically to national road preservation projects in Bali Province, providing a comprehensive quantitative risk assessment framework that generates Risk Priority Numbers (RPN) for systematic decision-making; (2) identifying and categorizing 55 specific risk indicators across six risk dimensions (material, geographical, technical, human resources, environmental, and cost) tailored to the unique geographical and operational context of island-based road infrastructure; (3) establishing empirical RPN thresholds that enable practitioners to distinguish between low, medium, high, and very high priority risks in road preservation contexts; and (4) bridging the gap between theoretical risk management frameworks and practical application in regional road infrastructure management, providing actionable insights for the National Road Implementation Task Force Region II of Bali Province.

The primary objectives of this research are to identify and categorize comprehensive risk factors affecting the cost of national road preservation projects in Bali Province and to quantify and prioritize these risks using the Failure Mode and Effects Analysis (FMEA) method. This involves calculating Risk Priority Numbers (RPN) based on severity, occurrence, and detection parameters to determine which factors constitute priority risks requiring immediate mitigation. Ultimately, the study aims to provide empirical evidence on the dominant risk factors that significantly impact project costs within the unique context of geographically challenging island environments.

This research offers significant practical, managerial, theoretical, and policy benefits. Practically, it provides stakeholders like the National Road Implementation Task Force in Bali with a systematic framework for prioritizing risk mitigation and allocating resources efficiently. For project managers, it offers quantitative assessment tools to facilitate proactive planning, potentially reducing cost overruns. Theoretically, it contributes to construction risk management knowledge by demonstrating FMEA application in road preservation, while the insights gained can inform the development of risk management guidelines and procedures for similar regions in Indonesia.

This study uses the Failure Mode and Effects Analysis (FMEA) method to identify and prioritize risks based on the Risk Priority Number (RPN) to determine the dominant risks that affect project implementation. The results of the study are expected to provide a quantitative picture of the influence of risks on project costs and to serve as a reference for mitigation strategies in national road preservation projects in Bali Province.

METHOD

The research was carried out on the preservation of national roads in Bali Province with the initial stage being problem identification, namely identifying problems that occur through observation and literature study, and determining the parties who play the role of expert judgement in providing data. Furthermore, the formulation of the problem and the purpose of the research is carried out, including the determination of research limits. The next stage is a literature review to obtain the basis for relevant theories and methods, namely Failure Mode and Effect Analysis (FMEA) for the identification of risks that affect project costs. Risk analysis through interviews with experts is carried out to parties who understand the conditions of the project firsthand. The identification results were then analyzed using the FMEA method by assessing the severity of the risk, the level of possible risk (occurence), and the level of risk detection (Ebrahemzadih et al., 2014).

Table 1. Risk Severity

Score	Criterion	Information	Examples of Risks
1	Insignificant	There is no real impact. Even if it does, there is no need for corrective action	Typos on project boards that have no technical or cost impact
2	Very Light	It has almost no impact on project quality, time, or cost. Only minor disturbances are not visible	Temporary incorrect position of signs, immediately corrected at no additional cost
3	Light	Aesthetic problems, do not require direct action. Minimal cost increases (<1%), can be handled directly by supervisors	Minor defects in road markings, only need partial repainting
4	Quite Light	Minor impacts that do not directly affect structures or operations. Costs increased by 1–3%, not requiring major revisions to the budget	5% excess material, saved for other segments
5	Keep	Local disruptions, can be fixed without changing the main schedule of the project. Costs increase by 3-5%, the impact can still be borne by the reserve fund (contingency)	The actual volume of work is slightly higher than planned
6	Moderately Heavy	Operational disruption that does not endanger safety, additional costs of 5–7%, implementation corrections and partial rescheduling	The road is jammed due to poor traffic management, work becomes overtime
7	Pretty Bad	Costs go up by 7–10%, the need for additional labor, equipment, or additional materials.	Suppliers fail to deliver, have to find new sources at higher prices
8	Severe	Failure has an impact on the main functions of the structure. Costs increased by 10–15%, delays and significant schedule changes	Mispositioned drainage, leading to inundation and re-coating
9	Very Severe	The cost impact is very large (15–20%), requiring major method changes or thorough rework	An error in the selection of the type of asphalt causes the coating to have to be repeated
10	Disaster	Costs swell drastically (>20%), projects stall or contracts are threatened with cancellation	Road structure failure due to completely wrong design

Source: (Ebrahemzadih et al., 2014)

Table 2. Level of Possible Risk (Occurence)

Score	Criterion	Information	Examples of Risks
1	Impossible	Failure is unlikely to occur because the process is tightly controlled and proven to	Tsunami hits project in non-coastal areas

Score	Criterion	Information	Examples of Risks
		be safe Unlikely to happen on this type of project	
2	Almost Never	It has never happened in a project of this kind, but it is still theoretically possible	Heavy work accidents on small projects
3	Very Rare	Failure almost never happens, unless there is a combination of causes	Big mistakes in advance planning
4	Infrequently	Failures are rare, they only arise if there is an operational negligence	Incomplete administrative documents at the time of payment
5	Keep	It can occur if quality control or planning is inconsistent, but not a routine occurrence	Minor damage to the machine in the field
6	Routine Occurrence	It may happen, depending on the readiness of the project team	Poor coordination between subcontractors
7	Quite often	Failures occur in some types of projects under similar conditions and are at risk of recurrence if there is no prevention	Initial measurement errors in the field
8	Often	Occurs in most projects, if supervision is not strictly carried out, especially in critical stages	Delay in starting work due to logistical factors
9	Very Possible	It almost always happens in similar conditions, it has happened repeatedly in similar projects. Occurs regularly unless there is very strict control	Late delivery of materials from suppliers
10	Very Often	Occurs in almost all preservation projects, difficult to prevent	Rain during asphalt work

Source: (Ebrahemzadih et al., 2014)

Table 3. Risk Detection Level

Score	Criterion	Information	Examples of Risks
1	Very easy to detect	Almost always detected before causing cost loss	Asphalt mixture quality checklist checked daily
2	Almost Definitely Detected	Automatic detection system and It is very possible to know from checklists, dashboards, or cost deviation reports	Insufficient material stock in the warehouse
3	Easy to Detect	Easily visible to field supervisors or project monitoring systems	Tools are not available on schedule
4	It's Pretty Easy	Can be found during daily measurements and checks	The volume of asphalt used is less/more than the plan
5	Keep	Can be detected during weekly field reviews or implementation reports	Wrong schedule for the implementation of heavy equipment
6	Detectable with Extra Effort	Detection is possible with additional testing or through thorough evaluation and technical documentation	Uneven coarse base placement

Score	Criterion	Information	Examples of Risks
7	Difficult to Detect	Often overlooked field standards	Error in the installation of signs that do not match the design point
8	Very Difficult to Detect	Detection requires advanced technical testing or specialized expertise to find out or after an impact begins to emerge	Too thin foundation layer that is only discovered after surface cracking
9	Almost Undetectable	It is very difficult to detect before an impact occurs, despite inspection or surveillance	Selection of material specifications that do not fit in the document
10	Undetectable	There is no detection method available. New failures are only known when the cost has been incurred or after major damage has occurred	Errors in BOQ that are not realized until implementation

Source: (Ebrahemzadih et al., 2014)

The three risk assessment parameters will be used in obtaining the Risk Priority Number (RPN) value to determine the risk priority calculated in accordance with Formula 1 and the determination of the risk level in Table 4 (Ebrahemzadih et al., 2014).

RPN = Severity x Occurence x Detection (1)

Table 4. Determination of Risk Level

Level Risk	RPN Value Scale
Very Low	$x < 20$
Low	$20 \leq x < 80$
Medium	$80 \leq x < 120$
High	$120 \leq x < 200$
Very High	> 200

Based on the high and very high level of risk, it is a priority risk that needs to be mitigated (Mascia et al., 2020). One of the things that can be done is to simulate the probability of cost success using Cost Budget Plan (RAB) data under optimistic, realistic, and pessimistic conditions which are then replicated for the generation of random numbers in the simulation. Simulation of the Monte Carlo model was used to estimate the effect of risk on project costs with results showing the probability of additional project costs due to the risks obtained.

RESULT AND DISCUSSION

Risk Acceptance and Brainstorming

The results of risk acceptance in Table 5 show that there are 41 risks that can be accepted by expert judgement based on the results of the literature study and obtained and 14 risks from brainstorming. The risks identified include material risks, geographical, technical, human resources, environmental, and cost risks.

Table 5. Risk acceptance and brainstorming

Stages of Work	Sources of Risk	Risk ID	Category Risk	Information
DIVISION 1. COMMON				
Prep Work	Risk material	A.1	Delay in the arrival of supporting materials (signs, banners, PPE, etc.)	Accepted
		A.2	Damage to materials due to improper storage	Accepted
		A.3	Loss of supporting materials (fire extinguishers, traffic cones, PPE) during project implementation	Accepted
		A.4	The quality of supporting materials (fire extinguishers, traffic cones, PPE) is not good and does not comply with specifications	Accepted
	Cost Risk	A.5	The cost of mobilizing equipment and labor increased due to the increase in fuel prices during the project	Accepted
		A.6	The cost of procuring medical devices and materials has increased due to regulatory changes	Accepted
		A.7	Work accidents occur during the implementation of the project due to the ineffectiveness of the determination of K3	Accepted
	Technical Risk	A.8	Equipment damage due to travel time in tool mobility increases due to the considerable project location	Accepted
		A.9	Traffic signs and complements were damaged and lost during the implementation of the project	Accepted
		A.10	Road damage around the project due to being passed by dump trucks transporting project materials	Accepted
		A.11	P3K equipment does not work well in handling work accidents	Accepted
		A.12	Limited on-site laboratory facilities lead to additional costs of external testing	Accepted
		A.13	Additional costs for making K3 documents and safety reports according to local government standards	Accepted
		A.14	Delay in emergency response due to distance of medical facilities from the project site	Brainstorming
	HR Risk	A.15	Undisciplined workers using PPE cause work accidents and additional compensation costs	Accepted
		A.16	Low level of understanding of the local workforce towards K3 training	Accepted
		A.17	Lack of labor coordination during the mobilization of tools and materials	Accepted
DIVISION 2. DRAINAGE				
Drainage Work	Geographic Risk	B.1	Obstruction of vehicles loaded with tools/materials reaching the project site due to narrow/unpaved roads	Accepted
		B.2	Bad weather or high waves cause delayed material/tool crossing	Accepted
		B.3	Material damage during sea crossing	Brainstorming
	Technical Risk	B.4	Blockage of the duct due to residual material that can cause stagnation in the duct	Brainstorming

Stages of Work	Sources of Risk	Risk ID	Category Risk	Information
		B.5	Material damage during loading and unloading of materials at the job site	Accepted
		B.6	Limited workspace for tools and material stock, requiring gradual delivery	Brainstorming
		B.7	Error in the installation of the u-ditch due to inappropriate elevation so it is necessary to reassemble it	Brainstorming
DIVISION 3. EARTHWORKS AND GEOSYNTHETICS				
Earthworks and Geosynthetics	Technical Risk	C.1	Unavailability of spare parts at the job site if there is damage to the heavy equipment or work aids	Accepted
		C.2	Damage to the lower and upper ground utilities in tree pruning	Brainstorming
		C.3	Damage to the surrounding structure when hard rock excavation work is carried out	Brainstorming
		C.4	Bad weather causes difficulties in the mobilization of tools and materials	Brainstorming
	HR Risk	C.5	Work accidents due to workers who are not disciplined in the use of PPE or K3 procedures are not fully implemented	Accepted
DIVISION 5. GRANULAR PAVEMENT AND CEMENT CONCRETE PAVEMENT				
Cement Concrete Foundation and Pavement Coating Work	Technical Risk	D.1	Poor material quality and not in accordance with specifications	Accepted
		D.2	Delays in sea transportation lead to the risk of delayed supply of aggregate or cement	Brainstorming
		D.3	The surface of the base foundation is unstable due to the limitations of the tool	Brainstorming
	HR Risk	D.4	Shortage of skilled labor on job sites	Accepted
DIVISION 6. ASPHALT PAVEMENT				
Asphalt Work	Technical Risk	E.1	Deterioration of asphalt quality due to improper storage	Accepted
		E.2	Lack of equipment to support work in the field	Accepted
		E.3	Damage to the machine and supporting equipment that impedes work	Accepted
		E.4	Damage or disturbance that occurs to the AMP (Asphalt Mixing Plant)	Accepted
		E.5	The equipment used is not performing well or the productivity is not as planned	Accepted
		E.6	Errors in the mixing or temperature of the asphalt	Brainstorming
		E.7	Incompatibility of asphalt thickness	Brainstorming
		E.8	Suboptimal compaction due to inappropriate tools or unskilled labor	Brainstorming
		E.9	Delays in material delivery are hampered due to damage to the transport ship	Brainstorming
	HR Risk	E.10	Labor is not in accordance with competency requirements	Accepted

Stages of Work	Sources of Risk	Risk ID	Category Risk	Information
		E.11	Lack of discipline of workers in complying with K3 and the use of PPE which can cause the potential for work accidents to increase	Accepted
DIVISION 7. STRUCTURE				
Stone Couple Jobs	HR Risk	F.1	Work errors due to lack of K3 training and supervision	Accepted
		F.2	Low productivity/work motivation of workers	Accepted
	Technical Risk	F.3	The quality of materials such as stone and cement is at risk of breaking and being damaged during the loading/unloading process	Accepted
		F.4	Delays in the delivery of materials that can hinder work	Accepted
		F.5	The occurrence of work increases less during the construction process	Accepted
DIVISION 9. DAILY JOBS & OTHER JOBS				
Day Jobs & Other Jobs	Technical Risk	G.1	Application of markings on dirty or wet road surfaces	Accepted
	Cost Risk	G.2	The quality of thermoplastic paints decreases due to non-standard storage due to high temperature sensitive materials	Accepted
		G.3	Delays in the delivery of tools and materials for thermoplastic marking work	Accepted
	HR Risk	G.4	Late payment of workers that can reduce worker productivity	Accepted
DIVISION 10. PERFORMANCE MAINTENANCE WORK				
Foundation and Asphalt Coating Repair Work	Technical Risk	H.1	Hot asphalt mixture does not reach the optimum temperature when it arrives at the site	Accepted
		H.2	Delays in the delivery of materials and equipment due to weather and transportation disruptions	Accepted

Validity and Reliability Tests

The significance test was carried out by comparing the value of r calculated with the r table for degree of freedom (df) = n – 2 and alpha = 5%, where n is the number of samples. The use of df = 5% because the researcher works directly in the project being studied, so the understanding of context, terminology, and real conditions in the field is more in-depth. From the test results, all risk assessment items have a value of r calculated > r table (> 0.284) so as to prove that all items can be used in the study or are valid.

The reliability test is tested with the statistical test of Cronbach's Alpha which is said to be reliable if it gives a value of Cronbach's Alpha > 0.60. Using Cronbach's Alpha limit ≥ 0.6 because the research is applied and exploratory, with the object being a national road preservation project in Bali Province. The use of a limit of 0.6 is considered methodologically and practically adequate, as it is in accordance with the provisions of the literature and the characteristics of field case-based research. In addition, the researcher works at the research site so that the understanding of the context and substance of each outcome indicator obtained remains valid and representative of the actual conditions in the field. In the results of the reliability test, it was found that the Cronbach's Alpha value for all items was > 0.6 which proved that all variables used in this study were trustworthy or reliable.

Qualitative Risk Analysis

Based on the results of the qualitative analysis, an RPN assessment was obtained which was carried out on the mode value of each item of the questionnaire results calculated with Formula 1 so that the risk level was obtained ranging from low to very high RPN as shown in Table 6.

Table 6. Results of risk assessment using the FMEA method

Risk ID	Category Risk	S	O	D	RPN	Level Risk
A.5	The cost of mobilizing equipment and labor increased due to the increase in fuel prices during the project	9	4	10	360	Very High
B.2	Bad weather or high waves cause delayed material/tool crossing	8	7	6	336	Very High
A.8	Equipment damage due to travel time in tool mobility increases due to the considerable project location	9	4	9	324	Very High
A.6	The cost of procuring medical devices and materials has increased due to regulatory changes	8	5	8	320	Very High
C.1	Unavailability of spare parts at the job site if there is damage to the heavy equipment or work aids	8	8	5	320	Very High
A.15	Undisciplined workers using PPE cause work accidents and additional compensation costs	9	5	7	315	Very High
C.2	Damage to the lower and upper ground utilities in tree pruning	9	5	7	315	Very High
G.2	The quality of thermoplastic paints decreases due to non-standard storage due to high temperature sensitive materials	9	5	7	315	Very High
F.4	Delays in the delivery of materials that can hinder work	8	6	6	288	Very High
A.16	Low level of understanding of the local workforce towards K3 training	8	5	7	280	Very High
G.3	Delays in the delivery of tools and materials for thermoplastic marking work	8	5	7	280	Very High
F.3	The quality of materials such as stone and cement is at risk of breaking and being damaged during the loading/unloading process	9	4	7	252	Very High
B.4	Blockage of the duct due to residual material that can cause stagnation in the duct	8	6	5	240	Very High
E.3	Damage to the machine and supporting equipment that impedes work	8	5	6	240	Very High

Risk ID	Category Risk	S	O	D	RPN	Level Risk
G.1	Application of markings on dirty or wet road surfaces	8	5	6	240	Very High
B.6	Limited workspace for tools and material stock, requiring gradual delivery	8	4	7	224	Very High
C.4	Bad weather causes difficulties in the mobilization of tools and materials	8	4	7	224	Very High
B.3	Material damage during sea crossing	9	4	6	216	Very High
F.5	The occurrence of work increases less during the construction process	9	4	6	216	Very High
E.11	Lack of discipline of workers in complying with K3 and the use of PPE which can cause the potential for work accidents to increase	7	5	6	210	Very High
D.2	Delays in sea transportation lead to the risk of delayed supply of aggregate or cement	8	4	7	224	Very High
B.1	Obstruction of vehicles loaded with tools/materials reaching the project site due to narrow/unpaved roads	8	4	6	192	Tall
A.4	Poor material quality and not in accordance with specifications	9	5	4	180	Tall
A.9	Traffic signs and complements were damaged and lost during the implementation of the project	7	5	5	175	Tall
F.1	Work errors due to lack of K3 training and supervision	7	5	5	175	Tall
H.2	Delays in the delivery of materials and equipment due to weather and transportation disruptions	7	4	6	168	Tall
A.3	Loss of supporting materials (fire extinguishers, traffic cones, PPE) during project implementation	8	5	4	160	Tall
D.1	The quality of supporting materials (fire extinguishers, traffic cones, PPE) is not good and does not comply with specifications	8	5	4	160	Tall
E.5	The equipment used is not performing well or the productivity is not as planned	8	4	5	160	Tall
E.6	Errors in the mixing or temperature of the asphalt	8	5	4	160	Tall
E.1	Deterioration of asphalt quality due to improper storage	7	3	7	147	Tall
C.3	Damage to the surrounding structure when hard rock excavation work is carried out	8	3	6	144	Tall
E.7	Incompatibility of asphalt thickness	8	3	6	144	Tall
A.14	Delay in emergency response due to distance of medical facilities from the project site	7	4	5	140	Tall
H.1	Hot asphalt mixture does not reach the optimum temperature when it arrives at the site	7	4	7	196	Tall
A.7	Work accidents occur during the implementation of the project due to the ineffectiveness of the determination of K3	9	5	3	135	Tall

Risk ID	Category Risk	S	O	D	RPN	Level Risk
A.10	Road damage around the project due to being passed by dump trucks transporting project materials	9	5	3	135	Tall
A.17	Lack of labor coordination during the mobilization of tools and materials	8	4	4	128	Tall
B.5	Material damage during loading and unloading of materials at the job site	8	4	4	128	Tall
E.9	Delays in material delivery are hampered due to damage to the transport ship	6	7	3	126	Tall
A.1	Delay in the arrival of supporting materials (signs, banners, PPE, etc.)	8	5	3	120	Tall
A.11	P3K equipment does not work well in handling work accidents	8	3	5	120	Tall
B.7	Error in the installation of the u-ditch due to inappropriate elevation so it is necessary to reassemble it	8	5	3	120	Tall
E.2	Lack of equipment to support work in the field	8	5	3	120	Tall
E.8	Suboptimal compaction due to inappropriate tools or unskilled labor	8	3	5	120	Tall
A.2	Damage to materials due to improper storage	7	4	4	112	Keep
A.12	Limited on-site laboratory facilities lead to additional costs of external testing	8	7	2	112	Keep
F.2	Low productivity/work motivation of workers	7	4	4	112	Keep
G.4	Late payment of workers that can reduce worker productivity	7	4	4	112	Keep
D.4	Shortage of skilled labor on job sites	7	5	3	105	Keep
E.4	Damage or disturbance that occurs to the AMP (Asphalt Mixing Plant)	7	4	3	84	Keep
E.10	Labor is not in accordance with competency requirements	7	3	4	84	Keep
A.13	Additional costs for making K3 documents and safety reports according to local government standards	8	5	2	80	Keep
D.3	The surface of the base foundation is unstable due to the limitations of the tool	9	4	2	72	Low
C.5	Work accidents due to workers who are not disciplined in the use of PPE or K3 procedures are not fully implemented	7	2	4	56	Low

From Table 6, 55 risk indicators that affect the cost of the National Road Preservation Project in Bali Province are obtained. The risk level is low (2), medium level (8), high level (24), and very high level (21). So the 45 risks for the very high and high categories will be the main focus in the simulation, while medium and low risks only need to be monitored periodically.

CONCLUSION

This study identified 55 risk indicators across material, geographical, technical, human resource, environmental, and cost categories in national road preservation projects in Bali Province, with 21 risks classified as very high priority and 24 as high priority based on Risk Priority Numbers (RPN). The highest-ranking risk was fuel price increases during the project (RPN = 360), followed by bad weather or high waves delaying material/tool crossing (RPN = 336 and 324) and equipment damage from extended travel times due to remote project locations (RPN = 320). For future research, scholars could extend this FMEA framework by incorporating real-time data analytics or machine learning models to dynamically monitor and predict risk occurrences in similar island-based infrastructure projects, enabling adaptive mitigation strategies amid climate variability.

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