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Comparative Risk Prioritization in the Initiation Phase of the Pagerungan Besar Photovoltaic Plant: A Failure Mode and Effect Analysis (FMEA) and Risk Matrix Approach

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Abstract

Photovoltaic (PV) power plant projects in East Java often face challenges during the initiation phase due to inadequate risk assessments. This phase is crucial for ensuring the project's long-term success; however, suboptimal risk identification has caused project delays. In the risk assessment process, high-priority risks need to be mitigated, but differences in the methods used can result in varying risk priority outcomes. One of the methods that can be used is Failure Mode and Effect Analysis (FMEA), while according to internal regulations at PT PLN (Persero), the Risk Matrix is applied. By using these two methods, the differences in the resulting risk priority rankings can be identified. Both tools rely on evaluations from experts experienced in decision-making during the initiation phase of PV power plant projects. From the analysis, 12 risks were identified during the initiation phase of the Pagerungan Besar PV power plant project. The highest-priority risks identified include Suboptimal feasibility study (Risk Priority Number/RPN: 74.27), unfavorable outcomes for the organization/company (RPN: 68.96), lack of budget (RPN: 64.00), and stakeholder Intervention (RPN: 53.69). Meanwhile, by plotting the Severity Level and Occurrence Level of each risk on the Risk Matrix according to PT PLN (Persero) regulations, the highest-priority risks identified include Suboptimal feasibility study (Extreme Risk Level, Zone E5), location-related issues (Extreme Risk Level, Zone E5), non-compliance with regulations (Extreme Risk Level, Zone E5), and suboptimal project team (Very High Risk Level, Zone D5). The two risk assessment methods produced different prioritizations, potentially impacting mitigation strategy decisions. This variation highlights the need for further analysis to ensure accurate and reliable risk prioritization, which is critical for project success and efficient resource allocation. Future studies should focus on evaluating prioritization methods to support effective decision-making and ensure timely project implementation in line with the targeted Commercial Operation Date (COD).

Keywords: FMEA; Initiation phase; PV power plant; Risk matrix

1. Introduction

Pagerungan Besar is one of the islands in Sapeken District, Sumenep Regency, East Java Province, that required an electricity supply. PT PLN (Persero) has planned to develop a Photovoltaic (PV) Power Plant. Based on the history of similar projects, PV power plant developments often experienced delays and cost overruns. Therefore, a comprehensive risk assessment was needed to identify potential risks. In addition, risk prioritization was necessary to determine appropriate mitigation actions, so that the project could be completed on schedule and within the planned budget.

One of the methods that can be used to determine risk priorities is Failure Mode and Effect Analysis (FMEA). While according to internal regulations at PT PLN (Persero), risk priorities are determined using a risk matrix. However, Pace, in his research, stated that the Risk Matrix should be designed for reporting as part of an overall risk assessment rather than being used in isolation. Additionally, the Risk Matrix has a high degree of uncertainty, requiring careful application [1].

FMEA is a method with a systematic and structured approach specifically designed to enhance project reliability by proactively identifying failure modes, reducing associated risks, and improving overall construction quality. This is achieved by minimizing the likelihood of operational errors and reducing delays that could disrupt project schedules and objectives [2]. FMEA has been used to analyze risks in PV Power Plant projects, including large-scale PV Power

Plant [3], PV Power Plant located in airport areas [4], centralized PV Power Plant designs [4], failure analysis of PV modules and overall PV Power Plant project evaluation [5], and overall PV Power Plant project evaluation [6]. In FMEA, the Risk Priority Number (RPN) is identified, and priority actions can be determined based on its value [7].

In ISO 31010:2019, the Risk Matrix is a method used to report and document risks. The Risk Matrix is created by plotting the impact level on one axis and the likelihood on the other, based on a predefined scale, with each cell in the matrix associated with a priority ranking. The Risk Matrix has been used to analyze construction projects in Malaysia to assess risk levels [8]. According to Anackovski et al., the Risk Matrix can also be used to prioritize risk mitigation actions [9].

According to Kumar, risk assessment needs to be conducted and should cover all stages of the project lifecycle, including the initiation phase [10]. The importance of risk analysis begins in the initiation phase, as this stage influences the outcomes of subsequent project phases [11]. However, in practice, risk assessments often fail to accommodate risks in the initiation phase. Both previous risk assessments conducted in similar projects and prior research on PV Power Plant have not analyzed risks during the initiation phase. Instead, analyses have been conducted during the planning phase [3], [12], execution phase [3], [4], [5], [6], [12], and monitoring and controlling phase [3], [6].

One of the main causes was the suboptimal risk assessment conducted during the initiation phase. At that stage, communal PV projects frequently faced various challenges, including 73% of projects had feasibility studies that were not financially or economically viable, 14% encountered issues with land availability, 28% experienced delays in the Commercial Operation Date (COD), and 17% required additional work due to discrepancies in the project scope. during the initiation phase.

This study aims to identify and compare the results of risk prioritization obtained using the FMEA and Risk Matrix methods in Initiation Phase of the Pagerungan Besar PV Power Plant Project. However, risk prioritization using FMEA and the Risk Matrix may yield different results. Therefore, this research seeks to analyze these differences to provide insights into selecting the most appropriate method for decision-making.

2. Method

Based on previous studies, risk analysis has been conducted in relation to PV Power Plant projects and the FMEA method, as illustrated in Figure 1. This figure describes how the nodes visualize the research topics discussed, with the size of each node reflecting the level of relevance or frequency of keyword occurrence. Additionally, the lines connecting the nodes represent relationships between keywords, where thicker lines indicate stronger connections between the two terms [13].

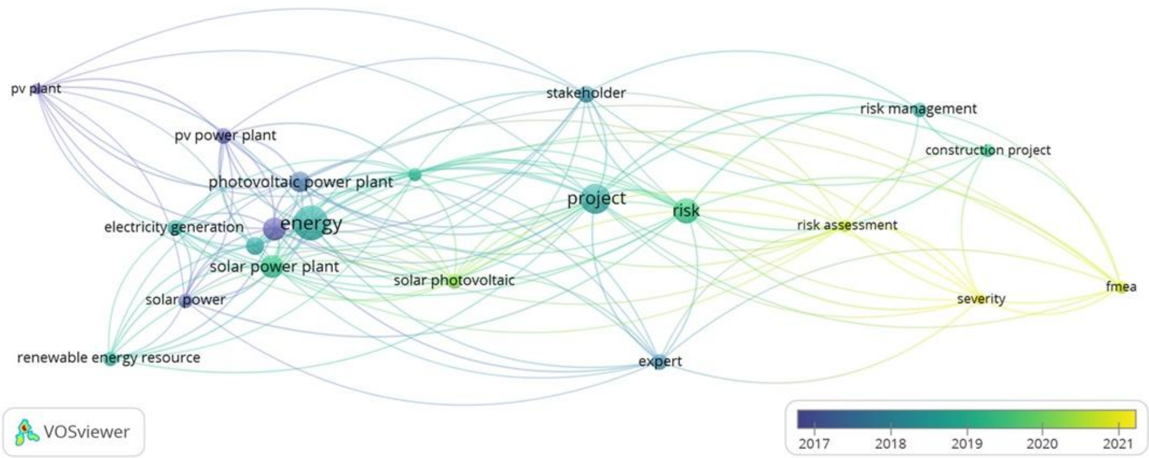

Figure 1. Bibliographic Analysis of Research from 2017 to 2021 (VOSviewer).

This study will utilize both FMEA and the Risk Matrix, where FMEA was used to identify risks, assess risks, and establish risk priorities [14], [15], [16]. These risk priorities will then be compared with the risk priorities derived from the Risk Matrix, as determined by PT PLN (Persero) regulations. The details of the research stages are as follows:

2.1 Identification of Potential Risk

This study identifies potential risks that can be analyzed through a literature review [17]. The potential risks were identified based on previous research related to risks that arise during the initiation phase of a project, particularly those related to PV Power Plant projects, with the results shown in Table 1.

Table 1. Identification of Potential Risk.

No.	Aspect	Risk	Cause of Risk	Cause of Risk References
1	Technologies	1. Suboptimal Feasibility Study	- Limited database	[18], [19]
			- Lack of standards/SOP	[20]
			- The review process is inefficient	[21], [22]
			- Scope of work is inaccurate	[20], [21], [23]
			- Changes in demographics	[24]
		2. Suboptimal PV Power Plant Design	- Obsolete products according to specifications	[21]
			- Lack of available land	[21]
		3. Technological Changes	- Data used not aligned with project conditions	[10], [22]
2	Politic and Legal	4. Stakeholder Intervention	- Other task priorities	[25]
		5. Non-compliance with Regulations	- Updates of standards, or regulations	[26]
3	Environment	6. Location-Related Issues	- Project location not yet determined	[20]
4	Social and Culture	7. Work Plan Inconsistency with Organizational Culture	- Lack of gender equality in the project team	[10], [20]
		8. Complaints from the Community	- Community opposition to project implementation	[27]
5	Operational/ Process	9. Suboptimal Top Management in Managing Project Activities	- Lack of experience	[10], [21], [22], [23], [28], [29]
		10. Suboptimal Project Team	- Lack of competence	[21], [30]
			- Organizational changes	[22]
			- Limited number of team members	[10], [20], [21], [22], [23]
			- Lack of coordination	[10], [20], [23]
			- Internal conflicts	[20]
			- Work overload	[30]
6	Finance	11. Lack of Budget	- Budget prioritized for other tasks	[20], [23], [31]
		12. Feasibility Study Results Unfavorable for the Organization/Company	- Unfeasible of Study Result:	
			• Financial	[20], [22], [23], [31]
			• Risk Analysis	[22], [25]
		13. Rejection of Loans/Capital	- Study results do not meet the stakeholder expectations	[21], [23]

Based on the literature review conducted, 13 risks were identified during the project initiation phase along with the causes of those risks. Then, interviews were conducted with six (6) experts who represented each division/unit at PT PLN (Persero) involved in the activities during the initiation phase of the Pagerungan Besar PV Power Plant project. The selected criteria for the respondents/experts were individuals who had a minimum of 10 years of work experience in divisions or units related to activities carried out during the project initiation phase and were involved in the decision-making process of the Pagerungan Besar PV Power Plant project. The interview was conducted to identify the project's objectives and risk variables, including their causes and impacts. The risks obtained from the interviews were collected and simplified by grouping similar risks together. The results of this grouping were then used as material for evaluation in the questionnaire.

2.2 Risk Relevance

After the interview-based risks were grouped under Identification of Potential Risk, a questionnaire was used to assess the relevance of risks by the respondents/experts. The respondents will evaluate whether the risk variables identified were considered relevant or not in the risk assessment of the Pagerungan Besar PV Power Plant Project. The relevance criteria ware as follows:

- A risk variable was considered relevant if the number of "relevant" assessments was greater than or equal to the number of "not relevant" assessments.
- A risk variable was considered not relevant if the number of "relevant" assessments was less than the number of "not relevant" assessments.

2.3 Risk Assessment

After identifying the risks considered relevant to the Pagerungan Besar PV Power Plant Project, the assessment was carried out to measure the levels of Impact (Severity), Likelihood (Occurrence), and Detection (Detection) based on the criteria used by PT PLN (Persero). The risk assessment was conducted by the respondents/expert, based on project data obtained from historical data and the Feasibility Study. The measurement scales for Severity (S), Occurrence (O) and Detection (D) use a Likert scale from 1 to 5. The ratings are as follows: strongly agree = 5, agree = 4, neutral = 3, disagree = 2, and strongly disagree = 1. This scale serves as a code to indicate rankings from highest to lowest [32]. For groups of respondents, the geometric mean can be used, as per the Equation (1).

$$S \ or \ or \ O \ or \ D = \sqrt[n]{\textstyle\sum_1^n X} \tag{1}$$

Where S (Severity) refers to the level of impact or consequence when a failure occurs, O (Occurrence) refers to the likelihood or frequency of occurrence of the identified failure mode, and D (Detection) refers to the likelihood of detecting the failure mode if it occurs. X represents the assessment result from the respondents, and n is the number of respondents.

2.4 Risk Priority Number (RPN)

The Risk Priority Number (RPN) in FMEA can be calculated using the Equation (2).

$$RPN = S \ x \ D \ x \ O \tag{2}$$

Risks with a Risk Priority Number (RPN) greater than the average RPN were considered critical risks, therefore, the higher the RPN value, the more critical the risk is deemed to be.

2.5 Risk Matrix

The assessment of Impact/Severity (S) and Likelihood/Occurrence (O) in the Risk Matrix uses the same scoring system as the FMEA method. To determine priority actions, the values of impact level (Severity) and likelihood level (Occurrence) were plotted on a risk map or Risk Matrix following ISO 31010:2019. In this matrix, the X-axis represents the impact level, while the Y-axis represents the likelihood level. The Risk Matrix used aligns with the Board of Directors Regulation of PT PLN (Persero) No. 0071.P/DIR/2021 on the General Guidelines for Integrated Risk Management at PT PLN (Persero).

2.6 Risk Priority

Risk prioritization using the FMEA method is determined by ranking the RPN values from highest to lowest, where priority is assigned based on the magnitude of the RPN value. Meanwhile, risk prioritization based on the Risk Matrix, following the Board of Directors Regulation of PT PLN (Persero) No. 0071.P/DIR/2021 on the General Guidelines for Integrated Risk Management at PT PLN (Persero), was established according to the ranking criteria shown in Figure 2.

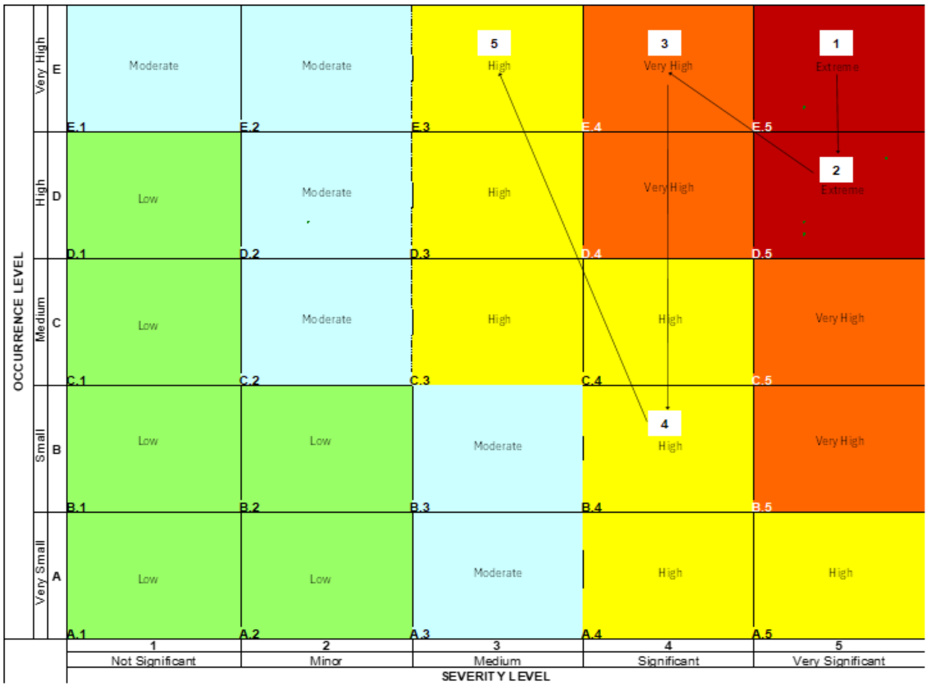

Figure 2. Risk Matrix and Risk Prioritization.

Based on Figure 2, there were five risk levels: Extreme, Very High, High, Moderate, and Low. Risk prioritization can be determined according to the numbered order shown in the figure.

3. Result and Discussion

3.1 Potential Risk Identification

The literature review summarized in Table 1 forms the basis for designing the risk variables, which are presented in Table 2.

Table 2. Draft of Variable Risk.

Aspect	ID Risk	Risk
Technology	R01	Suboptimal Feasibility Study
	R02	Suboptimal PV Power Plant Design
	R03	Technological Changes
Politics and Law	R04	Stakeholder Intervention
	R05	Non-compliance with Regulations
Environment	R06	Location-Related Issues
Social and Cultural	R07	Work Plan Inconsistency with Organizational Culture
	R08	Complaints from the Community
Operational / Process	R09	Suboptimal Top Management in Managing Project Activities
	R10	Suboptimal Project Team
Finance	R11	Lack of Budget
	R12	Feasibility Study Results Unfavorable for the Organization/Company
	R13	Rejection of Loans/Capital

These identified risks were then further analyzed by examining their frequency of occurrence in previous similar projects. The frequency (Fr) was calculated by comparing the number of occurrences of each risk with the total number of similar projects, which consists of 30 projects, with the results shown in Table 3.

Table 3. Frequencies of Variable Risks.

ID Risk	Risk	Incident Amount	Frequency
R01	Suboptimal Feasibility Study	22	0.734
R02	Suboptimal PV Power Plant Design	4	0.134
R03	Technological Changes	1	0.034
R04	Stakeholder Intervention	22	0.734
R05	Non-compliance with Regulations	14	0.467
R06	Location-Related Issues	4	0.134
R07	Work Plan Inconsistency with Organizational Culture	0	0.000
R08	Complaints from the Community	1	0.034
R09	Suboptimal Top Management in Managing Project Activities	30	1,000
R10	Suboptimal Project Team	30	1,000
R11	Lack of Budget	30	1,000
R12	Feasibility Study Results Unfavorable for the Organization/Company	22	0.734
R13	Rejection of Loans/Capital	16	0.534

The frequency analysis presented in Table 3 indicates that one of the risks, R07: Work Plan Inconsistency with Organizational Culture, has a frequency of 0, meaning this risk has never occurred in previous projects. Therefore, this risk was excluded from the list of potential risks.

3.2 *Risk Relevance*

A questionnaire was used to assess whether the risk variables were considered relevant by the respondents, with the results presented in Table 4. With a total of 6 (six) respondents/experts, if at least 3 respondents/experts declare the risk as relevant, then the risk is considered relevant.

Table 4. Assessment of Risk Relevance

ID Risk	Risk	Amount to Consider Relevance	Relevance Results (≥ 3)
R01	Suboptimal Feasibility Study	6	Relevant
R02	Suboptimal PV Power Plant Design	6	Relevant
R03	Technological Changes	3	Relevant
R04	Stakeholder Intervention	6	Relevant
R05	Non-compliance with Regulations	3	Relevant
R06	Location-Related Issues	6	Relevant
R08	Complaints from the Community	4	Relevant
R09	Suboptimal Top Management in Managing Project Activities	4	Relevant
R10	Suboptimal Project Team	6	Relevant
R11	Lack of Budget	6	Relevant
R12	Feasibility Study Results Unfavorable for the Organization/Company	6	Relevant
R13	Rejection of Loans/Capital	6	Relevant

From Table 4, all previously identified risks are considered relevant to be included in the risk assessment in the next stage.

3.3 *Risk Assessment*

The risk assessment for risks considered relevant was conducted by respondents through a questionnaire, evaluating the impact level (Severity), likelihood level (Occurrence), and detection level (Detection) using a scale from 1 to 5. The assessment results from the respondents vary. To obtain a group evaluation result, Equation (1) was used to calculate the values of Severity (S), Occurrence (O), and Detection (D). The group assessment results for Severity

(S), Occurrence (O), and Detection (D) for each risk were then used to calculate the Risk Priority Number (RPN) using Equation (2). The final RPN values were presented in Table 5.

Table 5. Risk Priority Number (RPN)

ID Risk	Risk	Severity (S)	Occurrence (O)	Detect (D)	RPN
R01	Suboptimal Feasibility Study	4.309	4,000	4.309	74.27
R02	Suboptimal PV Power Plant Design	4.309	3.000	2.140	27.66
R03	Technological Changes	3.148	2.621	2.140	17.66
R04	Stakeholder Intervention	3.428	3.635	4.309	53.69
R05	Non-compliance with Regulations	4.108	2.621	3.302	35.55
R06	Location-Related Issues	4.818	3.732	2.000	35.96
R08	Complaints from the Community	3.813	2.000	2.000	15.25
R09	Suboptimal Top Management in Managing Project Activities	2.450	2.621	2.402	15.42
R10	Suboptimal Project Team	3.148	3.087	3.000	29.15
R11	Lack of Budget	4.000	4.000	4.000	64.00
R12	Feasibility Study Results Unfavorable for the Organization/Company	4.152	4.152	4.000	68.96
R13	Rejection of Loans/Capital	3.000	3.635	3.302	36.01
	Total				473.58

From the RPN calculations, the values ranged from 15.25 to 74.27, with a total RPN of 473.58, resulting in an average RPN of 39.47. Therefore, risks with an RPN greater than 39.47 are considered critical, and the risk with the highest RPN value is Suboptimal Feasibility Study.

3.4 Plotting of Risk Matrix

Based on the Severity (S) and Occurrence (O) values obtained in Table 5, the Risk Matrix plotting was conducted using the following approach:

- The Severity Level was taken from the Severity (S) values in Table 5 was plotted on the X-axis
- The Occurrence Level was taken from the Occurrence (O) values in Table 5 was plotted on the Y-axis

The bottom-left corner represents the coordinate (0,0), and each line to the right along the X-axis and each line upward represents an increment of 1.

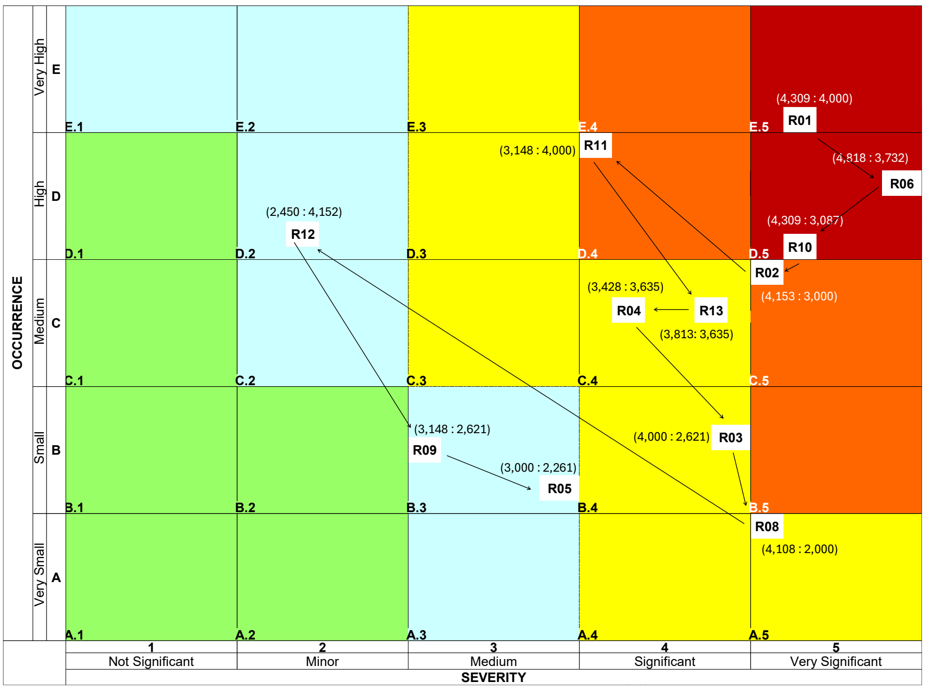

Figure 3. The Risk Matrix Plotting Results.

The Severity (S) values were plotted on the X-axis, while the Occurrence (O) values were plotted on the Y-axis, resulting in the Risk Matrix visualization shown in Figure 3 and the arrows indicate the sequence of risk priorities. These arrows point to the risks with higher priority, helping to visually identify which risks should be addressed first based on their position in the Risk Matrix, considering both their Severity (S) and Occurrence (O) levels.

Therefore, based on the difference in risk prioritization using FMEA based on the RPN values in Table 6 and risk prioritization using the Risk Matrix shown in Figure 3, the comparison can be observed in Table 6. This table will display the prioritization of risks according to both methods, allowing for a clear comparison of the results.

Table 6. Comparison of Risk Priority

Priority	Method						
	FMEA			Risk Matrix			
	Risk Number	Risk	RPN	Risk Number	Risk	Risk Level	Zone
1	R01	Suboptimal Feasibility Study	74.27	R01	Suboptimal Feasibility Study	Extreme	E5
2	R12	Unfavorable for the Organization/Company	68.96	R06	Location-Related Issues	Extreme	E5
3	R11	Lack of Budget	64.00	R10	Suboptimal Project Team	Extreme	E5
4	R04	Stakeholder Intervention	53.69	R02	Suboptimal PV Power Plant Design	Very High	D5
5	R13	Rejection of Loans/Capital	36.01	R11	Lack of Budget	Very High	D4
6	R06	Location-Related Issues	35.96	R13	Rejection of Loans/Capital	High	C4
7	R05	Non-compliance with Regulations	35.55	R04	Stakeholder Intervention	High	C4
8	R10	Suboptimal Project Team	29.15	R03	Technological Changes	High	B4
9	R02	Suboptimal PV Power Plant Design	27.66	R08	Complaints from the Community	High	A5
10	R03	Technological Changes	17.66	R12	Unfavorable for the Organization/Company	Moderate	D2
11	R09	Suboptimal Top Management in Managing Project Activities	15.42	R09	Suboptimal Top Management in Managing Project Activities	Moderate	B3
12	R08	Complaints from the Community	15.25	R05	Non-compliance with Regulations	Moderate	B3

Based on Table 6, the results were as follows:

1. Using the FMEA method, the prioritized risks were as follows:
   a. Suboptimal Feasibility Study (RPN = 74.27, Priority 1)
   b. Unfavorable for the Organization/Company (RPN = 68.96, Priority 2)
   c. Lack of Budget (RPN = 64.00, Priority 3)
   d. Stakeholder Intervention (RPN = 53.69, Priority 4)
2. Using the Risk Matrix method, the prioritized risks were as follows:
   a. Suboptimal Feasibility Study (Extreme Risk Level, Zone E5, Priority 1)
   b. Location-Related Issues (Extreme Risk Level, Zone E5, Priority 2)
   c. Suboptimal Project Team (Extreme Risk Level, Zone E5, Priority 3)
   d. Suboptimal PV Power Plant Design (Very High Risk Level, Zone D5, Priority 4)

The key factor that differentiates the risk prioritization results between the FMEA and Risk Matrix methods is the Detection (D) element, which is exclusively used in the FMEA method. In the context of Failure Mode and Effect Analysis (FMEA), Detection refers to the measure of how likely it is that a risk or failure can be identified before it causes an impact or loss. The Detection (D) component significantly influences the Risk Priority Number (RPN). The more difficult a risk is to detect, the higher the RPN value will be. As a result, the risk is considered more critical and requires immediate mitigation even if its Severity (S) or Occurrence (O) is not particularly high. In contrast, the Risk

Matrix method only considers two dimensions: Severity/Impact and Likelihood/Occurrence. It does not assess the Detection aspect, and therefore, it does not take into account how easily a risk can be prevented or detected early. Consequently, some risks may be prioritized higher in FMEA due to high Detection scores but may not receive the same level of priority in the Risk Matrix. Detection is important because:

1. Risks that are difficult to detect tend to cause greater impact as they cannot be prevented or addressed early.
2. In FMEA, the Detection score directly affects the overall Risk Priority Number (RPN).
3. Since Detection is not considered in the Risk Matrix, the prioritization results between the two methods can differ significantly.

The different risk prioritizations potentially affect decision-making for risk mitigation strategies including resource allocation. Inaccurate determination of risk mitigation priorities will lead to ineffective and inefficient project execution, potentially resulting in the project's failure to meet the targeted Commercial Operation Date (COD) timeline.

4. Conclusions

Based on the analysis, there were 12 potential risks identified during the initiation phase of the Pagerungan Besar PV Power Plant project, which include Suboptimal Feasibility Study, suboptimal PV Power Plant Design, technological Changes, Stakeholder Intervention, Non-compliance with Regulations, Location-Related Issues, Complaints from the Community, Suboptimal Top Management in Managing Project Activities, Suboptimal Project Team, Lack of Budget, Feasibility Study Results Unfavorable for the Organization/Company, Rejection of Loans/Capital. The risk prioritization results obtained using the FMEA method differ from those obtained using the Risk Matrix. According to FMEA, the prioritization was as follows Suboptimal Feasibility Study (Priority 1), Feasibility study results not benefiting the organization/company (Priority 2), Lack of budget (Priority 3), and Stakeholder intervention (Priority 4). On the other hand, the prioritization using the Risk Matrix results in the following order Suboptimal Feasibility Study (Priority 1), Location-related issues (Priority 2), Suboptimal project team (Priority 3), and Suboptimal PV Power Plant design (Priority 4). For further research, a more comprehensive study of the identified risks in this study is needed, including an evaluation of the determination of risk priorities using the Risk Matrix. Project planners may consider integrating both methods to develop hybrid prioritization frameworks.

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