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Original Article

A Hybrid FMEA and K-Means Clustering Approach for Risk Identification and Analysis on Road Infrastructure Project in Nepal

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Abstract *- Road infrastructure plays a significant role for the socio-economic development in Nepal. But this area faces various challenges such as delays, cost overrun, safety issues, quality downfall etc. Unmanaged uncertainties in the technical, financial, environmental, and managerial areas frequently give rise to these problems. The Failure Mode Effect Analysis (FMEA) framework is used in this study to effectively identify, assess, and rank the risk factors affecting Nepal's road construction project. A total 56 risk factors were identified through an extensive literature review and expert consultations. Data were collected using a structured questionnaire from 90 professionals representing clients, consultants and contractors. Reliability was checked by Cronbach's alpha, and Validity was checked for extraction values; one factor (G1F1) did not meet the validity threshold of 0.5 and was removed, and only 55 factors were retained and used to test the validity and reliability of the data. A critical risk was ranked by Risk Priority Number (RPN) based on severity, occurrence and detection rating through Relative Important Index (RII). The results show that hazardous working conditions, inaccurate time estimation, extra work due to scope variations, unrealistic project schedule, cost and time overrun, poorly designed project scope and unsuitable construction program planning are the overall risk factors which impact Nepal's road construction projects. Also, the k-means clustering (k=3) grouped the factors into three tiers: high, moderate and low risk. Spearman's rank correlation compared the ranking of the three groups. Only unsafe or hazardous working conditions on-site shows (G8F1) is a major risk factor among all stakeholders. The consultant and contractor rankings were moderately correlated, while the client ranking was not significantly correlated with either. The study offers a framework for integrated risk assessment, along with knowledge that can help Nepal's road infrastructure project plan more proactively, evaluate more effectively and make better decision making.*

Keywords *- Failure Mode Effect Analysis (FMEA), K-Means clustering, Relative Importance Index (RII), Risk Priority Number (RPN), Road infrastructure project.*

1. Introduction

Risk is the occurrence of events which causes negative impacts on the objectives of the project [1]. The occurrence of unanticipated events that have adverse impacts on project objectives, commonly referred to as "risk", is an inevitable part of construction, especially in complicated highway projects [2]. In construction projects, there are always some risks that might happen which are out of the project control and cause delays, extra expenses and lower quality.

The construction sector, particularly in road infrastructure projects, is characterized by inevitable complexities and higher risk levels, usually leading to project delays, cost escalations, and performance failures. Excellent risk management frameworks are essential because poor handling of these complex problems events frequently results in projects falling short of their goals and expectations [3]. The long timelines, high expenses, and major resource requirements, including personnel, supplies, and equipment, inherent in road construction compound these difficulties [4].

Risk management is now a crucial part of building projects. The risk management process involves risk identification, risk assessment, and risk control. Risk is assessed using both qualitative and quantitative methods. The systematic method of identifying, evaluating and addressing project risk is known as risk management.

It means minimizing the likelihood and effects of characteristics that are detrimental to project goals while

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increasing the likelihood and effects of positive aspects. Insufficient planning, unexpected environmental circumstances, faulty design, financial instability, and poor collaboration among stakeholders are often the causes of these risks [5].

Infrastructure development is crucial to the socioeconomic advancement of developing countries like Nepal. Road transportation is an essential part of several infrastructure sectors, serving as a framework for connection, trade, and mobility. In construction projects, there is always some risk since things might happen that are out of the project's control and cause delays, extra expenses, and lower quality. However, a number of risks, such as delays and cost overruns, safety issues, and quality problems, commonly pose a challenge to road construction in Nepal. With a population of more than 29 million, Nepal is a developing country whose economy is largely dependent on the construction industry [6].

The Failure Mode and Effect Analysis (FMEA) is a widely recognized and practical method in reliability engineering. Its primary objectives are to investigate, identify, and prioritize potential failure modes in a given system, design, operation, or service [3]. Carbone & Tippett [7], in their studies fills this gap by systematically recognizing and evaluating possible risks during the road project construction phase using the Failure Mode and Effect Analysis (FMEA) technique, a popular preventive risk evaluation tool. By ranking risks based on their severity, occurrence, and detectability, the FMEA technique allows project stakeholders to focus on crucial areas that want immediate concern. In FMEA, risks are ranked on the basis of Risk Priority Number (RPN). A risk having higher RPN than others suggests that it requires more attention for others [8]. The use of FMEA for risk prioritization is recognized for its structured and systematic approach in construction project risk management [9].

K. Sharma and Gupta [8] studied “Risk Analysis in Highway Construction Projects using FMEA model” in India to find, rank, allocate and remedial measures of various risk factors. The researcher used assessment over the traditional methods by calculating the three main dimensions; frequency of occurrence, severity of consequences and ease of detectability. Based on their research, they have identified 48 critical risk factors and collect Likert ratings from 39 key stakeholders from client, consultant and contractor equally. Using five-point Likert scale and RII to calculate the RPN, the study of insufficient availability of land (RPN 44.16), unforeseen climate conditions (43.84), and uncertainties surrounding land acquisition costs and schedules (RPN 44.16) as the top-priority threats. The analysis reveals that 90% of the operational risks are allocated to the contractor, underscoring the heavy inappropriate exposure developed by the contractor in the highway projects and demonstrating the value of FMEA as a structured, decision-oriented approach for proactive management.

Issa et al. [4] entitled the study “Analysis of risk factors affecting the main execution activities of roadways construction project” in Egypt. The researcher identified five main activities of RCPs as; (A) Preliminary Preparation, (B) Earthwork (cut/fill), (C) Implementation of sub-base and base layers; (D) Implementation of bituminous layers and (E) Traffic safety and road furniture.

Researchers conducted a field survey in Egypt that introduced 39 crucial risk factors affecting RCP activities. The probability and impact of the risk factors on RCPs' objectives (time, cost and quality) and also the risk severity were calculated. The result shows a high effect on the quality of activities (A), (B), and (D) and a moderate effect on activities (C) and (E).

Banerjee Chattapadhyay et al. [9] studied “Risk identification, Assessments and Prediction for Mega Construction Projects: A Risk Prediction Paradigm Based on Cross Analytical Machine Learning Model”. In this research, a risk prediction system based on a cross-analytical machine learning model was developed for construction mega projects in India. A total of 63 risk factors pertaining to the cost, quality and scope of the mega project and primary data was collected from industry experts on a five-point Likert scale. The researcher used K-means clustering for a large set of features, which is based on high-risk factor and allied sub-risk component identification.

Al-Bataineh et al. [10] in their study “Unsupervised Machine Learning for Identifying Key Risk Factors Contributing to Construction Delays”. The study identified and classified the major risk factors for construction delays. The researcher examined the 68 contracting firms in Indonesia using K-means clustering. The results identified four clusters related to operational and external challenges, financial and managerial issues, labor and resources. The discussion highlighted delays in budget approval, delays in payment, design errors, and labor shortages as vital concerns, labor management and comprehensive risk mitigation strategies.

Research Gap and problem. The studies above show that FMEA is well established for construction risk, that K-means clustering can group risk factors, and that stakeholders perceive risk differently. In the literature reviewed for this study, however, FMEA-based risk ranking, data-driven grouping of the ranked factors into risk tiers, and a formal test of agreement between client, consultant and contractor rankings were not combined for a road project; no such analysis was found for Nepal. It is therefore not clear whether the risks that rank highest in a pooled analysis are also treated as critical by each party.

Traditional RPN ranking gives one list of priorities and does not show how risk tiers and priorities differ between the parties who must manage the risk together.
The major objectives of the research are given below:

- To identify and analysis the various key risk factors in the road infrastructure project in Nepal with FMEA, using RII and RPN
- To categorize the risk factors into High, Moderate, and Low Risk tiers with K-means Clustering
- To compare the RPN rank between stakeholder groups by Spearman's rank correlation.

The contribution of this study is the combination of these three steps for the road project in Nepal, with the clustering and correlation analysis carried out separately for each stakeholder group, with a fully specified calculation procedure (RII, RPN and normalization) that allows the results to be reproduced.

The outline of this paper is organized as follows; the methodology and proposed methods is stated in section 2, data analysis and results is presented in section 3, discussion and conclusion is presented in Sections 4 and 5, respectively.

2. Methodology

2.1. Research Flow Process

The study was classified into two steps. The first steps were to identify the various risk factors, and next step is the assessment of the various obtained risk factors. The identification of the risk factors is done by the literature review and then reduced to major risk events, as 56, from the structured interview by the experts from the road infrastructure project having more than 10 years of experience.

Now, the selected risk factors are defined by the numerical rating and linguistic term for risk severity, risk occurrence and risk detection, which is shown in Table 1. The second steps were the assessment of the major risk events, which is done by statistical data analysis, including the reliability test Cronbach's alpha, validity test, RII and RPN from FEMA approach, as Table 1.

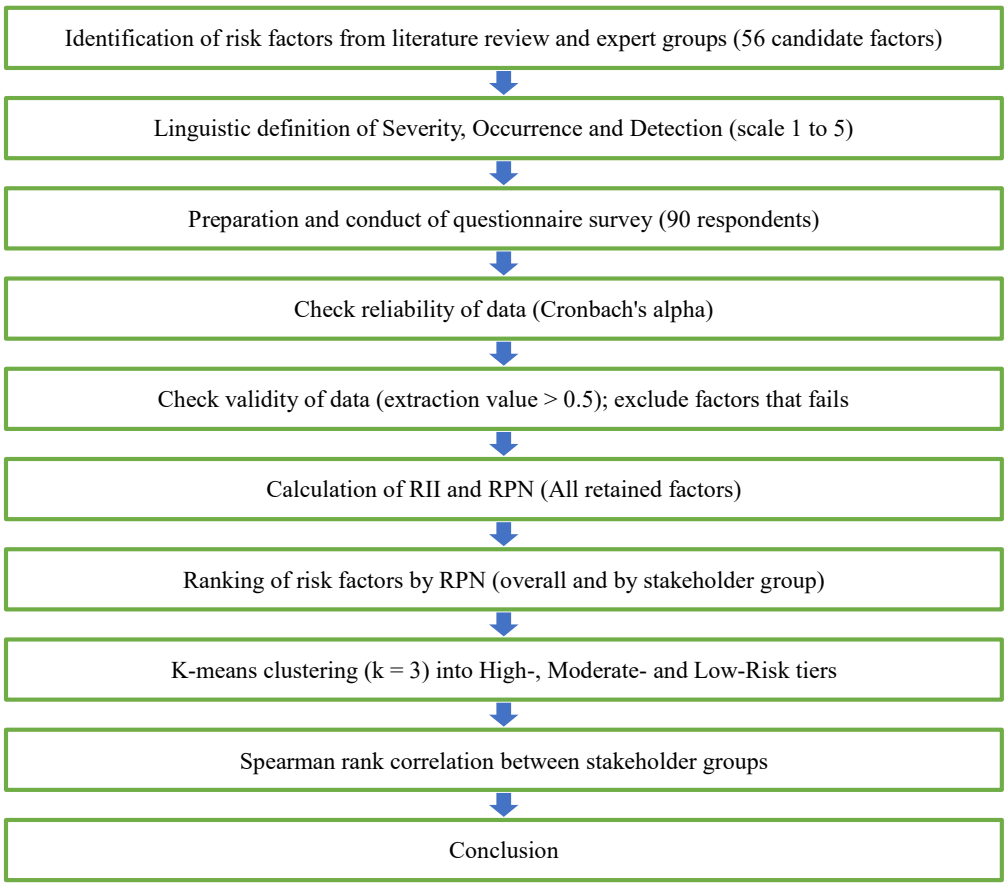


Fig. 1 Research implementation flow Process

2.2. Risk Identification Framework

An extensive literature review was carried out to identify the various risk factors in road infrastructure construction projects, with concerned for Nepalese context. From the various risk factors, only 56 key risk factors are used here for further assessment with the help from experts group opinion. The final 56 key risk factors are shown in Table 1.

Table 1. Types of risk factors with references

Group 1	**Project Scope Risk**	**Code**	**References**
1	High Complexity of project component	G1F1	[1, 11-13, 15-17]
2	Designed or poorly designed project scope	G1F2	
3	Frequent changes in scope requirement	G1F3	
4	Lack of proper analysis on scope changes and their impact	G1F4	
Group 2	**Design and Specification Risk**	**G2**	**References**
1	Inadequate or insufficient design information	G2F1	[1, 11, 13, 14, 16, 18, 19]
2	Defective design	G2F2	
3	Likelihood of frequent design changes	G2F3	
4	Unrealistic or overly ambitious specification	G2F4	
5	Difficulties arising from interaction of design changes among disciplines	G2F5	
Group 3	**Legal, Political and Social Risk**	**G3**	**References**
1	Delay in permit approval and regulatory clearance	G3F1	[11-15, 17, 19, 20]
2	Excessive bureaucracy and red tape	G3F2	
3	Poorly written or vague contract terms	G3F3	
4	Frequently changes in laws and regulations	G3F4	
5	Improper contract verification before execution	G3F5	
6	Breach of contract by project partner	G3F6	
7	Political Instability affecting project continuity	G3F7	
8	Strikes, protests, and blockades disrupting work	G3F8	
9	Delays in dispute resolution mechanisms	G3F9	
Group 4	**Quality Risk**	**G4**	**References**
1	Absence of a structured Quality Assurance (QA) Plan	G4F1	[11, 13-16, 19]
2	Use of poor-quality or substandard materials	G4F2	
3	Inadequate or ineffective quality control measures	G4F3	
4	Irregular or no testing of construction materials	G4F4	
5	Quality inconsistencies due to unskilled or careless labor	G4F4	
Group 5	**Time Overrun Risk**	**G5**	**References**
1	Inaccurate estimation of activity durations	G5F1	[11-14, 16, 18, 19, 21]
2	Unrealistic or overly optimistic project schedules	G5F2	
3	Incomplete or vague Work Breakdown Structure (WBS)	G5F3	
4	Ineffective schedule monitoring and control systems	G5F4	
5	Delays in corrective actions when risks or issues arise	G5F5	
Group 6	**Cost Overrun Risk**	**G6**	**References**
1	Inaccurate cost estimates	G6F1	[11, 12, 14-16, 19, 21]

2	Inadequate cost planning, budgeting, and control mechanisms	G6F2	
3	Delayed payments on contract claims and invoices	G6F3	
4	Constant fluctuations in market conditions (material prices, labor, etc.)	G6F4	
Group 7	**Financial and Economic Risk**	**G7**	**References**
1	Inflationary impacts on local costs	G7F1	[11-17, 19, 21]
2	Increase in taxes or import/custom duties	G7F2	
3	Cash flow problems during execution	G7F3	
4	Cost and time overruns impacting project financing	G7F4	
5	Corruption and financial mismanagement	G7F5	
Group 8	**Safety, Health and Environment risks**	**G8**	**References**
1	Unsafe or hazardous working conditions on-site	G8F1	[12-16, 19, 21]
2	Workers lacking awareness and training on safety	G8F2	
3	Absence of regular safety audits and inspections	G8F3	
4	Natural disasters (e.g., landslides, floods, soil erosion, earthquakes)	G8F4	
5	Adverse weather conditions delaying or damaging work	G8F5	
Group 9	**Contractual Risks**	**G9**	**References**
1	Non-standard or inconsistent contract conditions	G9F1	[11-16, 19]
2	Insufficient time allotted for preparation of bids or tenders	G9F2	
3	Delays in handing over project site to the contractor	G9F3	
4	Errors or omissions in the bill of quantities	G9F4	
5	Unrealistic tendered amount	G9F5	
6	Extra work due to scope variations not included in the original contract	G9F6	
Group 10	**Construction Risk**	**G10**	**References**
1	Poor or unsuitable construction program planning	G10F1	[11-13, 15-18, 21]
2	Workers not adhering to scheduled work hours	G10F2	
3	Frequent design modifications during execution	G10F3	
4	Shortage of necessary technical skills	G10F4	
5	Low labor productivity and work efficiency	G10F5	
6	Delays due to late delivery of key materials	G10F6	
7	Transportation delay of special equipment/materials	G10F7	
8	Lack of communication between various stakeholders	G10F8	

2.3. FMEA Rating Criteria for Severity, Occurrence and Detection

The results from the questionnaire survey were obtained in the numerical value so the Likert scale ranges from 0 to 5 is used, and the numerical rating is obtained from the Linguistic Terms as Very Low, Low, Medium, High and Very High.

Table 2. Numerical rating and linguistic definition of risk severity, risk occurrence and risk detection

Numerical Rating	Linguistic Term	Linguistic Definition	
1	Very Low	S	Risk would cause minimal or negligible impact.
		0	Very unlikely to occur.
		D	Very high chance of detecting the risk before it causes harm.
2	Low	S	Risk is unlikely to cause serious impact.
		0	Low likelihood of occurrence.
		D	High chance of detecting the risk before it causes harm.
3	Medium	S	Risk may cause moderate impact.
		0	Moderate likelihood of occurrence.
		D	Moderate chance of detecting the risk before it causes harm.
4	High	S	Risk is expected to cause significant impact.
		0	High likelihood of occurring in the project.
		D	Low chance of detecting the risk before it causes harm.
5	Very High	S	Risk has high certainty of causing severe impact.
		0	Extreme likelihood of occurring during the project.
		D	Very low chance of detecting the risk before it causes harm.

2.4. Questionnaire Survey and Respondents

The questionnaire survey was done in two parts. The preliminary parts contain general information of the respondents as name, role (client, consultant or contractor), company/office name, qualification and years of experience. The second part consists of the rating of all 56 factors from very low to very high, as 1 to 5 form FMEA approach to calculate the Risk Priority Rating (RPN) by multiplying Severity (S), Occurrence (O) and Detection (D) of all the factors. The use of FMEA for risk prioritization is recognized for its structured and systematic approach in construction project risk management [9].

To optimize the bias and preserve objectively, responses were collected confidentially. The 90-questionnaire survey was carried out from the stakeholder's, i.e. client, consultant and contractor, of the road infrastructure construction project in Narayanghat-Butwal Road Project or similar national highway project in Nepal.

The type of the Project were Road infrastructure, and the respondents were technical representatives from client, consultant and contractor as Highway Engineer, Survey Engineer, Planning Engineer, Structure Engineer, Asst. Highway Engineer, Bridge Engineer, Team Leader, Resident Engineer (RE), Asst. Resident Engineer (ARE), Inspector of Work (IOW), Quality Surveyor and Site Supervisor. The respondents were given total freedom of choice whether to give the question and to keep this information confidential.

The survey targets respondents who are currently working on any construction project, so that is important to know their current position.

Table 3. Percentage of respondents

S.N.	Parties	No. of Respondents	Percentage of Respondents
1	Client	31	34.44%
2	Consultant	24	26.67%
3	Contractor	35	38.89%

Table 4. Percentage distribution of years of experience of respondents

S.N.	No. of years of experience in Construction Project	Total Number	Percentage of Respondents
1	0 to 4	15	16.67%
2	4 to 8	27	30.00%
3	8 to 12	36	40.00%
4	More than 12	12	13.33%

2.5. Rationale and Novelty of K-Means Framework

One ranked list for a dataset is provided by FMEA and RII/RPN based evaluation. It has a clustering stage in this study since there are three issues with such a ranked list. First of all, the ranking does not indicate if the components next to each other differ in any manner. Consider the overall RPN of ranks 1 and 2 in Table 7, which differ by just 0.37. Second, since each group's RPN is produced from its own group of RII values, a fixed cut-off from Tables 7 to 10 is arbitrary, and each group's RPN scale is unique for Table 11. Thirdly, it cannot determine which party deems a particular factor significant from a pooled ranking.

As a result, the framework comprises three steps. Step 1: FMEA score and RII and RPN computation for each stakeholder group and the pooled sample as provided in Section 3.3. Step 2: To create group-specific High, Moderate, and Low risk levels, Z-score standardization and k-means clustering of the 55 RPN values within each group are performed. Step 3 compares rank order using Spearman's correlation and tier membership among the three categories. The result is a map of stakeholder agreement, a tier classification for each stakeholder, and an RPN grade.

3. Data Analysis and Results

The available data were evaluated and analyzed for the various risk factors. The Risk Priority Number was calculated to quantify and prioritize the various risk factors in a systematic, objective and comparable ways, Relative Importance Index is used to calculate the RPN and the reliability of the data analysis was done through the Cronbach alpha.

3.1. Cronbach's Alpha

Numerous studies in construction management apply Cronbach's alpha to conform reliability of survey instruments used to measure risk variables. High Cronbach's alpha values suggest that the items in a questionnaire are assessing the same underlying construct and that the method used is reasonable for additional evaluation.

This coefficient indicates the reliability of the questionnaire used in the study [22]. In this case, Cronbach's alpha value is 0.811, 0.826 and 0.823 for severity, occurrence and detection of risk factors, respectively, which is greater than 0.7 and suggests a high level of internal consistency among the items included in the questionnaire.

Table 5. Cronbach's alpha of the risk factors

S. N	Risk Factors	Code	Cronbach's alpha		
			Severity	Occurrence	Detection
1	Project Scope Risk	G1	0.745	0.777	0.712
2	Design and Scope Risk	G2	0.843	0.856	0.799
3	Legal, Political, and Social Risk	G3	0.899	0.893	0.868
4	Quality Risk	G4	0.859	0.869	0.886
5	Time Overrun Risk	G5	0.706	0.778	0.806
6	Cost Overrun Risk	G6	0.836	0.843	0.847
7	Financial and Cost Risk	G7	0.727	0.707	0.823
8	Safety, Health and Environment Risk	G8	0.808	0.767	0.765
9	Contractual Risk	G9	0.826	0.874	0.852
10	Construction Risk	G10	0.863	0.898	0.879
Overall Cronbach's alpha			0.811	0.826	0.823

3.2. Validity Test

A validity test is a method of data analysis used to determine whether the researcher's goals have been met and whether the results are consistent with what the researcher intended to measure. In any research, achieving validity is crucial. It also demonstrates the accuracy of the data.

The validity test's value, with a score of 0.9 or higher denoting an excellent score, a score between 0.7 and 0.9 denoting high score, a score between 0.5 and 0.7 denoting a moderate score, and a score below 0.5 denoting a lower score that indicates the questionnaire's results fell short of its intended goals [23]. Validity values were calculated using the software SPSS Ver.23.0. Here, the factor G1F1 has the extraction value for the detection is 0.257, which fell short of its intended goals, so the factor G1F1 has been excluded. Thus, the results of the Validity test are shown in Table 6, in which G1F1 is omitted. The Risk factor column and extraction value, which identifies the validity strength, as it was discussed, the higher the value of validity, the better the results and at the bottom of the extraction column, the average value of Validity test is 0.709, 0.732 and 0.709, indicating an overall high score for severity, occurrence and detection, respectively

Table 6. Validity test

S. N	Factors	Code	Extraction value		
			Severity	Occurrence	Detection
1	Designed or poorly designed project scope	G1F2	0.685	0.784	0.542
2	Frequent changes in scope requirement	G1F3	0.631	0.664	0.522
3	Lack of proper analysis on scope changes and their impact	G1F4	0.685	0.784	0.542
4	Inadequate or insufficient design information	G2F1	0.784	0.522	0.681
5	Defective design	G2F2	0.658	0.689	0.717
6	Likelihood of frequent design changes	G2F3	0.697	0.677	0.577
7	Unrealistic or overly ambitious specification	G2F4	0.755	0.796	0.517
8	Difficulties arising from interaction of design changes among disciplines	G2F5	0.583	0.695	0.600
9	Delay in permit approval and regulatory clearance	G3F1	0.705	0.836	0.835
10	Excessive bureaucracy and red tape	G3F2	0.723	0.685	0.771
11	Poorly written or vague contract	G3F3	0.754	0.759	0.742
12	Frequently changes in laws and regulations	G3F4	0.734	0.823	0.701
13	Improper contract verification before execution	G3F5	0.701	0.626	0.649
14	Breach of contract by project partner	G3F6	0.789	0.770	0.693
15	Political Instability affecting project continuity	G3F7	0.730	0.729	0.773
16	Strikes, protests, and blockades disrupting work	G3F8	0.783	0.691	0.729
17	Delays in dispute resolution mechanisms	G3F9	0.607	0.737	0.737
18	Absence of a structured Quality Assurance (QA) Plan	G4F1	0.616	0.681	0.719
19	Use of poor-quality or substandard materials	G4F2	0.739	0.718	0.759
20	Inadequate or ineffective quality control measures	G4F3	0.816	0.762	0.829
21	Irregular or no testing of construction materials	G4F4	0.738	0.755	0.803
22	Quality inconsistencies due to unskilled or careless labor	G4F5	0.794	0.856	0.617
23	Inaccurate estimation of activity durations	G5F1	0.782	0.746	0.731
24	Unrealistic or overly optimistic project schedules	G5F2	0.726	0.758	0.736
25	Incomplete or vague Work Breakdown Structure (WBS)	G5F3	0.559	0.559	0.705
26	Ineffective schedule monitoring and control systems	G5F4	0.758	0.678	0.683
27	Delays in corrective actions when risks or issues arise	G5F5	0.566	0.602	0.809
28	Inaccurate cost estimates	G6F1	0.720	0.832	0.747
29	Inadequate cost planning, budgeting, and control mechanisms	G6F2	0.726	0.834	0.696
30	Delayed payments on contract claims and invoices	G6F3	0.718	0.690	0.722

31	Constant fluctuations in market conditions (material prices, labor, etc.)	G6F4	0.803	0.672	0.768
32	Inflationary impacts on local costs	G7F1	0.754	0.563	0.772
33	Increase in taxes or import/custom duties	G7F2	0.621	0.650	0.692
34	Cash flow problems during execution	G7F3	0.725	0.694	0.558
35	Cost and time overruns impacting project financing	G7F4	0.655	0.765	0.692
36	Corruption and financial mismanagement	G7F5	0.744	0.726	0.688
37	Unsafe or hazardous working conditions on-site	G8F1	0.773	0.752	0.657
38	Workers lacking awareness and training on safety	G8F2	0.735	0.816	0.675
39	Absence of regular safety audits and inspections	G8F3	0.645	0.546	0.777
40	Natural disasters (e.g., landslides, floods, soil erosion, earthquakes)	G8F4	0.567	0.684	0.751
41	Adverse weather conditions delaying or damaging work	G8F5	0.640	0.742	0.794
42	Non-standard or inconsistent contract conditions	G9F1	0.758	0.795	0.727
43	Insufficient time allotted for preparation of bids or tenders	G9F2	0.798	0.799	0.857
44	Delays in handing over project site to the contractor	G9F3	0.734	0.753	0.823
45	Errors or omissions in the bill of quantities	G9F4	0.684	0.824	0.804
46	Unrealistic tendered amount	G9F5	0.860	0.826	0.713
47	Extra work due to scope variations not included in the original contract	G9F6	0.749	0.759	0.595
48	Poor or unsuitable construction program planning	G10F1	0.661	0.798	0.615
49	Workers not adhering to scheduled work hours	G10F2	0.744	0.781	0.664
50	Frequent design modifications during execution	G10F3	0.531	0.723	0.783
51	Shortage of necessary technical skills	G10F4	0.701	0.809	0.619
52	Low labor productivity and work efficiency	G10F5	0.772	0.811	0.791
53	Delays due to late delivery of key materials	G10F6	0.754	0.760	0.708
54	Transportation delay of special equipment/materials	G10F7	0.693	0.749	0.794
55	Lack of communication between various stakeholders	G10F8	0.644	0.749	0.803
Overall average extraction value			0.709	0.732	0.709

3.3. Risk Priority Number based on the Failure Mode and Effect Analysis (FMEA)

To identify the significant risk and risk priority, each respondent rated Risk Severity, Risk Occurrence and Risk Detection for each risk factor based on Crisp Rating 1 to 5. The rating was used to calculate the Relative Importance Index (RII), and Risk Priority Number (RPN) was determined for all factors as per Failure Mode and Effect Analysis (FMEA). The risk factors are then ranked as per RPN.

The Weighted score (ΣW) of severity, occurrence and detection of each risk factors was calculated, and the RII of each factor was calculated by relation as RII = Sigma W/ (A x N), which is expressed in Equation (1)

$$RII = \frac{\Sigma W}{A \times N} \quad (1)$$

Where W = weighting given to each factor by the respondents (ranging from 1 to 5)

A = Highest weight
N= Total Number of respondents (N=90 in overall analysis; N=31 Clients,24 Consultants and 35 Contractors)

RPN is calculated from the RII severity, detection and occurrence of each factor. In this research, $RII_{(S)}$, $RII_{(O)}$ and $RII_{(D)}$ are calculated by using the relative importance index formula. Here, the values of $RII_{(S)}$, $RII_{(O)}$ and $RII_{(D)}$ are less than 1, so the multiplication of them will be less than 1. So, to easier understand and rank the risk factors, RPN of different risk factors, resulting in multiplication of $RII_{(S)}$, $RII_{(O)}$ and $RII_{(D)}$ is again multiplied by 100, which is expressed in Equation (2).

$$RPN = RII_{(S)} \times RII_{(O)} \times RII_{(D)} \times 100 \quad (2)$$

For example, the overall value of RII values of G8F1 (Unsafe or hazardous working condition on site) are 0.733for severity, 0.704 for occurrence and 0.668 for detection. So, RPN =0.733 x 0.704 x 0.668 x 100 = 34.47, this value is represented in Table 7. A greater RPN means more serious risk that requires an early reaction. Figures 2 to 5 and Tables 7 to 10 show the overall top 10 risk factors and top 10 risk factors from various stakeholder perspectives.

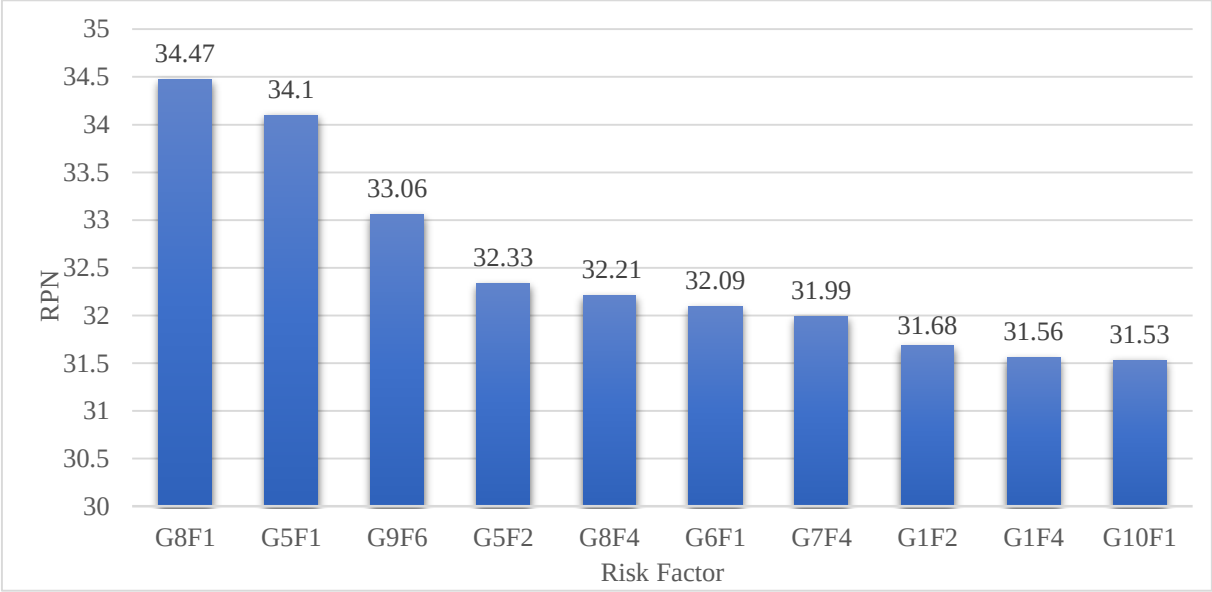


Fig. 2 Overall top ten high risk factors

Figure 2 shows the RPN value of the overall top 10 risk factors which are identified (G8F1, G5F1, G9F6, G5F2, G8F4, G6F1, G7F4, G1F2, G1F4, and G10F1 and further details regarding these risk factors on tabulated form is shown in Table 7.

Table 7. Overall top ten high risk

Rank	Risk Factors	Code	RPN
1	Unsafe or hazardous working conditions on-site	G8F1	34.47
2	Inaccurate estimation of activity durations	G5F1	34.10
3	Extra work due to scope variations not included in the original contract	G9F6	33.06
4	Unrealistic or overly optimistic project schedules	G5F2	32.33
5	Natural disasters (e.g., landslides, floods, soil erosion, earthquakes)	G8F4	32.21
6	Inaccurate cost estimates	G6F1	32.09
7	Cost and time overruns impacting project financing	G7F4	31.99
8	Designed or poorly designed project scope	G1F2	31.68
9	Lack of proper analysis on scope changes and their impact	G1F4	31.56
10	Poor or unsuitable construction program planning	G10F1	31.53

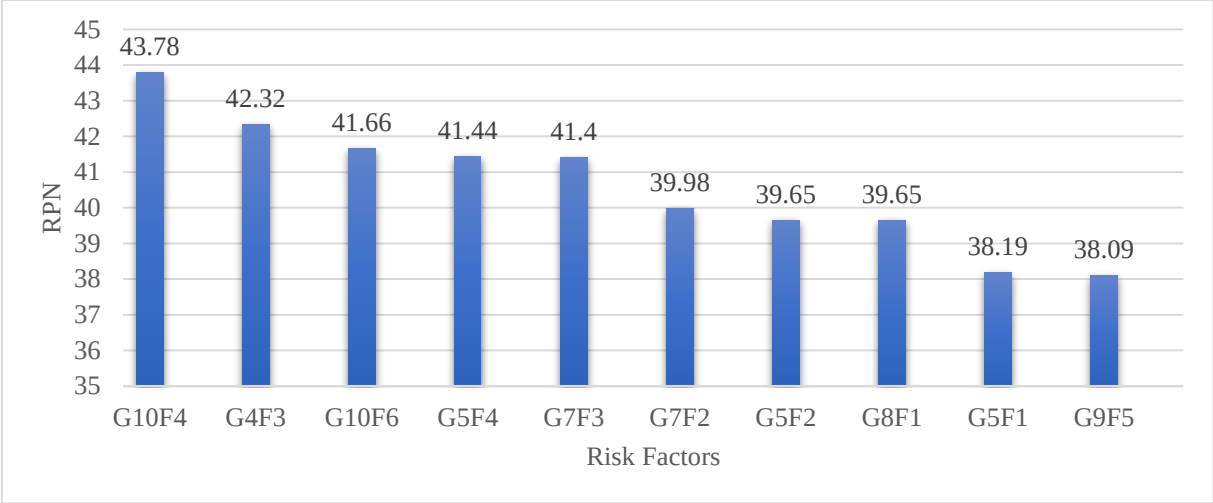


Fig. 3 Top ten risk factors from client perspectives

Figure 3 shows the RPN value of the top 10 risk factors from client's perspective, which are identified (G10F4, G4F3, G10F6, G5F1, G7F3, G7F2, G5F2, G8F1, G5F1, and G9F5) and further details regarding these risk factors on tabulated form is shown in Table 8.

Table 8. Top ten risk factors from client perspectives

Rank	Risk Factors	Code	RPN
1	Shortage of necessary technical skills	G10F4	43.78
2	Inadequate or ineffective quality control measures	G4F3	42.32
3	Delays due to late delivery of key materials	G10F6	41.66
4	Ineffective schedule monitoring and control systems	G5F4	41.44
5	Cash flow problems during execution	G7F3	41.40
6	Increase in taxes or import/custom duties	G7F2	39.98
7	Unrealistic or overly optimistic project schedules	G5F2	39.65
8	Unsafe or hazardous working conditions on-site	G8F1	39.65
9	Inaccurate estimation of activity durations	G5F1	38.19
10	Unrealistic tendered amount	G9F5	38.09

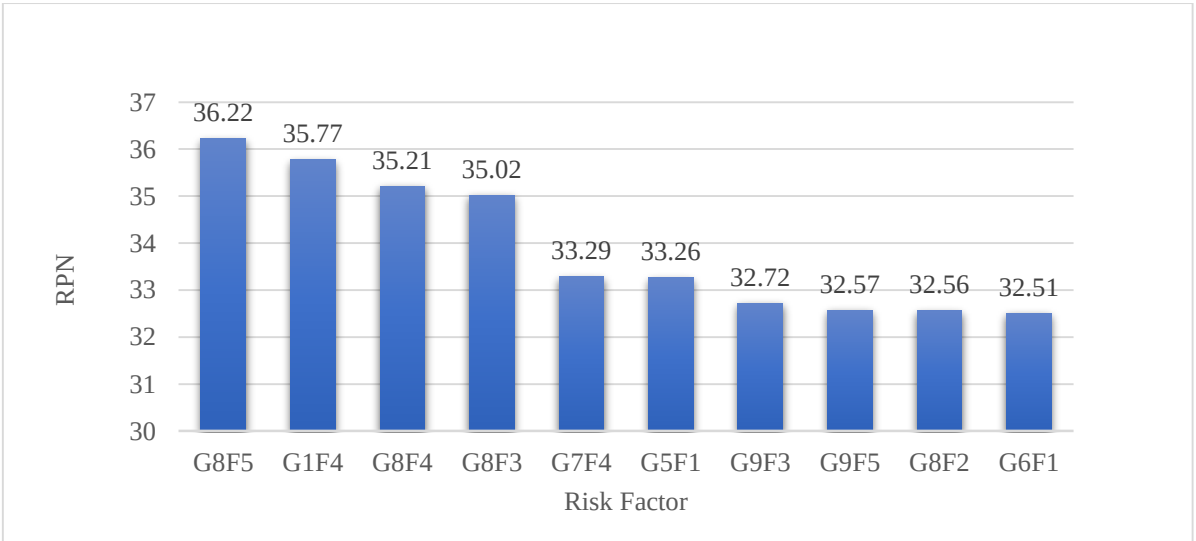


Fig. 4 Top ten risk factors from consultant perspectives

Figure 4 shows a RPN value of the top 10 risk factors from consultants' perspectives, which are identified (G8F5, G1F4, G8F4, G8F3, G7F4, G5F1, G9F3, G9F5, G8F2, and G6F1) and further details regarding these risk factors on tabulated form is shown in Table 9.

Table 9. Top ten risks from consultant perspectives

Rank	Risk Factors	Code	RPN
1	Adverse weather conditions delaying or damaging work	G8F5	36.22
2	Lack of proper analysis on scope changes and their impact	G1F4	35.77
3	Natural disasters (e.g., landslides, floods, soil erosion, earthquakes)	G8F4	35.21
4	Absence of regular safety audits and inspections	G8F3	35.02
5	Cost and time overruns impacting project financing	G7F4	33.29
6	Unsafe or hazardous working conditions on-site	G5F1	33.26
7	Delays in handing over project site to the contractor	G9F3	32.72
8	Unrealistic tendered amount	G9F5	32.57
9	Workers lacking awareness and training on safety	G8F2	32.56
10	Inaccurate cost estimates	G6F1	32.51

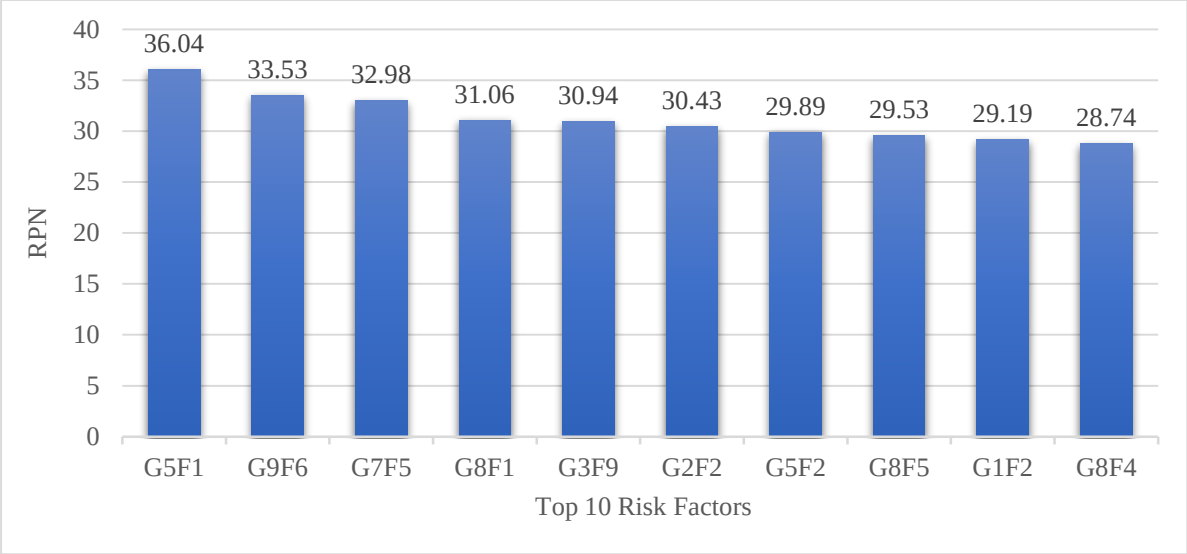


Fig. 5 Top ten risk factors from contractor perspectives

Figure 5 shows a RPN value of the top 10 risk factors from contractors' perspective, which are identified (G5F1, G9F6, G7F5, G8F1, G3F9, G2F2, G5F2, G8F5, G1F2, and G8F4) and further details regarding these risk factors is shown on tabulated form in Table 10.

Table 10. Top ten high and low risk from contractor perspectives

Rank	Risk Factors	Code	RPN
1	Inaccurate estimation of activity durations	G5F1	36.04
2	Extra work due to scope variations not included in the original contract	G9F6	33.53
3	Corruption and Financial mismanagement	G7F5	32.98
4	Unsafe or hazardous working conditions on site	G8F1	31.06
5	Delay in dispute resolution mechanisms	G3F9	30.94
6	Defective Design	G2F2	30.43
7	Unrealistic or overly optimistic project schedules	G5F2	29.89
8	Adverse weather conditions delaying or damaging work	G8F5	29.53
9	Design or poorly designed project scope	G1F2	29.19
10	Natural disaster (e.g., landslides, floods, soil erosion, earthquakes)	G8F4	28.74

3.4. K-Means Clustering for the Specific for the Client, Consultant and Contractor

K-means clustering is a type of partition clustering algorithm which is used to separate a dataset into clusters involves finding the minimum squared error between the various data points in the data set and the mean of cluster, then assigning each data point to the cluster center nearest to it [24]. The RPN ranking provides the components along one score and does not disclose which factors create grouping of similar risk level or whether all stakeholders put the same factor in the same group. The same 55 retained risk factors were scored independently by all stakeholders, so each group has its unique RPN values (top ten of each category as provided in Tables 8-10. The RPN for each group was calculated based on the RII values of each group itself. Then K-means clustering (k=3) was performed independently from 55 RPN values of each party for dividing the component into risk tiers between the parties. K=3 was chosen due to its short risk into high, moderate and low risk tiers and also k =3 is the smallest number cluster that gives a middle tier.

Before clustering, RPN values of each group were standardized independently with Z-score standardization, which is shown in Equation 3

$$Z_i = \frac{RPN_i - \mu}{\sigma} \quad (3)$$

Where RPN_i is the RPN of Risk Factor i in group (Client, consultant or Contractor), μ and σ are the mean and population standard deviation of the RPN values of that group, and Z_i is the standardized value used for clustering. Each group undergoes standardization to adjust for the difference in RPN levels among groups, so that each grouping represents the distribution of the group's own score.

K-means clustering was performed using 25 random initializations, maintaining the solution with the lowest within cluster sum of squares, and fixed random seed of 42 (scikit-learn, Python). The clusters of each group were classified as High Risk, Medium Risk and Low Risk. Figure 6: Number of clusters analysis with the elbow approach and silhouette score.

The within-cluster sum of squares steadily fell without a clear elbow (87.1, 68.3, 55.6, 46.6 and 40.1 for k = 2 to 6), and the silhouette score was highest for k = 2 (0.399) and lower for k = 3 (0.278). However, three clusters were preserved since they provide the common High-, Moderate- and Low-Risk levels utilized in FMEA practice. A low silhouette score for k = 3 suggests the components form a continuum rather than discrete groups, hence the tier boundaries should be interpreted as data-driven cut points and not as natural divisions.

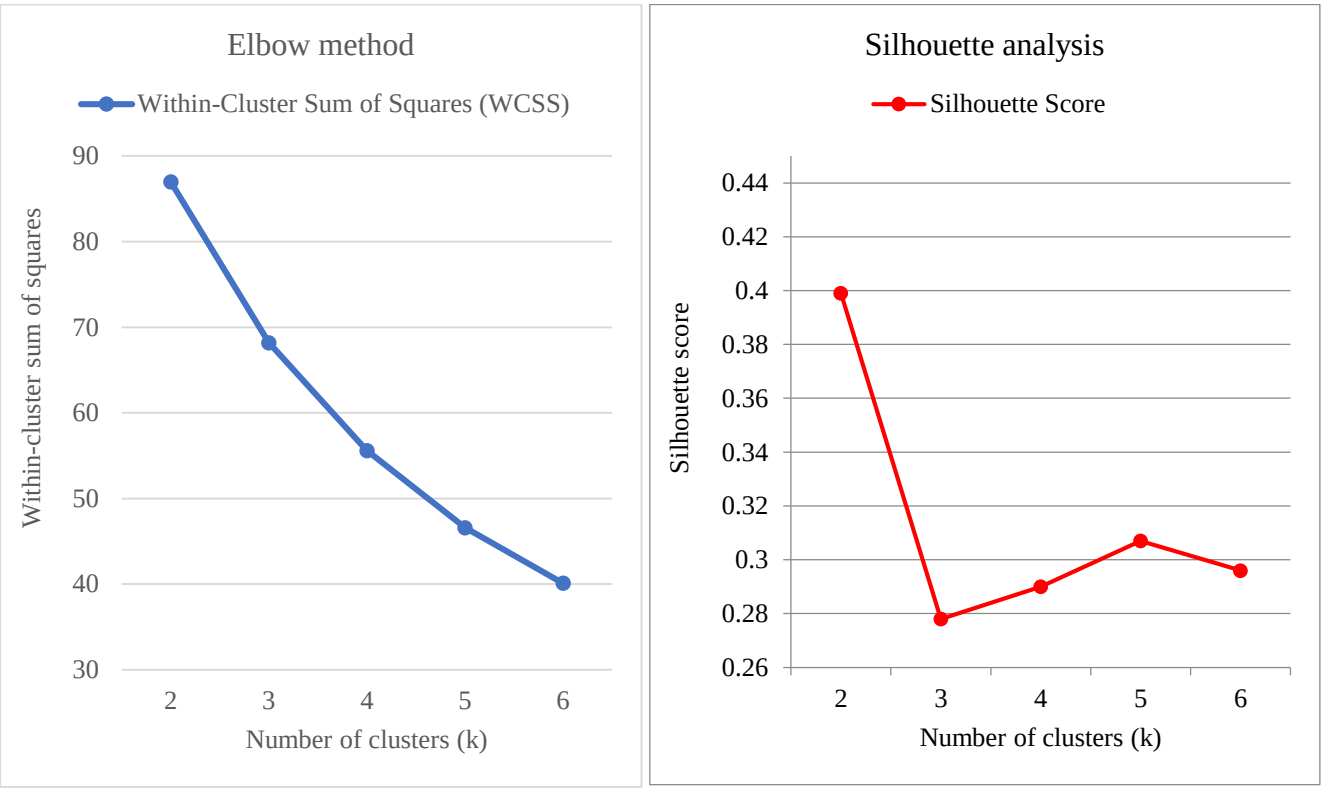


Fig. 6 Elbow method (left) and silhouette score (right) for k = 2 to 6 for all 55 risk factors

The K-Means clustering for all 55 risk factors for client, consultant and contractor are shown in Figure 7.

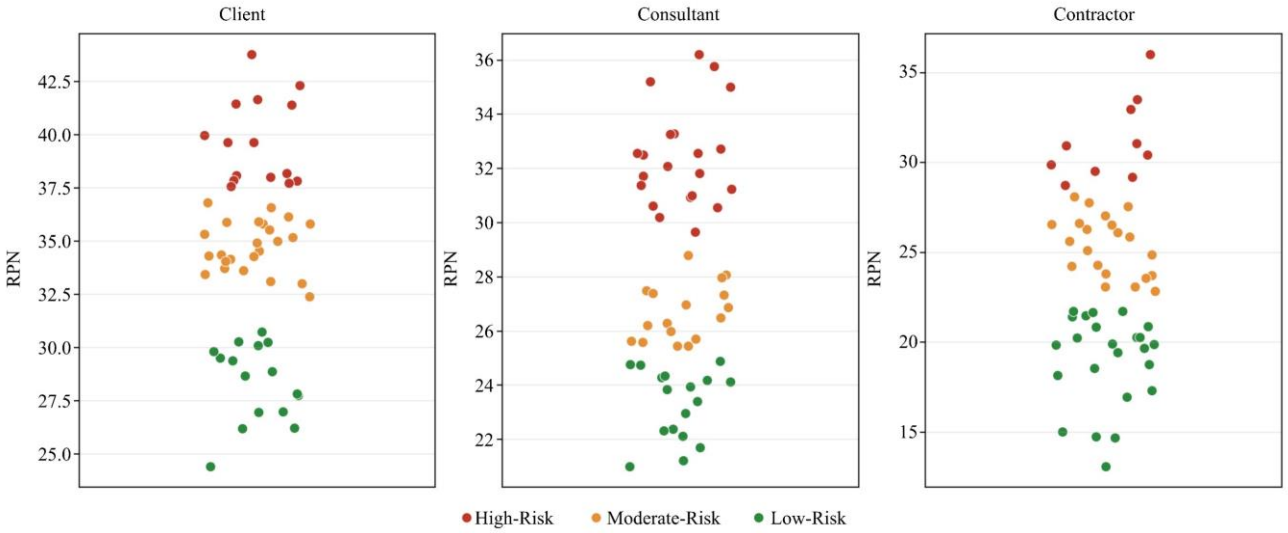


Fig. 7 K-Means clustering (k=3) of all 55 risk factors separately for client, consultant and contractor

Table 11. Cluster (Risk tier) statistics by stakeholder group for all 55 risk factors

Stakeholder	Risk Tier	n	Mean RPN	Min RPN	Max RPN
Client	High Risk	15	39.68	37.58	43.78
Client	Moderate Risk	24	34.74	32.40	36.82
Client	Low Risk	16	28.37	24.41	30.74
Consultant	High Risk	21	32.40	29.66	36.22
Consultant	Moderate Risk	17	26.69	25.44	28.80
Consultant	Low Risk	17	23.31	21.00	24.88
Contractor	High Risk	10	31.23	28.74	36.04
Contractor	Moderate Risk	21	25.38	22.86	28.12
Contractor	Low Risk	24	19.03	13.09	21.74

Table 11 shows that client, consultant and contractor groups different not only in which factors they are considered most critical, but also which shows they distinguish in risk level. The client group shows a narrow high-risk tier relative to its moderate tier, while the contractor group's high-risk cluster is both the smallest and most sharply separated from its low -risk cluster. Also, Figure 5 shows the same things in the chart, in which the vertical axis shows the RPN value, while the horizontal axis is only for visibility.

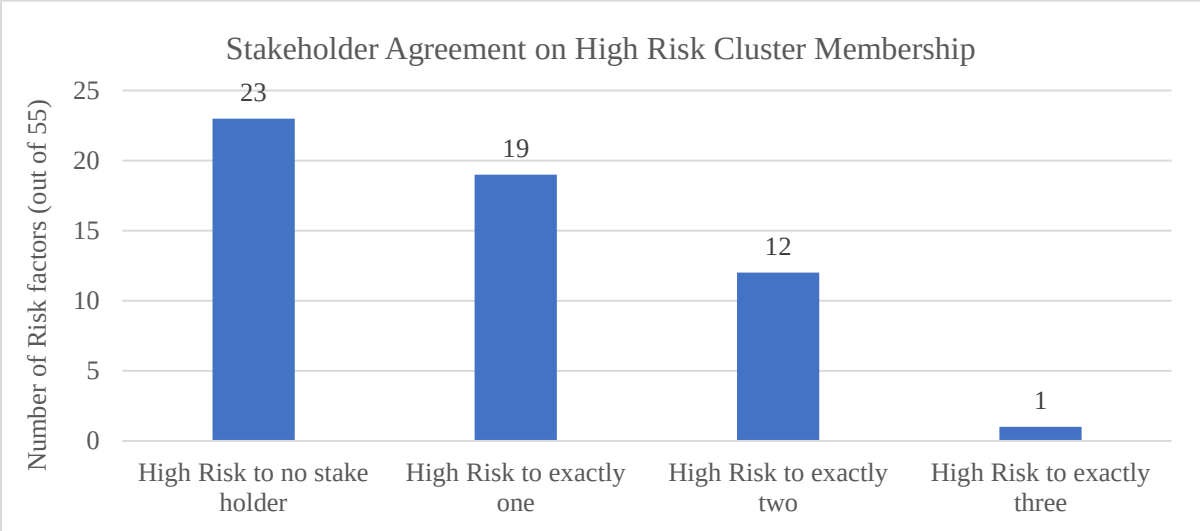


Fig. 8 High-Risk k-means cluster by 0, 1, 2 or all 3 stakeholders

Figure 8 says that high risk to all 3 stakeholders is 1, which is unsafe or hazardous working conditions on site (G8F1). All 55 risk factors with High risk by all stakeholders are also shown in Table 12.

Table 12. Risk factors placed in the high-risk cluster by all stakeholder groups for all 55 factors

Code	Risk factor	No. of groups with High-Risk	Groups with the factor in the High-Risk cluster
G8F1	Unsafe or hazardous working conditions on-site	3	Client, Consultant, Contractor
G1F2	Designed or poorly designed project scope	2	Consultant, Contractor
G2F1	Inadequate or insufficient design information	2	Client, Consultant
G2F2	Defective design	2	Consultant, Contractor
G5F1	Inaccurate estimation of activity durations	2	Client, Contractor
G5F2	Unrealistic or overly optimistic project schedules	2	Client, Contractor
G7F4	Cost and time overruns impacting project financing	2	Client, Consultant
G7F5	Corruption and financial mismanagement	2	Consultant, Contractor
G8F4	Natural disasters (e.g., landslides, floods, soil erosion, earthquakes)	2	Consultant, Contractor
G8F5	Adverse weather conditions delaying or damaging work	2	Consultant, Contractor
G9F5	Unrealistic tendered amount	2	Client, Consultant
G9F6	Extra work due to scope variations not included in the original contract	2	Consultant, Contractor
G10F1	Poor or unsuitable construction program planning	2	Client, Consultant
G1F4	Lack of proper analysis on scope changes and their impact	1	Consultant
G2F3	Likelihood of frequent design changes	1	Consultant
G2F4	Unrealistic or overly ambitious specification	1	Consultant
G3F5	Improper contract verification before execution	1	Consultant
G3F9	Delays in dispute resolution mechanisms	1	Contractor
G4F3	Inadequate or ineffective quality control measures	1	Client
G5F4	Ineffective schedule monitoring and control systems	1	Client
G5F5	Delays in corrective actions when risks or issues arise	1	Consultant
G6F1	Inaccurate cost estimates	1	Consultant
G6F4	Constant fluctuations in market conditions (material prices, labor, etc.)	1	Client
G7F2	Increase in taxes or import/custom duties	1	Client
G7F3	Cash flow problems during execution	1	Client
G8F2	Workers lacking awareness and training on safety	1	Consultant
G8F3	Absence of regular safety audits and inspections	1	Consultant
G9F2	Insufficient time allotted for preparation of bids or tenders	1	Consultant
G9F3	Delays in handing over project site to the contractor	1	Consultant
G10F3	Frequent design modifications during execution	1	Client
G10F4	Shortage of necessary technical skills	1	Client
G10F6	Delays due to late delivery of key materials	1	Client
G1F3	Frequent changes in scope requirement	0	-
G2F5	Difficulties arising from interaction of design changes among disciplines	0	-
G3F1	Delay in permit approval and regulatory clearance	0	-
G3F2	Excessive bureaucracy and red tape	0	-
G3F3	Poorly written or vague contract	0	-
G3F4	Frequently changes in laws and regulations	0	-
G3F6	Breach of contract by project partner	0	-
G3F7	Political Instability affecting project continuity	0	-

G3F8	Strikes, protests, and blockades disrupting work	0	-
G4F1	Absence of a structured Quality Assurance (QA) Plan	0	-
G4F2	Use of poor-quality or substandard materials	0	-
G4F4	Irregular or no testing of construction materials	0	-
G4F5	Quality inconsistencies due to unskilled or careless labor	0	-
G5F3	Incomplete or vague Work Breakdown Structure (WBS)	0	-
G6F2	Inadequate cost planning, budgeting, and control mechanisms	0	-
G6F3	Delayed payments on contract claims and invoices	0	-
G7F1	Inflationary impacts on local costs	0	-
G9F1	Non-standard or inconsistent contract conditions	0	-
G9F4	Errors or omissions in the bill of quantities	0	-
G10F2	Workers not adhering to scheduled work hours	0	-
G10F5	Low labor productivity and work efficiency	0	-
G10F7	Transportation delay of special equipment/materials	0	-
G10F8	Lack of communication between various stakeholders	0	-

3.5. Sperman's Rank Correlation RPN between Various Stakeholders

The Spearman rank correlation was used to compute the RPN ranking values of each pair of stakeholders of all 55 risk factors. Here, spearman's ρ was used rather than Pearson's r because it evaluates agreement in the relative ordering of risk factors between two groups. It is calculated by the Equation (4).

$$\rho = 1 - \frac{6\Sigma_{i=1}^{n} d_i^2}{n(n^2-1)} \quad (4)$$

Where d_i is the difference between the ranks of factor I in the two groups (where RN with high value is rank 1) and n=55. The tied values received the mean of their ranks. The significance (two tail test) was used to test the coefficient with Equation (5)

$$t = \rho\sqrt{\frac{n-2}{1-\rho^2}} \quad (5)$$

The Sperman's rank correlation between the stakeholders is shown in Figure 9, in which dashed line is a linear trend shown for visual reference only.

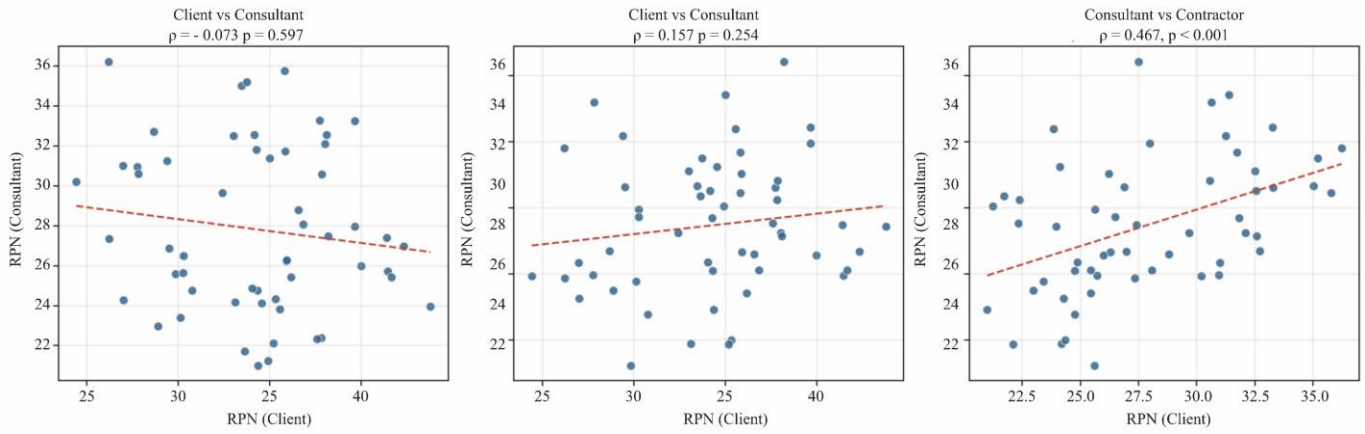


Fig. 9 Spearman rank correlation of RPN values between each pair of stakeholder groups

Table 13. Spearman rank correlation of RPN ranking between stakeholder groups

Stakeholder Pair	Spearman ρ	t-value	p-value	Interpretation
Client-Consultant	-0.073	-0.532	0.597	Not significant-no reliable agreement
Client-Contractor	0.157	1.154	0.254	Not significant-no reliable agreement
Consultant-Contractor	0.467	3.844	<0.001	Significant, moderate agreement

The result in Table 13 shows that the Consultant and Contractor RPN rankings are positively and significant correlated, indicating a moderate agreement. Also, the correlation between client and consultant, client and contractor are not significant.

4. Discussion

Construction projects face various risks, among them, environmental, physical, political, social and economic risks most affect clients, consultant and contractor [25]. RII and FMEA-based RPN scoring are used in this study of various risks of a major project in Nepal.

There is good internal consistency across all the risk groups in reliability, with average Cronbach's alpha values of 0.811, 0.826 and 0.823 for severity, occurrence and detection, shown in Table 5. The validity test shows out of 56, only 55 risk factors are retained, which are greater than 0.5, the single factor is (G1F14) which was excluded. Further used of this data shows that, data used in later are reliable and valid.

The factors like unsafe or hazardous working conditions on site (G8F1), inaccurate estimation of activity duration (G5F1), extra work due to scope variations not included in the original contract (G9F6), unrealistic or overly optimistic project schedules (G5F2), and Natural disasters (e.g., landslides, floods, soil erosion, earthquakes) (G8F4) were the overall high ranked risk. These findings were agreed with empirical studies that construction safety, defective or inaccurate planning and scheduling, improper scope of work as high impact risks in infrastructure projects [24].

Clients gave preference to technical skill shortages, quality control, delayed material delivery, cash flow, taxes and duties. This was agreed with a review of delay factors, which highlights late material delivery and price escalation [27]. Consultants gave the highest ranks to adverse weather, lack of analysis of scope changes, natural disasters and the absence of regular audits, which shows their responsibility for design accuracy, scheduling and safety compliance. Contractors identified inaccurate duration estimates, extra work due to scope variations, corruption and financial mismanagement, hazardous working conditions on site, delayed dispute resolution and defective design as most critical risks. A study in Saudi Arabia similarly get that contractors regarded unrealistic contract duration, financial difficulties and deficiencies in design documents as major risks [13].

The K-means clustering results support the RPN ranking. All ten factors of the overall top ten fall in the High-Risk cluster, and the lowest ranked factors fall in the low-risk tier. The stakeholder-wise clustering and correlation show that risk perception differs more between the parties than the overall ranking suggests. The consultant and contractor rankings are moderately and significantly correlated, whereas client ranking is not correlated with either. So, this study can say client perception is independently to others. In this context, the Narayanghat-Butwal road is the funding donation project in which consultant and contractor plays a significant role in the project while client participation does not play very high role as compare to the consultant and contractor.

While comparing with other existing research FMEA studies of construction and highway risk by RPN [7, 8], and the similar ranking was obtained here for overall data. The additional K-means clustering gives tiers and shows which factors are close to their boundary, which RPN list singly cannot show. Earlier [9, 10] used K-means clustering to group risk factors of mega projects and construction delays. Clustering is unsupervised method with no reference classification, so the contribution of this study is more detailed and reproducible description of risk tiers.

Comparison with other risk prioritization techniques and suitability of the conventional RPN. AHP, fuzzy FMEA were not applied, and the conventional RPN is justified for three reasons. First, AHP with 55 factors would need 1,485 pairwise comparisons from each respondent, which is impractical for site professionals and often gives inconsistent judgments; the simple 1 to 5 ratings used here were completed by all 90 respondents and checked for reliability and validity for Sections 3.1 and 3.2. Second, fuzzy FMEA need membership functions, rule bases or training data that add subjective inputs, whereas RII-based RPN uses only the ratings and can be recalculated from Equations (1) and (2). A numerical comparison with AHP-weighted or fuzzy FMEA rankings is recommended for future research.

5. Conclusion

This study used the Failure Mode and Effect Analysis (FMEA) approach to identify and priorities critical risks in order to assess the efficiency of risk management practices in road infrastructure projects in Nepal. The risks were calculated from all stakeholder perspectives by analyzing the severity, occurrence and detection ratings, with the RII and RPN is calculated as $RPN = RII_{(S)} \times RII_{(O)} \times RII_{(D)} \times 100$. Spearman rank correlation and K-means clustering were then used to group the 55 retained risk factors to compare the ranking and risk tiers of the client, consultant and contractor groups. The research offers a depth understanding of the risks that most significantly impact road construction performance from the perspectives of clients, consultants, and contractors by analyzing Severity, Occurrence and Detection ratings using the Relative Importance Index (RII) and calculating the Risk Priority Number (RPN).

The results show that all stakeholder groups consistently rate number of risks as highly significant. The most serious risks that need to be addressed right away include hazardous or unsafe working conditions, inaccurate cost estimates. These RPN values point to ongoing issues with scope control, safety management, planning accuracy, and cost forecasting, all of

which have a direct impact on time, cost and quality outcomes. The K-means clustering placed all of the top ten risks in the high-risk cluster. In contrast, risks like breach of contract, poorly written contracts, excessive bureaucracy, and inadequate bid preparation time for bid preparing bids were ranks lowest, indicating that administrative and contractual risks have a relatively small effect on the overall performance of the project.

Different priorities are further highlighted by the stakeholder-wise analysis. Client prioritizes schedule control, material delivery delays, and financial risk; consultants focus on safety hazards, scope issues, and natural disasters; while contractors experience greater risk related to cost overrun, dispute resolution and adverse conditions. The clustering confirmed that only unsafe or hazardous conditions on site (G8F1) was high risk for all clients, consultants, and contractors, and 23 out of 55 factors were high risk for none. Spearman correlation showed moderate agreement between consultant and contractor; the client was not significantly correlated with either of the other two groups. The differences highlight the need of collaborative and integrated framework for risk management that takes into account the concerns of all project stakeholders.

This result shows that Risk Priority Number-based risk identification and ranking, supported by K-means clustering and rank correlation, can help more to improve in resource allocation and decision-making in road construction projects. It also shows the need to strengthen cost and schedule estimation techniques, ensuring more clear scope identification, improve monitoring systems, and safety procedures. Further studies could evaluate the long-term effects of digital tools, real time monitoring systems, and prediction various methods to lower down the high RPN risks and investigate the creation of an integrated risk management framework especially designed for Nepal's road industry. In Nepal's construction sector, enhancing industrial capacity and encouraging scientifically increase project sustainability and efficiency.

Conflict of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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