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Development of a network-based risk management model for road transportation projects with emphasis on influential stakeholders (a study based on research synthesis and structural analysis)

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Abstract

Road transportation projects are exposed to diverse technical, stakeholder, financial, quality, and environmental risks, and inefficient risk identification and management can lead to schedule delays, cost overruns, and reduced project effectiveness. This study aimed to develop a network-based risk management model for road construction projects, with emphasis on influential stakeholders, and to explain the structural relationships among its dimensions. The study was applied in objective and adopted a mixed-methods qualitative–quantitative design. The qualitative phase used content analysis and the Delphi technique, while the quantitative phase used exploratory factor analysis and interpretive structural modelling. The statistical population comprised 25 road construction experts selected through purposive sampling, and data were collected via semi-structured interviews and Delphi questionnaires. The final model consisted of six principal factors—risk identification, risk assessment, planning, organizing, accountability, and control—and 41 subcomponents, explaining 33.90% of the total variance. Factor analysis indicated sampling adequacy (KMO = 0.873) and satisfactory construct validity, and the model showed high explanatory power $R^2 = 0.76$. Interpretive structural modelling identified "control" as the fundamental factor heavily affecting the others. Stakeholder interaction networks at all levels were common to risk management across stakeholders. Overall, network-based and multilevel approaches may help reduce uncertainty and improve strategic decision-making in road transportation projects.

Keywords: risk management, road construction projects, key stakeholders, interpretive structural modeling, Delphi technique
2020 MSC: Primary 90B50; Secondary 90B06, 91B30

1 Introduction

Construction risk management is a systematic process of evaluating and implementing procedures to mitigate the impact of risk on construction projects. This risk management process entails comprehensive planning to develop a risk management plan that enables project managers to identify, monitor, and mitigate risks as they arise [11]. A

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construction risk management plan is formulated during the early stages of the construction planning process [8]. An understanding of risks in the initial phases of a project helps project managers minimize adverse effects and complete the project more efficiently and effectively [9]. Such outcomes may be achieved through the proper application of risk management practices. The risk management process encompasses the identification, analysis, and implementation of measures designed to reduce identified risks [12]. In addition to identification and analysis, risks must be appropriately allocated to the relevant contracting parties, including owners, consultants, contractors, and other stakeholders, so that risk response decisions can be undertaken with proper authorization and without dispute [4].

The primary function of roads is to provide accessibility and mobility. At present, developing countries worldwide have prioritized improving and integrating their road networks. Given that a well-developed transportation network contributes substantially to economic development and national growth, road projects have been identified as a principal focus within national budget allocations. Accordingly, road projects must be completed on schedule to meet stakeholders' urgent needs. Regrettably, delays in road construction projects, arising from various causes, have remained a major challenge for construction professionals. Empirical evidence has shown that the inability to complete projects on time and within a predetermined budget remains a persistent global concern [18]. Although the causes of delays in developing countries are largely comparable, numerous factors are distinct to local industries, socioeconomic contexts, cultural conditions, and project-specific characteristics, such as land topography and right-of-way acquisition issues in road projects. Considering that road construction projects have generated substantial challenges for society—including heavy traffic congestion and an increased likelihood of road accidents—project personnel have likewise faced the consequences of project failure, reduced profitability, and related adverse outcomes. Consequently, the timely completion of road projects has assumed critical importance [3].

Delays are prevalent in most road construction projects. Delay refers to "the period of time during which an individual or entity must wait due to a problem that slows down or postpones an activity." Any extension of the duration beyond the planned schedule adversely affects project success in terms of cost, quality, and time performance [13]. Delays may occur in any construction project; however, their magnitude varies from one project to another. When the project schedule is established based on a reasonable timeframe, the uncertainties influencing project success are generally attributable to two plausible assumptions. To address this challenge, assessing delay-related risks is indispensable [6].

The implementation of road projects accounts for a substantial share of national budgetary allocations. The escalation of total project costs due to prolonged execution periods has been a major concern for policymakers and contractors alike. Evaluating the causes of delay and their impact on final project costs can significantly inform planning and decision-making in this sector. At present, delays in execution and the failure to deliver projects on schedule pose fundamental challenges in road construction. Delays impose significant financial burdens on employers, contractors, the government, and society at large. The presence of conflicts among stakeholders indicates that. Accordingly, identifying the underlying causes of delays, assessing their effects on schedule extension and cost escalation, and determining each project stakeholder's contribution to delay occurrence are regarded as essential components of delay analysis.

Moreover, although road transportation systems have been recognized as one of the most critical infrastructural foundations underpinning national growth and development, their significant and influential role in environmental degradation cannot be disregarded. In general, road corridors must be expanded over time or new routes must be constructed, a process that inevitably entails greater environmental intervention [26]. Given the extensive scope of road construction projects and their vital role in a country's economic and social development, the recurrence of delays, cost escalation, and stakeholder conflicts indicates that conventional risk management approaches are no longer sufficient to address the contemporary complexities of these projects. Despite numerous studies on risk identification and assessment, the absence of an integrated network-based framework that explicates the interrelationships among risk management components and the influential role of stakeholders remains a significant research gap. Accordingly, the central problem of the present study was to develop a structured, multilevel model for risk management in road transportation projects, with particular emphasis on key stakeholders and the causal relationships among its dimensions.

2 Theoretical foundations and literature review

Risk management, as one of the fundamental pillars of project management, is a systematic process for identifying, analyzing, responding to, and controlling uncertainties that may affect project objectives. In road construction projects, risks exhibit a dynamic and multidimensional nature due to technical complexity, environmental conditions, the multiplicity of stakeholders, and regulatory changes. Frameworks such as COSO and the PMBOK standard

have emphasised the need to align risk management with organisational strategy and to address its strategic, operational, and oversight dimensions. In parallel, stakeholder theory posits that project success depends on identifying all influential and affected groups, assessing their power and influence, and effectively managing their expectations.

Risk refers to an event for which the probability of occurrence of potential outcomes is known. Accordingly, wherever the possibility of unforeseen events exists, risk is present. Since projects inherently involve elements of uncertainty and unknown factors, they are naturally exposed to a variety of risks [15]. Risk management constitutes an integral and inseparable component of the engineering profession. It is defined as a systematic process for identifying, analyzing, and responding to risks related to the system. This process may be regarded as a decision-making framework for selecting and implementing the most cost-effective techniques and measures to address diverse system risks and minimize their impact. Risk management encompasses the avoidance, mitigation, transfer, and acceptance of adverse consequences, as well as the exploitation of potential opportunities [2]. The traditional perspective on risk has largely been negative, associating it with loss, hazard, and detrimental effects. Moghayedi and Windapo defined risk as the measurable probability and magnitude of failing to achieve predetermined project objectives and, more generally, characterized risk as the absence of knowledge regarding a future event [16]. The Project Management Institute defined risk as an uncertain event or condition that, if it occurs, has either a positive or negative impact on project objectives. Project risk, therefore, includes threats to project goals as well as opportunities to enhance them [20]. Consequently, if only a single possible outcome is considered, deviation—and thus risk—equals zero; however, when multiple potential outcomes exist, risk is non-zero. The greater the number of possible events that may occur (with any probability) and the wider the dispersion of their probability distribution, the higher the likelihood of deviation from a specific anticipated outcome, and thus the greater the level of risk. In contrast, uncertainty pertains to an event for which the probability of occurrence and its impact are not precisely known and about which limited knowledge exists. As a result, any uncertainty may give rise to a range of opportunities or risks [21].

As illustrated in Figure 1, a considerable proportion of project risks originates from the lack of awareness and performance of project participants; consequently, greater experience and enhanced awareness can substantially improve the effectiveness of risk management practices. As project complexity increases, risk management becomes correspondingly more demanding and must be undertaken with greater depth of knowledge and refined techniques.

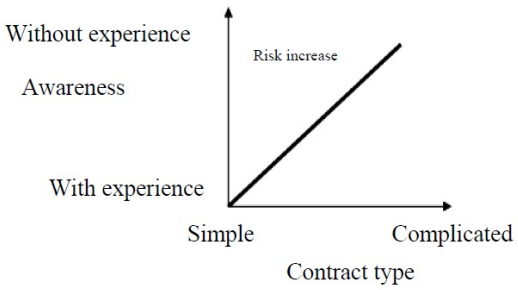


Figure 1: Relationship between the degree of project complexity and the level of awareness

For the implementation of the initial phase of the risk management system, namely "planning," the following inputs are required: all available project documentation, including the project contract; technical specifications and project scope; internal correspondence to the extent possible; communications with the employer and contractors; contracts concluded with contractors; the organizational chart and job descriptions; progress reports, where available; and records of prior implementation of risk management systems in other projects [4].

Risk identification is the process of determining risks that may affect the project and documenting their characteristics. The principal benefit of this process lies in systematically documenting existing risks and strengthening the project team's knowledge and capacity to anticipate potential events. The COSO framework is recognized as one of the most prominent enterprise risk management frameworks worldwide. Within this framework, eight components and four overarching principles are defined, based on which risk governance measures are implemented within organizations. These components include:

- Commitment to risk governance
- Risk governance policy
- Establishment of an integrated enterprise risk management unit

- Risk assessment
- Risk response
- Communication and reporting
- Information and communication
- Monitoring and oversight [5].

The four overarching principles of risk management within the COSO framework are as follows:

Strategy: alignment of high-level objectives with the overall mission of the organization

Operations: optimal and efficient utilization of resources

Financial reporting: reliability of operational and financial reports

Compliance: adherence to applicable laws and regulations

The COSO cube emphasizes the management of strategic, operational, reporting, and compliance risks [22].

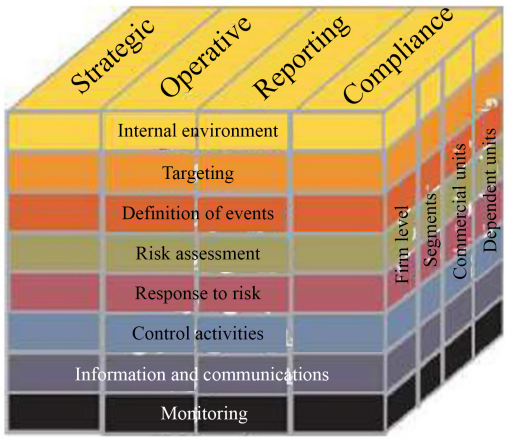


Figure 2: The COSO Cube

Stakeholder theory posits that stakeholders—including financial investors—constitute one of the groups to which a firm or organization must provide service. According to this theory, any individual or entity that is directly or indirectly affected by the organization or its activities is considered a stakeholder, encompassing employees, customers, suppliers, local communities, environmental groups, governmental bodies, and other relevant actors. Stakeholder theory maintains that organizations and firms should strive to create value for stakeholders and, by doing so, achieve genuine and sustainable success [25]. Stakeholder theory stands in contrast to shareholder theory. Under the shareholder theory, a company's sole motivation is to advance shareholder interests. Given that shareholders are primarily concerned with financial growth, shareholder theory is often translated into a "profit maximization at any cost" approach to business. From a project management perspective, stakeholder theory entails consideration of the interests and expectations of all parties who hold a stake in a particular project [23]. The following section presents prior research experiences relevant to the subject and research problem.

Diab et al. [1] conducted a study titled "Using risk assessment to improve highway construction project performance." The findings indicated that overlapping risks posed a substantial potential impact on total project cost, while they were associated with a relatively high probability of meeting the target project duration. Eight principal risks were identified as significantly influencing overall duration, total cost, or both. The optimal overlap strategy for minimizing economic impact while meeting the target project duration involved varying degrees of overlap.

Mahamid [14] conducted a study titled "Risk matrix for factors affecting time delay in road construction projects: owners' perspective." The study recommended that construction firms provide periodic training programs for technical personnel to familiarize them with the latest available technologies and enhance workforce quality. Such initiatives were found to contribute to significant savings in time, effort, and project-related costs. The existence of a documented procedure for risk identification and management was emphasised as an integrated solution to address potential threats throughout the project life cycle. Furthermore, the implementation of effective policies and programs designed to

improve the accuracy of risk identification and the appropriateness of risk management practices was identified as a means of reducing and managing project risks.

Mousavi et al. [19] conducted a study titled "Risk assessment for highway projects using jackknife technique." The research examined three dimensions of uncertainty management during the construction phase: people and organization, management processes, and tools and techniques. Particular emphasis was placed on the construction phase due to its rapid changes and inherent complexity. A longitudinal study was undertaken involving seven Norwegian road projects. All projects were large-scale, each exceeding 100 million USD in cost. The study evaluated how uncertainty emerged during the construction phase and how major uncertainties evolved throughout project execution. Furthermore, by introducing a conceptual framework, the study provided new insights into the critical factors influencing the management of risk and opportunity in large-scale road projects.

Khalaf et al. [10] conducted a study titled "Multilevel and tail risk management." In contemporary contexts, a substantial proportion of national capital—particularly in developing countries—is allocated to civil and construction projects, and the successful implementation of such projects is regarded as a key driver of economic growth and development. The objective of implementing the project risk management process was defined as the identification and root-cause analysis of risk events, their systematic assessment to the extent feasible, the planning and execution of response strategies, and the allocation of risks to competent parties to achieve effective control of priority project risks. The findings indicated that applying artificial intelligence can significantly enhance risk prediction and mitigation in road construction projects. Consequently, artificial intelligence was recognized as a leading technological advancement in construction management.

Karimi and Piroozfar [7] conducted a study titled "Exploring causes of delays in national road and highway projects in developing construction economy." By illustrating the role of the risk-sharing process in the formation of BOT projects, the study proposed a guiding framework for allocating risks among project stakeholders. Initially, thirty questionnaires were administered to identify the risks associated with the Tehran–Rasht freeway project, followed by qualitative risk allocation and sharing. The proposed qualitative model was evaluated using a Bayesian model, achieving accuracies of 93.56% and 98.31% in correctly allocating risks to the employer and the contractor, respectively. In the quantitative phase, game theory was applied to minimize the combined costs of the employer and contractor, resulting in an optimal allocation of 35% of the risks to the employer and 65% to the contractor.

Seid et al. [24] conducted a study titled "Risk management practices in road construction projects." The construction industry has been recognized as one of the most hazardous sectors in terms of work-related fatalities, injury rates, and compensation claims. This descriptive–analytical study was undertaken to identify the risk management process in small-scale construction projects. Drawing on prior research and by collecting and examining key activities related to hazard identification and safety risk assessment, the study evaluated and analyzed risk management practices in the construction of such projects.

A review of prior research indicates that studies such as Diab et al. [1] have focused on quantitative risk optimization, Mahamid [14] on the operational challenges of risk management, and Mousavi et al. [19] on uncertainty management during the construction phase. In contrast, domestic investigations, including Karimi and Piroozfar [7] and Khalaf et al. [10], have addressed risk allocation and the application of artificial intelligence, respectively. Nevertheless, the majority of these studies have examined risk dimensions in isolation and have paid limited attention to network-based analysis of interrelationships among components and to the structural positioning of stakeholders. Accordingly, the absence of an integrated model capable of explicating the interaction among risk identification, risk assessment, planning, organizing, accountability, and control within a multilevel structure underscores the necessity of the present study.

3 Research methodology

The present study was conducted with an objective and adopted an exploratory mixed-methods design. In the qualitative phase, initial indicators were extracted through content analysis and semi-structured interviews conducted with 25 experts in road construction projects. Subsequently, the Delphi technique was implemented over three rounds to achieve consensus and refine the identified indicators. In the quantitative phase, the data were analyzed using exploratory factor analysis and interpretive structural modeling. In contemporary research methodology, the scope of any investigation is delimited along three dimensions—temporal, spatial, and thematic—to ensure focused inquiry and enable the researcher to address research questions with precision. Accordingly, the scope of the present study is defined as follows: in terms of subject matter, the research falls within the domain of risk management in road construction projects; and with respect to spatial scope, the study was conducted in Iran and focused on road construction projects within this context.

The study's statistical population consisted of experts in road construction projects, including university faculty members, project managers, employers, and contractors. The sample size was determined using non-probability sampling. In the qualitative phase, experts were initially selected for interviews, contributing to the refinement and expansion of factors identified in the literature. Interviews continued until no new factors emerged, indicating theoretical saturation. In the Delphi phase, the same experts were invited to assess the degree of consensus regarding the identified factors, and their judgments were collected through Delphi questionnaires. In this context, conventional sampling rules were not applicable, as the determining criterion was expertise and specialized knowledge within the relevant field, which inherently constrained the researcher's selection options. Empirical evidence suggests that in expert-oriented methods, the number of participants typically remains below 50, with most commonly ranging between 15 and 30 individuals. In light of these considerations, the criteria for expertise in the present study included comprehensive knowledge of risk management in road construction projects, a master's degree, and at least 10 years of experience managing road construction projects. Based on these criteria, 25 experts were selected to participate in the study.

The data collection phase marked the initiation of a process in which the researcher systematically gathered both field and documentary evidence and, through an inductive approach, classified and subsequently analysed the data. The formulated research questions were then evaluated, leading to conclusions and the resolution of the research problem based on the collected evidence. In other words, reliance upon systematically obtained data enabled the discovery of empirical reality as it exists. Accordingly, the credibility of the information acquired was critical, as unreliable data would impede accurate identification of facts and compromise the validity of the research problem's resolution. Therefore, to test the research hypotheses, data were collected using the following methods.

The Delphi technique is a group decision-making method employed to achieve consensus among experts regarding the issue under examination. Interpretive Structural Modeling (ISM) is an exploratory approach that identifies relationships among indicators and establishes their hierarchical structure within an interpretivist paradigm. This method facilitates the identification of complex and causal interrelationships among a set of factors. For data analysis, sampling adequacy and construct validity were initially confirmed through the KMO and Bartlett's tests. Subsequently, principal component analysis with varimax rotation was applied to extract the model's dimensions. To elucidate the causal relationships among the factors, Interpretive Structural Modeling (ISM) was employed to determine the levels of influence and dependence among the factors. In addition, model fit indices, including the coefficient of determination and redundancy measures, were calculated to assess model quality. The results indicated an appropriate level of explanatory power for the proposed model.

4 Findings

The findings of the study were presented in both qualitative and quantitative sections. In the qualitative phase, following the analysis of interviews and three rounds of the Delphi technique, 41 subcomponents were identified and confirmed by experts within six principal dimensions. The Kendall's coefficient obtained in the third round (0.893) indicated a very high level of consensus among experts and theoretical saturation. Variables measured at the interval level are generally more appropriate for model analysis; however, in certain cases, ordinal and nominal variables may also be employed. It should be noted that the researcher may incorporate any number of variables relevant to the research problem into the analysis, provided that the variables have been measured appropriately and that their reliability coefficients are within an acceptable range. Regarding sample size, structural equation modelling typically requires substantial data. The minimum sample size should be at least 50. As the sample size increases, the accuracy and precision of model analysis improve. As a general rule, the sample size should be approximately four to five times the number of variables under study; however, this ratio is considered somewhat conservative. If the KMO value is below 0.5, the data are deemed unsuitable for structural equation modeling. Values between 0.5 and 0.69 warrant greater caution in proceeding with structural analysis, whereas values exceeding 0.7 indicate that the correlations among the data are adequate for model analysis. The results of this test are presented in Table 1.

Table 1: Measurement of Sampling Adequacy

Test		**Statistic**
Kaiser–Meyer–Olkin (KMO) Bartlett's Test of Sphericity	Measure of Sampling Adequacy	0.873
	Approximate Chi-Square	1243.234
	Degrees of Freedom	24
	Significance Level	0.000

Given that the KMO index equaled 0.873, the sample size was deemed sufficient for analysis. Furthermore, the

p-value for Bartlett's test was less than 0.05, indicating that the data were appropriate for identifying the model's underlying structure.

Following the identification of key textual units from the interviews and the literature review, axial coding was undertaken, and the results are presented in Table 2. In this stage, all previously identified textual segments—some of which had been referenced earlier—were transformed into clustered codes that represented each text's central concept. The codes provided by each expert were categorized as axial codes, and the interviewee codes were indicated alongside the corresponding codes.

Table 2: Axial Codes

Interviewee Code	**Axial Codes**
E1, E5, E7, E9	Sensitivity analysis; Qualitative analysis; Quantitative analysis; Clarification; Resource estimation; Risk classification
E2, E4, E9, E18	Determination of stakeholder expectations; Shared stakeholder interests; Enhancement of stakeholder participation; Stakeholder support; Stakeholder power and influence
E3, E8, E9, E10	Identification of appropriate stakeholders for risk assessment; Determination of risk type; Awareness of risk scope; Identification of positive and negative risks; Internal and external risk assessment; Brainstorming; Development of risk register; Probability of occurrence; Sensitivity analysis
E4, E11, E12, E13	Risk documentation; Precise stakeholder identification; Communication policies; Accurate and timely stakeholder communication; Stakeholder commitment; Stakeholder classification
E5, E14, E15, E16	Stakeholder social responsibility; Stakeholder legitimacy; Composition of decision-makers; Stakeholder integration; Stability in firm–stakeholder relationships; Stakeholder control
E6, E17, E18, E19, E20 [17]	Risk documentation; Precise stakeholder identification; Communication policies; Accurate and timely stakeholder communication; Stakeholder commitment; Stakeholder classification
E7, E21, E22, E23, E24, E25 [13]	Risk response; Risk records; Databases; Effectiveness

Subsequently, based on the codes identified in the previous stage, the selected codes were categorized into six groups, as presented in Table 3.

Table 3: Qualitative Findings

Factors / **Sub-components**	**Risk Identification**	**Risk assessment**	**Programming**	**Organizing**	**Response**	**Control**
Identification of appropriate stakeholders for risk assessment	•					
Determination of risk type	•					
Awareness of risk scope	•					
Identification of positive and negative risks	•					
Internal and external risk assessment	•					
Brainstorming	•					
Development of risk register	•					
Probability of occurrence		•				
Sensitivity analysis		•				
Qualitative analysis		•				
Quantitative analysis		•				
Clarification		•				
Resource estimation		•				
Resource estimation		•				
Risk documentation		•				
Precise stakeholder identification			•			
Communication policies			•			
Accurate and timely stakeholder communication			•			
Stakeholder commitment			•			
Stakeholder classification			•			

4.1 Delphi findings

The Delphi technique was implemented over three rounds. In each round, several indicators were removed from the model based on the mean Kendall's coefficient and the experts' evaluations, and subsequent rounds were repeated after the elimination of weaker indicators. Ultimately, three rounds of the Delphi process were conducted, and the results of the third round indicated a collective agreement, yielding the final set of indicators. The outcomes of the Delphi stages are presented in Table 4. According to the results reported in Table 4, the Kendall's test statistic obtained in

Determination of stakeholder expectations	•			
Shared stakeholder interests	•			
Enhancement of stakeholder participation		•		
Stakeholder support		•		
Stakeholder power and influence		•		
Stakeholder social responsibility		•		
Stakeholder legitimacy		•		
Composition of decision-makers		•		
Stakeholder integration		•		
Stability in firm–stakeholder relationships		•		
Stakeholder control		•		
Stakeholder value creation		•		
Inter-stakeholder		•		
Avoidance			•	
Transfer			•	
Prevention			•	
Acceptance			•	
Risk response				•
Risk records				•
Databases				•
Effectiveness				•

the third round (0.893) was statistically significant at the 0.01 level ($sig < 0.01$). This finding indicates a significant level of agreement among respondents on the items under consideration. Furthermore, the Kendall's coefficient value (0.825) reflected a very high degree of consensus among the participants.

Table 4: Results of Kendall's Test

Indicators	**First Round**	**Second Round**	**Third Round**
N	41	41	41
Kendall's W(a)	0.372	0.419	0.893
Chi-Square	856.18	1023.29	1145.74
Df	24	24	24
Asymp. Sig.	0.000	0.000	0.000

At this stage, given that Kendall's coefficient (0.893) reflected a very high level of consensus among respondents, the Delphi process was terminated.

4.2 Delphi results

The results of the first Delphi round are presented as agreement coefficients, mean scores for each indicator, and the corresponding evaluation outcome. Considering that the questionnaires used a five-point Likert scale, indicators with a mean score above 5 were considered confirmed. Moreover, based on the agreement coefficient, a value exceeding 0.5 indicated participant consensus on a given indicator. Accordingly, indicators with a mean below 5 and an agreement coefficient below 0.5 were excluded. In light of these criteria, the findings of the first Delphi round indicated that no indicators were removed from the analytical process, and the experts confirmed all indicators.

In the second Delphi round, certain indicators exhibited close mean values and agreement coefficients and were conceptually and substantively similar; these were scheduled for consolidation in the subsequent stage. The results of the second round also confirmed that all indicators were retained and none were eliminated from the analytical procedure. At this stage, several new indicators were incorporated into the initial model. To achieve theoretical saturation and ensure the validity of the components and indicators extracted in the first Delphi phase, the revised checklists—reflecting any adjustments—were reorganized and entered into the next Delphi phase. In this round, the confirmed indicators were redistributed to the experts as a revised checklist, and the results are presented in Table 5. No new indicators were added at this stage, and the level of collective agreement indicated theoretical saturation and consensus; therefore, the Delphi process was concluded.

Following the consolidation of conceptually similar indicators, the final model was identified and is presented in Table 5. The results indicate that the research model comprises six principal factors and 41 components and sub-indicators identified as influential elements.

Table 5: Results of the Third Delphi Round

Dimension	Components of Each Dimension	Mean	Agreement Coefficient	Result
Risk Identification	Identification of appropriate stakeholders for risk assessment	6.47	0.87	Confirmed
	Determination of risk type	7.49	0.88	Confirmed
	Awareness of risk scope	6.35	0.84	Confirmed
	Identification of positive and negative risks	7.40	0.84	Confirmed
	Internal and external risk assessment	7.17	0.73	Confirmed
	Brainstorming	6.21	0.74	Confirmed
	Development of risk register	8.00	0.70	Confirmed
Risk Assessment	Probability of occurrence	6.11	0.71	Confirmed
	Sensitivity analysis	8.00	0.70	Confirmed
	Qualitative analysis	7.30	0.80	Confirmed
	Quantitative analysis	7.21	0.73	Confirmed
	Clarification	8.39	0.84	Confirmed
	Resource estimation	6.04	0.71	Confirmed
	Risk classification	7.40	0.84	Confirmed
	Risk documentation	6.18	0.73	Confirmed
Planning	Precise stakeholder identification	6.00	0.70	Confirmed
	Communication policies	6.30	0.81	Confirmed
	Accurate and timely stakeholder communication	6.32	0.82	Confirmed
	Stakeholder commitment	7.13	0.72	Confirmed
	Stakeholder classification	7.17	0.73	Confirmed
	Determination of stakeholder expectations	7.00	0.90	Confirmed
	Shared stakeholder interests	5.54	0.88	Confirmed
Organizing	Enhancement of stakeholder participation	5.59	0.89	Confirmed
	Stakeholder support	5.11	0.71	Confirmed
	Stakeholder power and influence	7.00	0.70	Confirmed
	Stakeholder social responsibility	5.17	0.73	Confirmed
	Stakeholder legitimacy	6.21	0.74	Confirmed
	Composition of decision-makers	6.34	0.83	Confirmed
	Stakeholder integration	7.30	0.80	Confirmed
	Stability in firm–stakeholder relationships	8.21	0.74	Confirmed
	Stakeholder control	8.43	0.87	Confirmed
	Stakeholder value creation	7.35	0.84	Confirmed
	Inter-stakeholder collaboration	7.40	0.86	Confirmed
Accountability	Avoidance	8.12	0.71	Confirmed
	Transfer	7.40	0.84	Confirmed
	Prevention	6.47	0.87	Confirmed
	Acceptance	7.49	0.88	Confirmed
Control	Risk response	6.99	0.98	Confirmed
	Risk records	5.43	0.44	Confirmed
	Databases	3.45	0.34	Confirmed
	Effectiveness	1.89	0.77	Confirmed

4.3 Descriptive findings of subcomponents

This section examines the descriptive findings for the model's subcomponents. Based on the results, since the subcomponents were measured on a five-point Likert scale, Table 6 shows that the mean values of all subcomponents exceed the midpoint of the scale (3). Given that these mean scores are above the cutoff point of the five-point Likert scale, no particular concern arises in this regard. The findings further indicate that respondents provided answers aligned with the research objectives, and the data exhibit appropriate dispersion around the mean, as reflected by the corresponding standard deviations. The results derived from the analysis of means and standard deviations are presented in the following table.

4.4 Exploratory factor analysis

To conduct the exploratory factor analysis, the principal component analysis method with varimax rotation was employed. In this stage, the six dimensions previously identified as the model's core components, together with their respective subcomponents, were examined. Collectively, these six dimensions accounted for 90.33% of the total variance. The criterion for retaining subcomponents as indicators of the factors was an eigenvalue greater than one, along with a factor loading of 0.70 or higher, provided that the loading on other factors remained below this threshold. Based on these criteria, 41 subcomponents were ultimately selected. The corresponding indicators, their associated factors, and the magnitude of their factor loadings are presented in Table 7.

Table 6: Descriptive Findings of Subcomponents

Subcomponents	Mean	Standard Deviation
Identification of appropriate stakeholders for risk assessment	3.45	0.435
Determination of risk type	3.21	0.654
Awareness of risk scope	3.65	0.324
Identification of positive and negative risks	3.32	0.657
Internal and external risk assessment	3.25	0.611
Brainstorming	3.04	0.543
Development of risk register	2.97	0.577
Probability of occurrence	3.78	0.765
Sensitivity analysis	3.94	0.432
Qualitative analysis	3.11	0.654
Quantitative analysis	3.67	0.610
Clarification	3.44	0.656
Resource estimation	3.56	0.732
Risk classification	3.41	0.546
Risk documentation	4.01	0.756
Precise stakeholder identification	4.53	0.875
Communication policies	3.67	0.633
Accurate and timely stakeholder communication	3.23	0.382
Stakeholder commitment	3.17	0.365
Stakeholder classification	3.77	0.435
Determination of stakeholder expectations	3.54	0.461
Shared stakeholder interests	3.09	0.547
Enhancement of stakeholder participation	3.44	0.632
Stakeholder support	3.87	0.616
Stakeholder power and influence	3.52	0.734
Stakeholder social responsibility	3.67	0.453
Stakeholder legitimacy	3.54	0.422
Composition of decision-makers	3.98	0.432
Stakeholder integration	3.43	0.265
Stability in firm–stakeholder relationships	3.65	0.435
Stakeholder control	3.25	0.465
Stakeholder value creation	3.90	0.534
Inter-stakeholder collaboration	3.45	0.656
Avoidance	3.67	0.544
Transfer	3.65	0.656
Prevention	3.46	0.632
Acceptance	3.98	0.581
Risk response	5.67	0.777
Risk records	4.87	0.435
Databases	3.78	0.276
Effectiveness	3.28	0.656

Table 7: Results of Exploratory Factor Analysis

Subcomponents	Risk Identification	Risk Assessment	Planning	Organizing	Accountability	Control
Identification of appropriate stakeholders for risk assessment	0.764					
Determination of risk type	0.735					
Awareness of risk scope	0.793					
Identification of positive and negative risks	0.744					

4.5 Assessment of model quality

To evaluate the model's quality, the redundancy index and the coefficient of determination were used. Positive values of these indices indicate acceptable model quality. The principal criterion for assessing the structural model is the coefficient of determination (R^2), which reflects the proportion of variance in the dependent variable explained by the independent variables. As shown in Table 8, 76 percent of the variance in the model was explained by the identified subcomponents. Furthermore, when the redundancy index exceeds zero, the observed values are adequately reconstructed, and the model demonstrates predictive capability. In the present study, this index was greater than zero, indicating satisfactory predictive performance of the model.

Internal and external risk assessment	0.784					
Brainstorming	0.755					
Development of risk register	0.876					
Probability of occurrence		0.765				
Sensitivity analysis		0.711				
Qualitative analysis		0.744				
Quantitative analysis		0.790				
Clarification		0.773				
Resource estimation		0.865				
Risk classification		0.843				
Risk documentation		0.712				
Precise stakeholder identification			0.764			
Communication policies			0.777			
Accurate and timely stakeholder communication			0.705			
Stakeholder commitment			0.815			
Stakeholder classification			0.790			
Determination of stakeholder expectations			0.792			
Shared stakeholder interests			0.798			
Enhancement of stakeholder participation				0.766		
Stakeholder support				0.743		
Stakeholder power and influence				0.744		
Stakeholder social responsibility				0.833		
Stakeholder legitimacy				0.732		
Composition of decision-makers				0.762		
Stakeholder integration				0.769		
Stability in firm–stakeholder relationships				0.755		
Stakeholder control				0.811		
Stakeholder value creation				0.865		
Inter-stakeholder collaboration				0.762		
Avoidance					0.833	
Transfer					0.787	
Prevention					0.711	
Acceptance					0.803	
Risk response						0.788
Risk records						0.796
Databases						0.987
Effectiveness						0.721

Table 8: Model Quality Assessment Indices

Model	**Coefficient of Determination** (R^2)	**Redundancy**
Presentation of a Multilevel Risk Management Model for Road Construction Projects Based on Key Stakeholders	0.760	0.566

4.6 Assessment of data dispersion

The normality of the data distribution was assessed by calculating skewness and kurtosis to quantify how the data deviated from a normal distribution. However, normality is not a strict assumption in partial least squares. The results in Table 9 indicate that the distributions of all model subcomponents were normal, as their skewness and kurtosis values fell within the range -1 to $+1$.

4.7 Assessment of multicollinearity among subcomponents

Another essential prerequisite for data analysis is verifying that variables are not multicollinear. This condition was examined using the Variance Inflation Factor (VIF) and tolerance values. A VIF greater than 5 and a tolerance value less than 0.1 indicate multicollinearity among variables. As shown in Table 10, none of the model dimensions

Table 9: Test of Normal Distribution for Model Dimensions

Model Dimensions	Skewness	Kurtosis
Risk Identification	0.633	0.533
Risk Assessment	0.546	0.732
Planning	0.656	0.289
Organizing	0.376	0.308
Accountability	0.409	0.478
Control	0.676	0.434

exhibited a VIF exceeding 5 or a tolerance value below 0.1. Accordingly, no evidence of multicollinearity was observed among the model's dimensions.

Table 10: VIF Test for Assessing the Absence of Multicollinearity Among Subcomponents

Model Dimensions	VIF	Tolerance
Risk Identification	2.207	0.433
Risk Assessment	1.870	0.535
Planning	2.874	0.454
Organizing	1.791	0.266
Accountability	1.901	0.209
Control	1.767	0.545

4.8 Assessment of discriminant validity for the model dimensions

One method for assessing discriminant validity is the Fornell–Larcker criterion. Table 11 presents the results for the research model's dimensions. The table indicates that the constructs are clearly distinct from one another, as the values along the main diagonal for each latent variable exceed the corresponding correlations with the other reflective latent dimensions included in the model.

Table 11: Fornell–Larcker Criterion for Assessing Discriminant Validity

Row	Dimensions	1	2	3	4	5	6
1	Risk Identification	1					
2	Risk Assessment	0.831	1				
3	Planning	0.764	0.886	1			
4	Organizing	0.490	0.789	0.449	1		
5	Accountability	0.499	0.691	0.891	0.406	1	
6	Control	0.384	0.344	0.232	0.276	0.554	1

4.9 Interpretive structural modeling

Step 1. Formation of the Structural Self-Interaction Matrix

At this stage, the relationships among the factors were examined pairwise using Interpretive Structural Modeling (ISM) and the conceptual relation "leads to." The resulting matrix was constructed with dimensions corresponding to the identified factors, which were positioned along both the rows and columns. The matrix entries consisted of symbols reflecting the dominant patterns observed in expert judgments. The results are presented in the following table.

Table 12: Structural Self-Interaction Matrix (SSIM)

Factors	1	2	3	4	5	6
Risk Identification	X	V	A	V	O	A
Risk Assessment		O	V	O	A	V
Planning			V	O	X	A
Organizing				A	V	V
Accountability					V	A
Control						V

Step 2. Formation of the Initial Reachability Matrix

To derive the reachability matrix, the symbolic entries of the Structural Self-Interaction Matrix were converted into binary values (0 and 1). The initial reachability matrix was obtained in accordance with the following rules:

- If the cell (i, j) in the Structural Self-Interaction Matrix contained the symbol V, the corresponding cell in the reachability matrix was assigned the value 1, and its symmetric cell was assigned 0.
- If the cell (i, j) contained the symbol A, the corresponding cell in the reachability matrix was assigned the value 1, and its symmetric cell was assigned 0.
- If the cell (i, j) contained the symbol X, the corresponding cell in the reachability matrix was assigned the value 1, and its symmetric cell was assigned 0.
- If the cell (i, j) contained the symbol O, the corresponding cell in the reachability matrix was assigned the value 1, and its symmetric cell was assigned 0.
- When i = j, the corresponding diagonal entry in the reachability matrix was set to 1.

Table 13: Initial Reachability Matrix

I (Factors)	**1**	**2**	**3**	**4**	**5**
Risk Identification	1	1	1	1	0
Risk Assessment	0	1	0	1	1
Planning	0	1	1	0	1
Organizing	0	0	1	1	1
Accountability	0	0	1	0	1
Control	0	1	0	1	0

Table 14: Final Reachability Matrix

I (Factors)	**1**	**2**	**3**	**4**	**5**	**Driving Power**
Risk Identification	1	1	0	1	1*	5
Risk Assessment	0	0	1*	1	1	4
Planning	0	0	0	0	1	2
Organizing	0	1	0	0	0	2
Accountability	1*	0	1	0	0	2
Control	0	1	1	0	0	2
Dependence	4	3	3	3	3	

Step 3. Level Partitioning

To determine the relationships and hierarchical levels among the factors, the reachability and antecedent sets for each driving factor were extracted from the final reachability matrix. The reachability set comprised the factor itself along with the factors it influenced. The antecedent set included the factor itself and the factors that influenced it. Subsequently, the intersection set (common set) for each factor was identified, comprising the elements common to both the reachability and antecedent sets. Based on these derived sets, the factors were hierarchically partitioned. Typically, factors whose reachability set is identical to their intersection set are positioned at the top level of the hierarchy. Such top-level factors do not serve as antecedents for any other factors. Once a top-level was identified, it was separated from the remaining factors, and the process was iteratively repeated to determine subsequent levels. The results are presented in Table 15.

Table 15: Hierarchical Level Partitioning of Factors

Factors	**Antecedent Set**	**Reachability Set**	**Intersection Set**	**Level**
Risk Identification	1, 2, 3, 5, 7	2, 3, 4, 5, 6, 11, 12, 13	2, 3, 5, 11, 12, 13	1
Risk Assessment	2, 4, 5, 7, 14, 15, 16, 17	2, 4, 5, 6, 18, 19, 20, 21	2, 4, 5	2
Planning	3, 4, 6, 7, 8, 27, 28, 29, 30	4, 22, 23, 24, 25, 26	4	3
Organizing	4, 5, 7, 8, 35, 36, 37	4, 5, 6, 7, 8, 31, 32, 33, 34	4, 5, 7, 8	4
Accountability	2, 3, 4, 5, 6, 7, 10	1, 2, 3, 4, 5, 10	2, 3, 4, 5, 10	5
Control	2, 4, 5, 6, 40, 41	3, 7, 9, 2, 38, 39	2	6

The results of the exploratory factor analysis indicated that the six extracted dimensions collectively explained more than 90 percent of the total variance, reflecting the model's coherence and structural adequacy. Furthermore, the interpretive structural modeling results identified "control" as the most foundational level with the highest driving power, whereas "risk identification" was positioned at the uppermost level of the hierarchy. These findings underscore the network-based nature and interdependent relationships among the dimensions of risk management in road construction projects.

5 Discussion and conclusion

The findings of the present study demonstrated that risk management in road transportation projects exhibits a multidimensional, dynamic, and network-based nature, and therefore cannot be adequately explained through linear or single-stage approaches. The identification of six principal dimensions—risk identification, risk assessment, planning, organizing, accountability, and control—and the extraction of 41 subcomponents indicate that risk management in such projects requires a systemic and integrated perspective. The fact that these dimensions collectively accounted for more than 90 percent of the total variance, coupled with a coefficient of determination of 0.76, suggests that the proposed model has substantial explanatory and predictive power and may serve as an operational framework for road construction projects. These findings are consistent with enterprise risk management frameworks, including COSO, which emphasize the integration of strategic, operational, and control levels. The results further suggest that any disjunction among these levels may undermine the effectiveness of risk management practices.

One of the study's significant findings was the hierarchical positioning of "risk identification" at the upper level of the interpretive structural model. Its placement at the first level indicates that the quality and comprehensiveness of the initial risk identification constitute the foundation for all subsequent activities related to assessment, planning, and accountability. This finding is consistent with Mahamid [14], which emphasized that documented, structured procedures for risk identification are necessary to mitigate threats throughout the project life cycle. Moreover, the emphasis on identifying appropriate stakeholders for risk assessment suggests that the identification process is not merely technical in nature, but inherently social and interactive. Without considering the power, influence, and interests of stakeholders, it is not possible to obtain an accurate and comprehensive understanding of project risks.

Within the dimension of "risk assessment," indicators such as sensitivity analysis, quantitative and qualitative analysis, and resource estimation exhibited the highest factor loadings, underscoring the importance of systematic analytical approaches in reducing uncertainty. This finding is consistent with the results reported by Diab et al. [1], who demonstrated that the quantitative optimization of overlapping risks can significantly influence project cost and schedule control. At the same time, the present study indicated that reliance solely on quantitative tools is insufficient for comprehensive risk assessment. The integration of qualitative analyses, expert judgment, and contextual understanding of the project environment was essential. Such a combined approach establishes a flexible framework better suited to the environmental complexities of road construction projects in developing countries.

The findings related to the dimensions of "planning" and "organizing" indicate that risk management cannot achieve desirable outcomes without the formulation of effective communication policies and the establishment of alignment among stakeholders. Indicators such as the determination of stakeholder expectations, the enhancement of participation levels, and the demonstration of legitimacy and social responsibility demonstrate that risk management in road projects is intrinsically intertwined with stakeholder management. This finding supports stakeholder theory [25], which posits that sustainable organizational success depends upon consideration of the interests of all influential groups. Furthermore, the results of the present study are consistent with Mousavi et al. [19], who emphasized the roles of organizational structures and human interactions in managing uncertainty during the construction phase.

At the level of "accountability," strategies such as avoidance, transfer, prevention, and acceptance were identified as the principal responses to risk. These results are consistent with international project management standards, including PMBOK, which recommend a range of risk response strategies proportionate to the nature and severity of threats. Nevertheless, the present model indicates that selecting any of these strategies is influenced by the degree of stakeholder influence and the level of organizational preparedness. In other words, risk response is not merely a technical decision, but rather a strategic choice shaped by the distribution of power within the project structure.

One of the most significant findings of the study was the positioning of "control" at the lowest level of the hierarchy while simultaneously exhibiting the highest driving power, suggesting that control mechanisms—including continuous monitoring, systematic documentation, the establishment of risk databases, and the evaluation of response effectiveness—constitute the foundation for the sustainability of the entire risk management system. In the absence of efficient control mechanisms, even well-designed identification and assessment plans are likely to fail during implementation. This conclusion aligns with domestic findings such as those of Khalaf et al. [10], which emphasized the role of technology and artificial intelligence in monitoring and predicting risks, indicating that the development of information infrastructures can enhance project control capacity.

Furthermore, the results of the interpretive structural modeling indicated that the relationships among the dimensions of risk management are interactive and non-linear, with certain factors simultaneously exhibiting high driving power and high dependence. This characteristic suggests that risk management in road construction projects should be analyzed through a network-based perspective, as any modification in one dimension may generate cascading effects across other dimensions. This finding, to some extent, addresses the gap in prior studies that have largely examined

each dimension in isolation and provides a comprehensive framework for analyzing the causal relationships among components.

From a practical standpoint, the proposed model may serve as a strategic instrument for policymakers and managers of road transportation projects. Emphasizing key stakeholders, designing integrated control systems, and employing both quantitative and qualitative analyses can reduce the likelihood of delays and cost overruns. In addition, the findings indicated that strengthening a culture of accountability and transparency of information among project stakeholders can mitigate conflicts and enhance collective decision-making.

In conclusion, the present study has advanced the body of knowledge in risk management for road construction projects by developing a multilevel, network-based model. By integrating theoretical perspectives from risk management and stakeholder theory and employing both qualitative and quantitative methodologies, the study has proposed a coherent and robust structural framework. The findings indicate that the effectiveness of risk management in road transportation projects is achieved when the structural interactions among the six dimensions are systematically managed and when stakeholders' roles are actively and purposefully incorporated throughout all phases of the project life cycle.

In light of the research findings, the following practical recommendations are proposed:

1. The design and implementation of an integrated national risk database system for road construction projects.
2. The development of a national guideline for stakeholder management in road transportation projects.
3. The application of quantitative analytical tools and artificial intelligence for the assessment and continuous monitoring of risks.

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