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Prioritizing Risk Factors in Bridge Construction Projects: Evidence from the Gwalior-Chambal Region, India

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Abstract- Bridge construction projects combine structural complexity, long delivery periods, multi-party coordination, and exposure to uncertain geotechnical and hydrological conditions. This study identifies and prioritizes the risks affecting bridge projects in the Gwalior-Chambal region of Madhya Pradesh, India. A cross-sectional questionnaire measured 30 risk factors across technical, financial, construction, environmental, managerial, and legal/regulatory categories. Valid responses from 150 contractors, consultants, government engineers, project-management consultants, and other professionals were analyzed using descriptive statistics, the Relative Importance Index (RII), Cronbach's alpha, Pearson correlations, and one-way ANOVA. The instrument demonstrated excellent internal consistency (alpha = .915). Technical risk ranked first (mean = 3.7773; RII = .7555), followed by environmental and construction risk. Design errors and changes were the highest individual risk (RII = .8427), followed by inappropriate construction methods (RII = .8253); delayed payments, poor site management, and flooding each recorded an RII of .8080. Construction and environmental risks were strongly correlated (r = .769), as were financial and legal/regulatory risks (r = .768). Risk effects were greatest for time (RII = .7947) and quality (RII = .7846). Perceptions were stable across organization, designation, experience, and project type, but differed partly by the number of completed projects. The resulting framework links regional evidence, statistical priority, assigned responses, and continuous monitoring, offering a practical basis for more resilient bridge delivery.

Keywords— bridge construction; construction risk; Gwalior-Chambal; Relative Importance Index; infrastructure projects; risk prioritization

I. INTRODUCTION

Bridge infrastructure enables regional mobility, market access, public services, and economic integration, yet its delivery is unusually exposed to uncertainty. A bridge project must coordinate geotechnical investigation, hydraulic assessment, structural design, temporary works, specialized equipment, traffic management, environmental permissions, and multiple contracting interfaces. Project risk is therefore not a single hazard but an uncertain condition that can alter cost, time, quality, safety, or other performance objectives (Project Management Institute, 2021). International evidence shows that weak risk recognition and optimistic assumptions contribute to cost and schedule escalation in major public works (Flyvbjerg et al., 2002). For bridges, the consequences are especially serious because technical deficiencies or construction-stage failures can interrupt connectivity and threaten life; historical failure analyses emphasize the combined roles of design, construction practice, loading, deterioration, and environmental action (Wardhana & Hadipriono, 2003).

Construction risks also propagate across project objectives. Design changes may trigger rework, additional quantities, claims, delayed approvals, and compromised quality. Late payment can constrain procurement and labor availability, while poor site management converts otherwise manageable uncertainties into schedule loss. Studies in different developing-country settings consistently connect delays with time overrun, cost overrun, disputes, litigation, or abandonment (Aibinu & Jagboro, 2002; Assaf & Al-Hejji, 2006; Sambasivan & Soon, 2007). Indian evidence similarly identifies client decisions, contractors' planning, resource constraints, and coordination problems as important delay drivers (Doloi et al., 2012), while cost and quality performance depend on managerial competence and stakeholder coordination (Iyer & Jha, 2005; Jha & Iyer, 2006). These patterns justify analyzing risks as an interacting portfolio rather than as isolated checklist entries.

The Gwalior-Chambal region presents a distinctive bridge-delivery environment. The study area includes Gwalior, Morena, Bhind, Shivpuri, and Sheopur districts and contains river crossings, ravine topography, heterogeneous soils, marked seasonal temperature variation, and intense monsoon episodes. These features heighten the relevance of foundation investigation, erosion, flooding, water-level fluctuation, and construction-method selection. At the same time, public infrastructure works face payment cycles, land acquisition, approval procedures, contract administration, and coordination across agencies and private participants. Risk priorities established in other countries or for general building projects may therefore be insufficiently sensitive to this regional combination of physical and institutional conditions. This research addresses that need by pursuing five objectives: identifying region-relevant bridge construction risks; measuring practitioners' assessments of their importance; ranking individual factors and categories; evaluating perceived effects on cost, time, quality, and safety; and translating the evidence into a decision framework. The paper contributes an empirical risk profile based on 150 experienced professionals, combines simple prioritization with reliability, correlation, and group-difference tests, and distinguishes consensus risks from those whose perception changes with accumulated project exposure. The intended contribution is practical as well as analytical: limited management attention can be directed first to the design, construction, financial, and environmental conditions most likely to disturb bridge delivery.

II. LITERATURE REVIEW AND RESEARCH POSITIONING

1. Construction risk as a connected system

Formal construction risk management normally proceeds through identification, analysis, response planning, ownership, and monitoring. Al-Bahar and Crandall (1990) framed this as a systematic process rather than a one-time contingency exercise. However, contractors have often relied more heavily on intuition, judgement, and experience than on formal analytical tools (Akintoye & MacLeod, 1997). Such reliance is problematic in bridge projects because the same initiating event may move through several interfaces. Inadequate soil investigation can require redesign; redesign can alter methods and quantities; the resulting rework can stress cash flow and schedule; and accelerated recovery can affect safety or quality. Knowledge-based models therefore emphasize causal relationships and reusable organizational learning (Tah & Carr, 2001), while developing-country frameworks stress allocation among clients, contractors, consultants, and public authorities (Wang et al., 2004).

The literature commonly groups construction risk into technical, financial, operational or construction, environmental, managerial, and legal/contractual domains. Technical risk concerns design completeness, site information, material quality, methods, and structural behavior. Financial risk covers funding, escalation, cash flow, and payment. Construction risk concerns equipment, labor, productivity, site control, and accidents. Environmental risk includes weather, flooding, erosion, and clearance requirements. Managerial risk arises from planning, communication, supervision, coordination, and decisions, whereas legal risk concerns land, approvals, contracts, policy, and compliance. Empirical surveys confirm that the salience and allocation of these domains vary across institutional settings (El-Sayegh, 2008; Zou et al., 2007), reinforcing the need for regional evidence.

2. Assessment approaches and remaining gap

Questionnaire-based risk studies frequently use an importance index because it converts ordinal professional ratings into a transparent, normalized priority. Its advantage is interpretability: decision makers can see why one factor is ranked above another. Its limitations are equally important. A rank does not establish causation, and individual RII values do not represent interdependence or uncertainty in the weights. More elaborate approaches use fuzzy logic, influence diagrams, Bayesian reasoning, or multi-criteria decision methods to model ambiguity and trade-offs (Dikmen et al., 2007; Zavadskas et al., 2010). Factor analysis has also been applied to reveal latent risk structures in large infrastructure projects (Ghosh & Jintanapakanont, 2004). These methods add sophistication but can require larger datasets, extensive elicitation, or assumptions that are difficult to maintain in routine regional practice.

A broad review of construction risk research finds substantial variation in terminology, identification tools, and classification systems (Siraj & Fayek, 2019). The central challenge is thus not merely to add another list of hazards, but to produce a coherent regional hierarchy and show how its categories move together. Table 1 positions the present study against representative work. Existing research provides mature concepts and analytical options, yet three gaps remain for the Gwalior-Chambal context: limited bridge-specific primary evidence, limited simultaneous treatment of cost-time-quality-safety consequences, and no concise pathway from ranked factors to assigned mitigation and monitoring.

Table 1. Representative construction risk literature and the research gap

Study	Focus	Method	Principal contribution	Gap for this study
Al-Bahar & Crandall (1990)	Systematic construction risk process	Conceptual process model	Established identification-analysis-response logic	No regional bridge validation
Akintoye & MacLeod (1997)	Industry risk practice	Contractor questionnaire	Formal tools underused; judgement dominates	General construction context
Tah & Carr (2001)	Risk knowledge and relationships	Knowledge-based model	Structured causal knowledge supports decisions	Data and maintenance demands
Wang et al. (2004)	Developing-country construction risk	Framework and case evidence	Allocation must reflect institutions and stakeholders	Not bridge- or region-specific
Zou et al. (2007)	Key risks and project objectives	Stakeholder survey	Risks affect cost, time, quality, safety, sustainability	Different national setting
Zavadskas et al. (2010)	Multi-criteria risk assessment	TOPSIS-grey and COPRAS-G	Handles multiple attributes and interval judgements	Greater modelling complexity

Study	Focus	Method	Principal contribution	Gap for this study
Doloi et al. (2012)	Delays in Indian construction	Survey and statistical modelling	Planning, decisions, resources, and coordination matter	Not focused on bridge risk portfolios
Siraj & Fayek (2019)	Risk identification and classification	Literature review/content analysis	Methods and taxonomies remain heterogeneous	Calls for context-specific synthesis

Accordingly, the study asks which bridge construction risks are most important, how the six risk categories are associated, which project-performance dimensions are most affected, and whether professional background changes the assessment. Five null hypotheses test whether perceived risk differs by organization type (H01), designation (H02), years of experience (H03), bridge project type (H04), and number of projects completed (H05).

III. METHODOLOGY

1. Research design, instrument, and study area

The research used a quantitative, cross-sectional, descriptive-analytical design. Risk factors were first assembled from the construction risk literature and bridge-project practice, then organized into six categories. The resulting instrument contained three sections: respondent characteristics; 30 risk factors rated from 1 (very low) to 5 (very high); and perceived risk effects on cost, time, quality, and safety using the same five-point scale. The six-category structure and all item codes are shown in Table 2. The scope was limited to professionals with direct exposure to bridge projects in the Gwalior-Chambal region.

Table 2. Risk categories and questionnaire factors

Category	Codes	Included risk factors
Technical	T1-T5	T1 Inadequate soil investigation; T2 Design errors and changes; T3 Poor material quality; T4 Inappropriate construction methods; T5 Structural failure risk
Financial	F1-F5	F1 Cost overruns; F2 Delayed payments; F3 Material price escalation; F4 Budget constraints; F5 Poor financial planning
Construction	C1-C5	C1 Equipment failure; C2 Labor shortage; C3 Low labor productivity; C4 Site accidents and safety issues; C5 Poor site management
Environmental	E1-E5	E1 Flooding and water-level rise; E2 Extreme weather; E3 Soil erosion and instability; E4 Environmental clearance delays; E5 Natural disasters
Managerial	M1-M5	M1 Poor project planning; M2 Ineffective communication; M3 Lack of stakeholder coordination; M4 Delayed decision-making; M5 Inadequate supervision
Legal/regulatory	L1-L5	L1 Land acquisition; L2 Delayed regulatory approvals; L3 Contract disputes; L4 Government-policy changes; L5 Legal compliance issues

2. Sampling and respondent profile

Purposive sampling was appropriate because informed risk assessment required direct project knowledge. The target population included contractors, consultants, government engineers, project-management consultants (PMCs), project managers, site and design engineers, and supervisors. After screening, 150 valid questionnaires were retained. The sample was deliberately diverse: no organization group exceeded 22.7%, respondents covered four experience bands, and river, flyover, railway, highway, and other bridge types were represented. Nearly half of participants had completed at least 10 bridge projects. Table 3 provides the full distribution.

Table 3. Respondent profile (N = 150)

Characteristic	Group	n	%
Organization	Contractor	34	22.7
	Consultant	27	18.0
	Government agency	31	20.7
	PMC	31	20.7
	Other	27	18.0
Designation	Project manager	26	17.3
	Site engineer	34	22.7
	Design engineer	24	16.0
	Supervisor	39	26.0
	Other	27	18.0
Experience	Less than 5 years	42	28.0
	5-10 years	39	26.0
	10-15 years	36	24.0
	More than 15 years	33	22.0
Bridge type	Highway bridge	27	18.0
	Railway bridge	29	19.3
	Flyover	30	20.0
	River bridge	35	23.3
	Other	29	19.3
Projects completed	Less than 5	40	26.7
	5-10	37	24.7
	10-20	36	24.0
	More than 20	37	24.7

3. Data analysis

Microsoft Excel supported coding, screening, and index calculation, while SPSS was used for reliability, descriptive, correlation, and variance analyses. For each factor, the Relative Importance Index was calculated as RII = sum(W)/(A x N), where W is the total assigned weight, A is the maximum scale value (5), and N is the number of respondents (150). Higher values indicate greater perceived importance. Category scores were formed from the five items in each domain. Internal consistency was examined with Cronbach's alpha (Cronbach, 1951); alpha describes score consistency but, by itself, does not prove construct validity. Pearson coefficients assessed linear association among category scores. One-way ANOVA tested the five group-difference hypotheses at alpha = .05. The analyses are interpreted as perception-based priorities rather than observed event probabilities or causal effects.

IV. RESULTS

1. Reliability and category priorities

The 30-item scale produced Cronbach's alpha = .915, indicating excellent internal consistency and supporting use of the item set for aggregate comparison. Category results in Table 4 show a clear hierarchy. Technical risk ranked first (mean = 3.7773; RII = .7555), followed by environmental risk (mean = 3.4853; RII = .6971) and construction risk (mean = 3.4253; RII = .6851). Financial risk occupied fourth place, while legal/regulatory and managerial risk had lower aggregate scores. Lower category position should not be read as irrelevance: a category mean can conceal a highly ranked individual factor, such as ineffective communication or contract disputes.

Table 4. Category-wise descriptive statistics and RII ranking

Risk category	Mean	SD	Variance	RII	Rank
Technical	3.7773	0.74385	0.553	0.7555	1
Environmental	3.4853	0.82359	0.678	0.6971	2
Construction	3.4253	0.64310	0.414	0.6851	3
Financial	3.3280	0.70217	0.493	0.6656	4
Legal/regulatory	3.0613	0.72536	0.526	0.6123	5
Managerial	2.8880	0.57625	0.332	0.5776	6

2. Individual risk ranking

Table 5 reports the 15 highest-ranked factors. Design errors and changes (T2) led the ranking with a mean of 4.2133 and RII of .8427. Inappropriate construction methods (T4) followed at .8253. Delayed payments (F2), poor site management (C5), and flooding or water-level rise (E1) formed a three-way cluster at .8080. The top 10 included factors from every category except none was excluded: technical factors appeared three times, construction twice, and financial, environmental, managerial, and legal factors also entered the priority set. This cross-category composition demonstrates why a bridge risk plan cannot be confined to design checking alone. The corrected lower-order sequence places delayed decision-making (RII = .4720) above government-policy changes (RII = .4520), resolving a rank inconsistency in the source thesis table.

Table 5. Highest-ranked individual bridge construction risks

Code	Risk factor	Category	Mean	RII	Rank
T2	Design errors and changes	Technical	4.2133	.8427	1
T4	Inappropriate construction methods	Technical	4.1267	.8253	2
F2	Delayed payments	Financial	4.0400	.8080	3
C5	Poor site management	Construction	4.0400	.8080	4
E1	Flooding and water-level rise	Environmental	4.0400	.8080	5
M2	Ineffective communication	Managerial	3.9000	.7800	6
C3	Low labor productivity	Construction	3.8600	.7720	7
L3	Contract disputes	Legal/regulatory	3.7933	.7587	8
F1	Cost overruns	Financial	3.7600	.7520	9
T5	Structural failure risk	Technical	3.7133	.7427	10
E2	Extreme weather	Environmental	3.6400	.7280	11
L1	Land acquisition	Legal/regulatory	3.6400	.7280	12
C1	Equipment failure	Construction	3.6333	.7267	13
F3	Material price escalation	Financial	3.6067	.7213	14
T1	Inadequate soil investigation	Technical	3.5467	.7093	15

3. Inter-category relationships

All category correlations were positive and statistically significant at $p < .01$ (Table 6). The strongest association occurred between construction and environmental risk ($r = .769$), closely followed by financial and legal/regulatory risk ($r = .768$) and financial and environmental risk ($r = .745$). Technical risk correlated most strongly with construction risk ($r = .668$). These patterns are operationally plausible: weather, flooding, and unstable ground interrupt site operations and add cost; legal or contractual problems affect payment and cash flow; and technical deficiencies generate method changes and rework. The coefficients do not establish causal direction, but they show that separate category registers would overlook meaningful co-movement.

Table 6. Pearson correlations among risk categories

Category	TR	FR	CR	ER	MR	LR
Technical (TR)	1.000	.625**	.668**	.552**	.555**	.487**
Financial (FR)	.625**	1.000	.672**	.745**	.483**	.768**
Construction (CR)	.668**	.672**	1.000	.769**	.605**	.624**
Environmental (ER)	.552**	.745**	.769**	1.000	.601**	.570**
Managerial (MR)	.555**	.483**	.605**	.601**	1.000	.569**
Legal/regulatory (LR)	.487**	.768**	.624**	.570**	.569**	1.000

4. Project impacts and hypothesis tests

Time was the most affected performance dimension (mean = 3.9733; RII = .7947), followed closely by quality (mean = 3.9232; RII = .7846). Cost ranked third and safety fourth, although both retained moderately high RII values. ANOVA results showed no significant differences across organization type, designation, years of experience, or bridge type; H01-H04 were therefore not rejected. H05 was partially rejected because the number of completed projects differentiated financial risk ($p = .044$), legal risk ($p = .043$), and total impact ($p = .017$), while the remaining categories were nonsignificant. Table 7 combines the performance and hypothesis results.

Table 7. Project-performance impacts and ANOVA hypothesis decisions

Analysis	Statistic	Result	Decision/interpretation
Panel A. Perceived effects on project performance			
Impact on time	Mean 3.9733; SD 0.85095	RII .7947; rank 1	Highest effect
Impact on quality	Mean 3.9232; SD 0.81879	RII .7846; rank 2	High effect
Impact on cost	Mean 3.7164; SD 0.82565	RII .7423; rank 3	Moderately high effect
Impact on safety	Mean 3.5761; SD 0.84175	RII .7152; rank 4	Moderately high effect
Panel B. One-way ANOVA hypothesis summary			

Analysis	Statistic	Result	Decision/interpretation
H01 Organization type	All p = .267-.710	No category significant	Not rejected
H02 Designation	All p = .652-.990	No category significant	Not rejected
H03 Years of experience	All p = .511-.946	No category significant	Not rejected
H04 Bridge project type	All p = .333-.968	No category significant	Not rejected
H05 Projects completed	Financial p = .044; legal p = .043; total impact p = .017	Other categories p > .05	Partially rejected

V. DISCUSSION

The dominance of technical risk reflects the path-dependent nature of bridge delivery. Decisions made during investigation and design define foundation type, span arrangement, temporary works, sequencing, quantities, and construction tolerances. When design errors or late changes reach the site, their effect is multiplied through rework, idle resources, claims, and recovery pressure. This result agrees with research that places design information and stakeholder coordination among the central sources of construction cost and schedule difficulty (Doloi, 2013; Iyer & Jha, 2005). It also clarifies the local priority: design assurance should include constructability, hydrology, geotechnical sufficiency, and method compatibility, rather than only checking structural calculations. The high position of inappropriate construction methods reinforces the need to integrate designers, temporary-works specialists, contractors, and equipment planners before mobilization.

The next cluster is operational and financial. Delayed payments, poor site management, and flooding all produced RII = .8080. Payment delay has a cascading mechanism: weakened cash flow postpones materials, subcontractor payments, equipment maintenance, and labor deployment. Comparable links between finance and delay have been reported across large construction projects (Assaf & Al-Hejji, 2006; Sambasivan & Soon, 2007). Poor site management and low labor productivity likewise indicate that risk is realized through day-to-day control. A technically sound design will not protect the schedule if access, lifting, sequencing, interfaces, inspection, and work fronts are poorly coordinated. The high rank of ineffective communication further shows that managerial processes remain important even though the managerial category mean was lowest.

Environmental results are particularly salient for the study area. Flooding and water-level rise ranked jointly third by RII, extreme weather ranked eleventh, and erosion/instability remained within the upper half of the complete list. These are not merely external events to be recorded in a generic register. They affect cofferdams, foundations, temporary access, working windows, equipment stability, material storage, and worker exposure. The strong construction-environment correlation supports a coupled response: hydrometeorological thresholds should be linked to method statements, temporary works, evacuation plans, float, and procurement decisions. Treating flooding as the environmental officer's responsibility alone would fragment ownership and delay action when forecasts or river levels change.

The correlation structure extends the contribution beyond a simple ranking. Financial risk was closely associated with legal/regulatory and environmental risk, while technical risk moved with construction risk. These relationships are consistent with global-risk models that recognize the joint effect of market, organizational, and project conditions on cost performance (Baloi & Price, 2003) and with fuzzy approaches that explicitly model influence paths (Dikmen et al., 2007). In practice, high-ranked risks should therefore be analyzed in clusters. For example, a flood scenario should include schedule extension, escalation, insurance, contractual notice, access restoration, and quality reinspection. A design-change scenario should include approval time, temporary-work revision, quantity growth, and payment certification.

The performance ranking gives an important managerial signal. Time and quality were perceived as more affected than cost and safety. The time result is consistent with evidence that delay produces multiple downstream effects (Aibinu & Jagboro, 2002; Doloi et al., 2012). The near-equal quality score warns against schedule recovery that simply accelerates work or compresses inspection. Safety's fourth position must not be interpreted as an acceptable reduction in protection; the mean of 3.5761 still represents a material effect. Instead, the ranking suggests that respondents encounter schedule and quality disruption more visibly or frequently. Risk responses should preserve non-negotiable safety controls while preventing schedule pressure from degrading workmanship and review.

Finally, the nonsignificant ANOVA findings for four background variables reveal broad professional consensus. Contractors, consultants, public agencies, and PMCs viewed the aggregate risks similarly, which strengthens the case for a shared regional register. The partial difference by projects completed is equally informative. Repeated project exposure appears to sharpen awareness of financial, legal, and total-impact issues that may be less visible on a small number of assignments. Organizations should capture this tacit knowledge through close-out reviews and mentoring so that it becomes an institutional asset rather than remaining with a few experienced staff.

VI. RISK PRIORITIZATION FRAMEWORK AND IMPLICATIONS

Figure 1 converts the findings into a six-stage management cycle. The process starts with evidence from literature, project records, and experts and produces a coded regional register. Professional or project data are then validated before RII, category comparison, correlation, and group-difference analysis establish priority. Each critical risk receives a response strategy, accountable owner, trigger, budget, schedule allowance, and residual-risk rating. Monitoring closes the loop by comparing indicators and actual events with the original assumptions. This feedback is essential because river conditions, prices, designs, approvals, and contractor capacity change over a project's life.

For project owners, the first implementation priority is design governance: independent checks, constructability reviews, disciplined change control, and complete geotechnical and hydrological information before tendering. Payment certification should have defined turnaround times and cash-flow visibility. Contractors should connect the risk register to method statements, look-ahead planning, equipment reliability, labor-productivity tracking, and flood preparedness. Contracts should specify notice requirements, change valuation, differing site conditions, weather treatment, and dispute escalation. Public agencies can support consistency through a regional risk template, standardized stage-gate reviews, and timely coordination of land and approvals.

A tiered response is recommended. Tier 1 should contain design errors, method selection, payment delay, site management, and flooding; these require named senior owners and frequent review. Tier 2 should include communication, labor productivity, contract disputes, cost overrun, structural failure, extreme weather, land acquisition, equipment reliability, escalation, and soil investigation. Remaining factors should stay in the register with proportionate controls and escalation triggers. Because category correlations are substantial, review meetings should examine linked scenarios rather than discussing technical, commercial, and environmental registers in isolation.

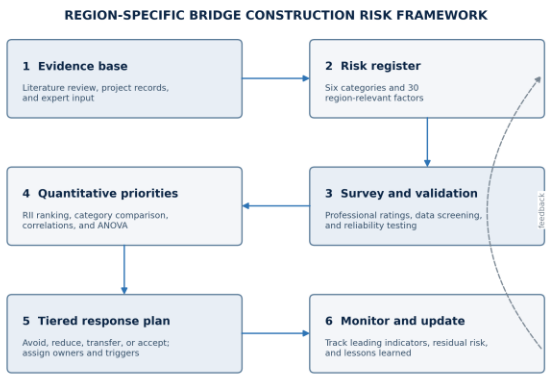

Figure 1. Region-specific bridge construction risk prioritization and management framework

VII. CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH

This study identifies a region-specific hierarchy of bridge construction risks in Gwalior-Chambal. Technical risk was the highest category, and design errors, unsuitable methods, delayed payments, poor site management, and flooding formed the critical individual priority set. Strong positive correlations showed that construction, environmental, financial, legal, and technical risks co-move, while impact analysis placed time and quality ahead of cost and safety. Risk perceptions were broadly shared across stakeholder and experience groups, except for partial differences associated with the number of completed projects. The proposed framework turns these results into a repeatable cycle of evidence, priority, ownership, response, and feedback.

The results are subject to four limitations. Purposive sampling and one regional setting constrain statistical generalization; ratings represent perceptions rather than audited event frequencies; the cross-sectional design cannot establish causality; and RII does not directly model probability, exposure duration, or nonlinear interaction. Future studies should validate the hierarchy using project records, expand sampling across Indian regions, compare bridge types and procurement routes, and test longitudinal links with actual cost, schedule, quality, and safety outcomes. Bayesian networks, system dynamics, Monte Carlo simulation, or interpretable machine learning could extend the present transparent baseline without replacing professional judgement.

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