Integrated Risk Prioritization Approach for Construction Material Supply in Remote Infrastructure Projects

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Abstract. Material delays remain a primary cause of schedule overruns in construction projects, particularly in remote infrastructure areas where logistical access and supply chain stability are limited. This study proposes an integrated risk prioritization approach to systematically evaluate and rank material supply risks in remote infrastructure projects. Risk identification was conducted through literature review and expert validation, followed by a structured assessment of impact and likelihood. A causal relationship matrix was developed to capture the interactions between risk agents and risk events, enabling an aggregated risk-priority ranking. Furthermore, mitigation strategies were evaluated based on their relative effectiveness and implementation complexity. The results reveal that external vendor dependency is the most critical risk agent, followed by logistical planning weaknesses and procurement inaccuracies, indicating that supply-side vulnerability is the dominant driver of material delays in remote infrastructure projects. Priority control actions include structured procurement scheduling, supplier diversification, and material buffer strategies. The integrated approach provides a structured basis for prioritizing supply chain risks and supports managerial decision-making in infrastructure projects with limited accessibility conditions.

1 Introduction

Material delays remain one of the primary contributors to time overruns and cost instability in construction projects [1], [2]. As construction supply chains become increasingly fragmented and multi-organizational, exposure to procurement inefficiencies and supplier unreliability intensifies disruption risks [3][4]. The temporary and project-based nature of construction operations further amplifies vulnerability when coordination gaps propagate across interdependent activities [5].

Traditional risk assessment frameworks commonly rely on impact–likelihood evaluation models to prioritize potential threats [6]. While structured, such approaches often evaluate

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risks individually and may not fully capture systemic relationships among delay drivers. Empirical evidence suggests that construction disruptions frequently arise from interconnected managerial and supply-related factors rather than isolated events [2].
Supply chain resilience literature highlights the importance of structured risk evaluation and prioritization mechanisms to stabilize vulnerable systems [7][8]. However, integrated prioritization approaches that combine severity, occurrence, and interaction intensity remain limited in construction contexts characterized by logistical constraints. Therefore, there is a need for an integrated risk prioritization approach that not only evaluates impact and likelihood but also captures causal interactions among risk factors and supports practical decision-making in remote infrastructure contexts.
Accordingly, this study aims to:

(1) Identify structural patterns of supply chain vulnerability in remote infrastructure projects.

(2) Develop an integrated risk prioritization framework incorporating impact, occurrence, and causal interaction; and

(3) Propose high-leverage mitigation strategies to strengthen supply stabilization under resource constraints.

2 Literature Review

2.1 Material Delays and Project Performance

Material delays significantly affect project time and cost outcomes ([1]. Procurement inefficiencies and supplier unreliability can trigger cascading effects across construction sequences [4]. Due to the interdependence of project activities, such disruptions tend to propagate throughout the construction supply system, amplifying overall project vulnerability [9].

2.2 Supply Chain Risk in Construction

The construction supply chain is temporary, multi-organizational, and inherently exposed to uncertainty [7]. In logistically constrained contexts, limited supplier redundancy increases vulnerability to disruption [3]. Supply chain resilience literature highlights the importance of structural stabilization and systematic prioritization of dominant risk drivers to reduce systemic exposure [10].

2.3 Synthesis and Research Gap

Traditional impact–likelihood models provide basic risk-ranking mechanisms [6], but they often assess risks individually and may overlook causal relationships and the feasibility of mitigation. More integrated prioritization approaches that incorporate systemic relationships offer stronger managerial guidance in supply risk management [8]. However, their application in logistically constrained or remote infrastructure contexts remains limited.

3 Research Methods

3.1 Research Design

This study adopts a structured quantitative risk assessment approach integrating: Risk identification, Severity–occurrence evaluation, Causal interaction mapping, Aggregated risk prioritization, and Mitigation evaluation. The framework emphasizes root-cause prioritization rather than symptom-based ranking.

3.2 Risk Identification

Risk variables were identified through a structured literature review [1]; [4] and subsequently validated via expert judgment. Fifteen Risk Events (Ei) and fourteen Risk Agents (Aj) met the Content Validity Index (CVI) threshold in the validation stage [8]. Risk Events represent observable disruption outcomes, whereas Risk Agents denote the underlying causal drivers.

3.3 Severity and Occurrence Assessment

Each risk event was evaluated based on Severity (Si) and Occurrence (Oi). The average score was calculated as:

$$S_i = \frac{\sum_{k=1}^{n} S_{ik}}{n} \quad (1)$$

$$O_i = \frac{\sum_{k=1}^{n} O_{ik}}{n} \quad (2)$$

This probability–impact approach aligns with structured construction risk assessment principles [6].

3.4 Causal Relationship Matrix

To capture systemic interactions, a causal relationship matrix, Rij, was constructed to represent the influence of risk agent Aj on risk event Ei.

$$R_{ij} \in \{0,1,3,9\} \quad (3)$$

This weighting scheme follows structured correlation scaling commonly used in supply chain risk interaction modeling [8], enabling the identification of dominant risk agents that influence multiple delay events.

3.5 Aggregated Risk Prioritization

The aggregated priority value for each risk agent was calculated as:

$$RP_j = O_j \times \sum_{i=1}^{m} (S_i \times R_{ij}) \quad (4)$$

This formulation integrates severity, occurrence, and interaction intensity within a structured risk evaluation framework [6][8].

3.6 Mitigation Strategy Evaluation

Mitigation alternatives were evaluated using an effectiveness-to-difficulty ratio:

$$ECR_k = \frac{E_k}{D_k} \quad (5)$$

Higher ETD values indicate stronger implementation leverage under resource constraints within structured risk mitigation frameworks [8].

3.7 Data Analysis and Output

The methodological process produces structured outputs to support risk-informed decision-making in remote infrastructure projects. The overall methodological framework adopted in this study is illustrated in Figure 1. First, it generates a ranked list of dominant risk agents by integrating severity, occurrence, and causal interaction, enabling identification of key structural drivers of material supply disruptions. Second, it develops a causal interaction matrix linking risk agents to risk events, illustrating how underlying causes propagate across interdependent supply chain activities and enabling a systemic assessment of vulnerability. Third, it establishes a hierarchy of mitigation strategies, evaluated by their influence and feasibility, ensuring practical and impactful interventions. Finally, these results are synthesized into managerial recommendations to strengthen supply chain governance and enhance resilience in geographically constrained infrastructure environments.

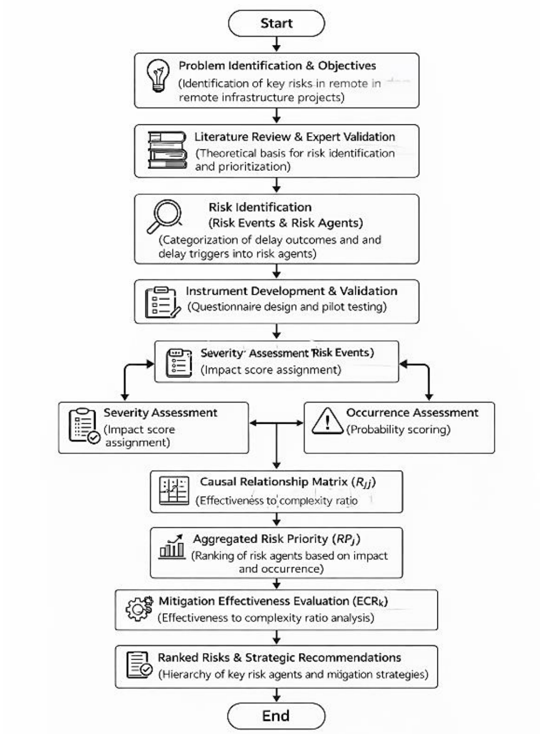

Fig. 1. Research flow of the integrated risk prioritization approach

4 Results and Discussion

4.1 Risk Identification and Classification

Risk identification was conducted through a structured literature review and expert validation involving construction practitioners experienced in material procurement and project execution. The dataset was derived from prior master's thesis research on remote building construction [11]. Using the Content Validity Index (CVI), fifteen Risk Events (Ei) and fourteen Risk Agents (Aj) met the validity threshold and were retained. Severity and occurrence were quantified using mean scores from 39 practitioners [11] and their relationships were modeled using weighted interaction analysis.

The identified events indicate that material delays arise from procurement weaknesses (E1–E3), coordination failures (E4), design variations (E5–E7), managerial limitations (E12–E13), and logistical constraints (E19, E21, E24, E25). These findings suggest that supply vulnerability in remote construction projects is structural, shaped by both external disruptions and internal governance inefficiencies (see Table 1).

Table 1. Identified Material Delay Risk Events

Code	Risk Event	Code	Risk Event	Code	Risk Event	Code	Risk Event
E1	Incorrect purchase request	E8	Difficulty in sourcing materials	E16	Material reorder due to schedule inaccuracy	E24	Security disturbances during material delivery
E2	Failure to control the purchase request schedule	E12	Lack of managerial capability of the subcontractor	E19	Difficulty in obtaining materials due to limited local stock	E25	Delivery constraints from the vendor
E3	Delayed procurement process of materials and components	E13	Negligence of the subcontractor and contractor in material handling	E21	Limited accessibility to the project site		
E4	Failure in communication and coordination among the project parties	E5	Additional material order due to specification changes	E6	Additional material order due to functional space changes	E7	Additional material order due to sudden design changes by the owner

The study identified fourteen Risk Agents (Aj) representing the root causes of material delays, all of which met validation criteria and were retained for analysis (see Table 2). These agents reflect both internal governance weaknesses—such as decision delays (A2), coordination failures (A3, A10), and planning inaccuracies (A8, A17) —and external constraints, including weather uncertainty (A1), logistical disruptions (A15), and off-island vendor dependency (A7). Together, they confirm that material delays result from both logistical barriers and structural management limitations.

Table 2. Identified Material Supply Risk Agents

Code	Risk Agent	Code	Risk Agent	Code	Risk Agent
A1	Unpredictable weather conditions	A8	Weaknesses in logistics planning	A14	Inaccuracy in vendor selection
A2	Errors and delays in decision-making	A9	Prolonged technical evaluation process	A15	Logistical disruptions due to social and political issues
A3	Poor working relationships between the owner, consultant, and contractor	A10	Conflicts among project stakeholders	A16	Incompetent human resources
A5	Prolonged permit approval process	A11	Ineffective workforce performance	A17	Inaccuracy in material procurement planning
A6	Design changes initiated by the owner	A7	High dependency on off-island vendors		

The identified risks indicate that material delays stem from interconnected procurement weaknesses (E1–E3), design variations (E5–E7), managerial limitations (E12–E13), and logistical constraints (E19, E21, E24, E25). From the agent perspective, environmental drivers (A1, A15), supply dependency (A7), and governance inefficiencies (A2, A8, A17) jointly shape supply vulnerability. These findings confirm that material delays in remote infrastructure projects are structural rather than incidental, arising from the interaction between environmental exposure and internal planning constraints [7][9][10].

4.2 Severity and Occurrence Assessment

Following risk identification, severity (S) and occurrence (O) were assessed using mean Likert-scale scores (1–5). E1 (limited local stock availability) shows the highest severity (3.52), followed by vendor delivery instability (E4 = 3.33) and procurement delays (E8 = 3.29), highlighting strong dependence on supply reliability. On the agent side, unpredictable weather (A13) has the highest occurrence (3.5), with owner-initiated design changes (A4) and stakeholder conflicts (A7) also relatively frequent. Overall, the results indicate that material supply instability arises from the interaction between environmental uncertainty and governance limitations, providing a quantitative basis for subsequent risk prioritization (see Tables 3 and 4).

Table 3. Severity Scores of Risk Events

Code	Risk Event (E)/Risk Agent (A)	S	Code	Risk Event	S
E1	Difficulty in obtaining materials due to limited local stock	3.52	E5	Difficulty in sourcing materials	3.26
E3	Security disturbances during delivery	3.10	E8	Delayed procurement process	3.29
E4	Delivery constraints from the vendor	3.33	E12	Additional material order due to sudden design changes	3.24
A1	Errors and delays in decision-making	2.5	A8	Ineffective workforce performance	2.5
A2	Poor stakeholder relationships	2.2	A9	Inaccuracy in vendor selection	2.4
A3	Prolonged permit approval process	2.6	A10	Social & political logistical disruption	2.5
A4	Owner-initiated design changes	3.0	A11	Incompetent human resources	2.2
A5	Weaknesses in logistics planning	2.4	A12	Inaccuracy in procurement planning	2.2
A6	Prolonged technical evaluation	2.4	A13	Unpredictable weather conditions	3.5
A7	Conflicts among project actors	2.7			

4.3 Aggregated Risk Priority Results

An aggregated prioritization was conducted by integrating event severity, agent occurrence, and their interaction to calculate the Aggregate Risk Priority (ARP), which identifies dominant root causes (see Table 4). The results indicate that off-island vendor dependency (A14) is the primary risk driver, reflecting structural vulnerability due to limited redundancy [7]. Logistics planning weaknesses (A5) and procurement inaccuracies (A12) further demonstrate that internal governance limitations intensify the effects of disruption [12] [13]. Although unpredictable weather (A13) has the highest occurrence, its priority depends on interaction with high-severity events, underscoring systemic interdependence [10]. Overall, integrated prioritization provides a stronger decision basis than impact–likelihood assessment alone [6][8].

Table 4. Aggregated Risk Priority Ranking of Risk Agents

Rank	Code	Risk Agent	ARP
1	A14	High dependency on off-island vendors	250.30
2	A5	Weaknesses in logistics planning	175.73
3	A12	Inaccuracy in material procurement planning	151.14
4	A1	Errors and delays in decision-making	149.38
5	A4	Design changes initiated by owner	144.57
6	A13	Unpredictable weather conditions	137.94

4.4 Mitigation Strategy Evaluation

Following the ARP analysis, mitigation strategies were evaluated using an effectiveness–implementation framework, in which the Effectiveness-to-Difficulty (ETD) ratio indicates relative implementation leverage [8]. Structured procurement scheduling (PA8) shows the highest leverage, highlighting the importance of governance strengthening to reduce cascading delays [12]. Supplier prioritization (PA6) and long-term contracts (PA7) support supply network stabilization [7] [14], while buffer stock (PA4) and adaptive scheduling (PA10) enhance flexibility under uncertainty [15][10]. Although digital integration improves coordination, governance-based interventions provide greater immediate impact in remote contexts. Overall, effective mitigation requires strengthening procurement governance, stabilizing supplier networks, and applying adaptive buffering strategies. (See Table 5)

Table 5. Mitigation Strategy Evaluation Results

Rank	Code	Mitigation Strategy	ETD	Rank	Code	Mitigation Strategy	ETD
1	PA8	Structured procurement scheduling	1097.89	6	PA1	Comprehensive design planning prior to execution	779.78
2	PA6	Supplier prioritization and structured supplier management	1003.21	7	PA10	Time and material buffer adjustment based on environmental conditions	745.93
3	PA4	Provision and storage of buffer material stock	906.29	8	PA9	Workforce training and placement based on procurement competence	710.53
4	PA2	Routine coordination meetings among project stakeholders	880.38	9	PA11	Standard operating procedures for decision escalation	676.51
5	PA7	Long-term contractual cooperation with material suppliers	781.52	10	PA3	Early contract finalization before project commencement	660.28

5 Conclusion And Contributions

This study proposes an integrated risk prioritization approach that combines impact, occurrence, and causal interaction to assess structural supply chain vulnerability in remote infrastructure projects. The findings reveal that material supply risk is primarily driven by supply dependency, weak logistics planning, and governance limitations, indicating that disruption in remote contexts is structural rather than incidental. High-leverage mitigation strategies—such as structured procurement scheduling, supplier prioritization, and buffer planning—demonstrate stronger implementation impact than purely technological measures. By integrating severity, occurrence, interaction intensity, and implementation feasibility within a unified prioritization mechanism, this study contributes both methodologically and practically. It advances structural understanding of supply vulnerability in logistically constrained environments and provides a structured decision-support framework that links dominant risk drivers to implementable mitigation strategies. This approach offers a more robust basis for resource allocation and supply stabilization than conventional impact–likelihood assessment alone. Future research may incorporate dynamic simulation or resilience modeling to enhance predictive capability and broader applicability.

6 Limitations and Future Research

This study is limited to a single empirical case within a remote infrastructure context, which may constrain generalizability across different regions or project types. In addition, the risk assessment and mitigation evaluation rely on structured expert judgment, which may introduce subjective bias despite validation procedures. Future research should extend the framework through multi-project comparative analysis, dynamic simulation modeling, or integration with quantitative resilience assessment approaches to enhance predictive capability under large-scale or prolonged disruption scenarios.

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