MITIGATING RISK IN THE CONSTRUCTION SUPPLY CHAIN THROUGH THE INTEGRATION OF THE SUPPLY CHAIN OPERATIONS REFERENCE MODEL AND THE HOUSE OF RISK METHOD

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ABSTRACT

Background: During construction, companies face various risks that can disrupt operational efficiency. Potential risks include payment schemes that do not align with the initial contract, errors in estimating material requirements, and inaccuracies in work planning.
Purpose: This study focuses on identifying risk events and risk agents within the construction supply chain process, determining the priority of risk agents based on Aggregate Risk Potentials (ARP), and proposing mitigation strategies to address these risk agents.
Design/methodology/approach: This research employs the Supply Chain Operations Reference (SCOR) 11.0 model and the House of Risk (HOR) method, utilizing Phase 1 for risk identification and Phase 2 for determining actions to mitigate the identified risk sources.
Findings/Results: Seventeen risk agents and sixteen risk events were identified. The priority risk agents include a payment system that deviates from the initial contract, inaccuracies in estimating material requirements, and errors in work planning calculations. In response to these risks, five risk mitigation strategies were proposed: (1) estimating unexpected costs, (2) establishing an alternative payment system, (3) formulating Standard Operating Procedures for material specifications, (4) forecasting material prices, and (5) creating an automated system for estimating labor requirements.
Conclusion: In the construction supply chain, among the identified risk events and risk agents, the top-priority risk agents include payment schemes that do not align with the initial contract, inaccuracies in calculating material requirements, and errors in work planning calculations. These results show that risks associated with money, materials, and planning are very important for making the building supply chain less effective. Combining SCOR and the HOR method provides an organized, data-driven approach to identify, rank, and reduce risks in a methodical manner. In practice, the results help businesses better allocate resources, reduce project delays, and keep costs down by using focused and proactive risk management measures.
Originality/value (State of the art): This study contributes to the existing literature by developing a hybrid risk management framework by integrating the SCOR model with the HOR method, enabling systematic mapping and assessment of risks across the entire construction supply chain.

Keywords: risk mitigation, house of risk, supply chain operations reference, construction supply chain, supply chain management

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INTRODUCTION

Infrastructure development and the rising demand for construction projects have propelled the notable expansion of Indonesia's construction industry's notable expansion (Drakeley, 2005; Roberts and Sander, 2019; Jurriens and Tapsell, 2020). However, this growth has also intensified challenges within the construction supply chain, particularly in managing uncertainties related to material supply, labor availability, financial arrangements, and project planning (Reuter et al. 2010; Aghion et al. 2015; Margiansyah and Defbry, 2020). Companies operating in this sector are required to ensure efficient and reliable supply chain performance to remain competitive in the market. Construction supply chains are inherently complex and involve multiple stakeholders, making them highly vulnerable to various risks, such as delays, cost overruns, and quality issues (Ding et al. 2021; Bohm et al. 2022). Therefore, effective supply chain risk management has become essential to ensure project success and operational efficiency (Zahiraet al. 2024). A structured approach is required to systematically identify, assess, and mitigate risks across all stages of the construction supply chain.

As demand evolves rapidly, along with developments in customer preferences for goods and services, business competition becomes increasingly fierce (McGrath, 2013; Reimann et al. 2010). Companies are motivated to innovate to enhance efficiency and productivity, which are essential for maintaining their competitiveness. Innovation and adaptability are important in today's business landscape (Do et al. 2016; Tejeiro Koller, 2016; Stojcic et al. 2018).

The stronger Indonesia's economic growth, the greater the subsequent development efforts (Pepinsky and Wihardja, 2011; Widarni and Bawono, 2021). This rapid growth has led to a significant increase in infrastructure and construction activities, which in turn, has intensified the complexity of construction supply chains. Each year, both the central and regional governments advance infrastructure projects across the country. Activities related to facility and infrastructure construction are included in the construction sector. As the scale and volume of projects expand, construction supply chains become more vulnerable to various risks, including material shortages, delivery delays, cost fluctuations, and coordination issues among stakeholders. Effective construction supply chain management is essential for mitigating problems within this industry (Shojaei and Haeri, 2019; Ekanayake et al. 2022; Okika et al. 2025). It can serve as a vital strategy for reducing costs and minimizing delays in construction projects (Dallasega 2018; Mangla et al. 2018). Consequently, research into construction supply chain management is critical to enhancing project efficiency (Beske et al. 2014; Erik, 2010; Sreedevi and Saranga, 2017).

One of the companies in the Cilegon area focuses on providing labor and services across various industries in Indonesia. The company also offers services in sectors such as construction, agriculture, and mining. One specific focus within the construction sector is security services and parking management. In the course of their operations, the company strives for continuous innovation and development, as evidenced by the diverse range of services they offer.

Based on experiences in the construction sector, challenges often arise in the procurement of goods necessary to meet project requirements. Interviews conducted during development projects have identified several obstacles, including inaccuracies in pricing estimates, supplier failures to meet demand, and transportation resource limitations. However, recent research on construction supply chain management tends to focus on isolated concerns, such as material delays or cost estimation, rather than providing a holistic and integrated approach to identifying and prioritizing risks throughout the supply chain. This constraint leads to fragmented risk management strategies that may ignore the key interdependencies among risk sources. Therefore, an organized and systematic framework is required to identify, assess, and prioritize risks in the building supply chain.

During construction, companies face many risks that can disrupt operational efficiency. Potential risks include payment schemes that do not align with the initial contract, errors in estimating material requirements, and inaccuracies in work planning calculations. Therefore, this study aims to identify risks that may arise in construction projects and establish effective risk management practices. Risk management is a systematic and logical method used to identify, monitor, and manage risks within organizations. By implementing effective risk management strategies, companies can minimize potential risks (Tupa et al. 2017; Bahamid et al. 2022).

This study focuses on identifying risk events and risk agents within the construction supply chain process, determining the priority of risk agents based on Aggregate Risk Potentials (ARP), and proposing mitigation strategies to address these risk agents. To achieve these objectives, this study employs the Supply Chain Operations Reference (SCOR) 11.0 model and the House of Risk (HOR) methodology.

This study develops a hybrid risk management framework by integrating the SCOR model with the HOR method, enabling systematic mapping and assessment of risks across the entire construction supply chain. This study extends the application of the HOR method by considering a comprehensive range of risks, including material, labor, and financial risks, rather than focusing solely on material procurement, thereby providing a more holistic view of supply chain vulnerabilities. This study introduces quantitative tools, such as ARP and Pareto analyses, to precisely prioritize risk agents and events. This data-driven approach assists decision-makers in targeting the most critical risks. It proposes targeted risk mitigation strategies, including alternative payment schemes, improved material estimation protocols, and automated labor management systems designed to enhance operational efficiency and reduce project delays.

This study is positioned within existing studies on risk management in the construction supply chain using the HOR method. It critically reviews recent and relevant studies, summarizing their key findings, methodologies, strengths, and weaknesses. A comparative analysis highlights the gaps in the current literature, demonstrating the novelty of this study. However, previous studies have primarily focused on specific components of the construction supply chain, such as material procurement or project-level risks, and have frequently lacked an integrated framework for mapping supply chain operations and linking them to risk detection and mitigation. Furthermore, many studies depend significantly on qualitative assessments or expert judgment without using a structured process-based methodology to ensure complete risk coverage. Therefore, a more comprehensive and structured strategy that combines process mapping with quantitative risk prioritization and mitigation measures is required. Poor risk management in construction supply chains can lead to cost overruns, project delays, quality issues, safety hazards, regulatory non-compliance, and supply chain disruptions. These problems can damage a company's reputation and reduce stakeholder trust, highlighting the critical importance of effective risk management for project success and sustainability.

The HOR method has been increasingly adopted in construction supply chain risk management because of its proactive approach to addressing risk agents before they trigger risk events. The use of HOR in supply chain risk management demonstrates the importance of identifying risk agents and correlating them with potential risk events to prioritize preventive actions (Nyoman and Geraldin, 2009). The advantages of the HOR lie in its ability to quantify risk based on the ARP, allowing decision-makers to focus on the most critical risks (Siswanto et al. 2018; S. Kurniawan et al. 2021).

In a recent study, Dvaipayana et al. (2024) explores supply chain risk mitigation in the precast concrete industry using HOR framework and Fuzzy Analytical Hierarchy Process (Fuzzy AHP). It identified 26 risk events and 21 risk agents, prioritizing the most critical ones using the ARP values. Five key mitigation strategies were selected and implemented in a dashboard monitoring system to track the risks and mitigation efforts. The study aims to provide a structured approach to supply chain risk management, especially in construction-related industries (Dvaipayana et al. 2024).

Similarly, Ahmad and Susanty (2019) identified potential risk events in the material procurement supply chain of PT Samudera Rekso Asri (SRA), a construction company, and prioritized risk agents for mitigation using the HOR approach. After identifying 23 risk events and 17 risk agents, this study prioritizes three key risk agents: unbalanced project progress with material delivery, limited availability of transportation modes, and fluctuating supplier production. These risk agents require immediate mitigation strategies, which are planned to be addressed in the second phase of the HOR method (Ahmad and Susanty, 2019)).

A study by Hoi-Lam Ma and Wai-Hung Collin Wong (Hoi-Lam et al. 2018) expanded the application of HOR by improving the model using a fuzzy logic for risk assessment and aimed at manufacturers in global supply chains. The authors argue that risk management involves both quantitative and qualitative decisions, with the latter often being more subjective. The fuzzy-based approach helps address the limitations of qualitative decision-making by making risk prioritization more precise. The study identifies risk events and agents across several categories: internal risks, global environmental risks, supplier risks, customer risks, and third-party logistics risks (Hoi-Lam Ma et al. 2018). By applying fuzzy logic, this study demonstrates how risks can be better assessed and mitigated (Díaz-Curbelo et al. 2020).

Another study by Wibowo and Ahyudanari (Wibowo and Ahyudanari, 2020) provided a proactive framework for managing material risks in the procurement process of the Balikpapan Samarinda Toll Road Project, a significant infrastructure undertaking in Indonesia. This study focuses on managing material procurement risks that can delay project completion. The study identified 15 risk agents, four of which were prioritized for mitigation: changes in the implementation schedule, delays in supplier bill payments, problems in supplier selection, and material fabrication time (Wibowo and Ahyudanari, 2020).

However, despite these advancements, current research mostly concentrates on particular aspects of the construction supply chain, including the acquisition of materials or specific project settings, and does not fully address the supply chain process as a whole. Furthermore, without incorporating a process-based framework that methodically connects supply chain operations with risk identification and mitigation, most research focuses on either methodological improvements or case-specific applications. Thus, there is still a research gap in creating a comprehensive and integrated strategy that integrates structured risk prioritization and mitigation with end-to-end supply chain mapping. To close this gap, this study combines the HOR method with the SCOR 11.0 model to examine risks in the entire construction supply chain, including material, labor, and financial factors, within a single framework.

This study introduces a hybrid approach that combines HOR with SCOR 11.0, a comprehensive framework that enhances the effectiveness of HOR. This combination enables a more comprehensive risk prioritization and mitigation strategy that is applicable to larger and more complex construction projects. The inclusion of a literature table further illustrates the fundamental differences between this study and prior studies (Table 1). This study offers a structured method for methodically identifying, prioritizing, and mitigating risks throughout the entire supply chain by taking a comprehensive approach to the construction supply chain, covering important operational processes such as Plan, Source, Make, Deliver, and Return, and incorporating a quantitative risk assessment framework. This study provides a more complete and reliable approach to risk management in the construction industry. This integration improves the precision of identifying, ranking, and addressing potential risks.

Table 1. Previous Studies on Supply Chain Risk Management Using the HOR Method

Author	Tools	Remarks
Dvaipayana et al. (2024)	HOR integrated Fuzzy AHP in precast concrete industry	The study integrates HOR and Fuzzy AHP for structured supply chain risk mitigation in the precast concrete industry, with a practical monitoring dashboard
Ahmad and A. Susanty (2019)	HOR in material procurement	This study provides a practical approach for identifying and prioritizing risks in construction procurement. The study does not include quantitative analysis of the financial impact of the risks
Hoi-Lam Ma et al (2018)	HOR and Fuzzy logic in manufacture sector	The use of fuzzy logic improves the precision of qualitative risk assessments. The study focuses only on manufacture sector, leaving room to explore how other components, such as logistics providers and retailers, could benefit from this model
Wibowo and Ahyudanari (2020)	HOR in the procurement process of an infrastructure project	This study focuses on supply chain risk management for material procurement in large-scale projects, potentially setting a precedent for future projects of similar scale. The study is limited to material procurement, does not explore external risk factor such as global supply chain disruptions or natural disaster
This research	HOR and SCOR 11.0	This study provides a comprehensive risk assessment. SCOR 11.0 serves as the operational framework through the processes of planning, sourcing, making, delivering, and returning, whereas HOR provides analytical tools to assess and manage risks. This integration enhances the accuracy of risk detection, prioritization, and mitigation.

METHODS

The SCOR 11.0 model serves as a process reference tool for diagnosing SCM. By utilizing the SCOR model, each activity within a company's business process can be meticulously measured from upstream to downstream. The SCOR framework organizes supply chain management into key processes (Lu et al. 2016; Hammadi et al. 2018; Ahoa et al. 2018): planning, which balances demand and supply to optimize procurement, production, and delivery actions; sourcing, which focuses on acquiring goods and services; manufacturing, which converts raw materials or components into final products; delivery, which meets demand for goods or services; and returns, which handles the return of products for various reasons (El-Garaihy, 2021; Surange and Bokade, 2024; Surange and Bokade, 2023). The latest versions of SCOR, SCOR 12.0 and SCOR 13.0, have incorporated aspects of supply chain management through the addition of the Enable stage, which includes elements of technology enablement such as automation, the Internet of Things (IoT), and information system integration. However, the case study in this research has not yet implemented technology enablement, making this approach not fully relevant for application in the current context of this study. The basic operational activities (Plan, Source, Make, Deliver, and Return) that are directly related to risk detection in construction supply chains are highlighted in SCOR 11.0, a well-known and extensively proven process-based framework. In contrast to subsequent iterations, SCOR 11.0 provides a more targeted framework for mapping operational risks without adding extra complexity from technological enabling procedures that are not essential to the study goals. Its process-oriented architecture also facilitates integration with the HOR technique, which requires clearly defined operational tasks to methodically identify risk occurrences and risk agents. Therefore, SCOR 11.0 is considered the most appropriate framework for this study, as it focuses on the five core supply chain processes: plan, source, make, deliver, and return, which provide a clear and structured representation of operational activities. This structure ensures methodological consistency and clarity in mapping supply chain processes while avoiding additional complexity related to digital technology implementation. Moreover, SCOR 11.0 demonstrates strong compatibility with the HOR method, as it provides well-defined operational processes that support systematic risk identification, prioritization, and mitigation.

Several alternative risk management frameworks, such as Failure Mode and Effects Analysis (FMEA) and the Committee of Sponsoring Organizations of the Treadway Commission (COSO) framework, were considered during the early stages of this study. Although both methods are widely recognized in risk assessment practices, they present certain limitations when applied to complex supply chain contexts (Sutrisno and Kumar, 2023; Vinod et al. 2022). FMEA, for instance, is effective for identifying and evaluating potential failure modes at the component or process level but tends to be less comprehensive in mapping interrelated risks across the broader supply chain. Similarly, although the COSO framework is valuable for enterprise risk management, it lacks the systematic structure and specificity required for detailed supply chain risk analysis. In contrast, HOR offers a more structured and quantifiable approach, particularly suited for prioritizing risk agents and formulating targeted preventive actions within the supply chain.

This study employs primary and secondary data. The primary data were obtained from the project manager and general affairs manager, who were directly engaged in construction activities. Both respondents were chosen for their vast expertise and in-depth knowledge of construction project management, procurement processes, and financial administration, all of which are crucial to the construction supply chain management. Their responsibilities include decision-making and coordination across diverse supply chain operations, ensuring thorough awareness of potential risks and operational issues. Although the number of respondents is restricted, the use of expert judgment is deemed appropriate in the HOR method, which prioritizes the quality and relevance of expert input over the number of respondents. Secondary data were collected from academic journals, books, and prior studies related to supply chain risk management, the SCOR model, and the HOR method.

Data were collected through interviews with the project manager and general affairs manager of a construction company in Cilegon City, who served as experts. To ensure data consistency, a structured interview process was designed using the SCOR framework and the HOR method. The interview tool included predefined evaluation scales for determining the severity of risk events, the presence of risk agents, and the relationship between risk agents and risk events. These scales were derived from existing HOR research and evaluated during preliminary conversations with professionals to guarantee clarity and applicability to the context of building. They assessed the severity of risk events, the occurrence of risk agents, and the correlation between risk agents and risk events using a scale. Specifically, severity (S) and occurrence (O) were measured using a Likert scale ranging from 1 (very low) to 9 (very high), where severity reflects the impact of a risk event on project performance, and occurrence represents the likelihood of a risk agent. The correlation between risk agents and risk events (R) was evaluated using a discrete scale of 0 (no correlation), 1 (weak correlation), 3 (moderate correlation), and 9 (strong correlation), according to the standard HOR framework. Using a standardized evaluation scale, they assessed the relationship between priority risk agents and preventive activities, as well as the difficulty in implementing each preventive action.

The HOR model emphasizes proactive supply chain risk management by focusing on preventive actions to reduce the occurrence of risk agents, thereby preventing associated risk events (Nyoman and Geraldin, 2009). Risk agents are potential causes of risk events, and multiple risk events can be avoided by mitigating these agents.

Traditional FMEA calculates Risk Priority Numbers (RPN) by considering the probability of occurrence, severity, and detection of risk events (Mc Dermott et al. 2009; Kyungmee et al. 2018). A failure mode refers to the way in which a system or process can fail, whereas the impact resulting from the occurrence of that failure mode is known as the failure effect (Vinod et al. 2022; Sutrisno and Kumar, 2022). After identifying all potential failure modes and their consequences, the risk associated with each failure mode is assessed to prioritize the most critical failure modes and determine suitable actions to mitigate their risks (Bhattacharjeeet al. 2020; Kwai-Sang et al. 2009). Unlike FMEA, the HOR model assigns the probability to risk agents and severity to risk events. The ARP of a risk agent is calculated based on its probability of occurrence (O_j), the severity of its associated risk events (S_i), and the correlation between the risk agent and the risk events (R_{ij}), reflecting how likely a risk agent will trigger specific risk events (Nyoman et al. 2009).

$$ARP_j = O_j \sum_i S_i R_{ij} \quad (1)$$

The HOR model introduces two specific deployment strategies. First, HOR 1 is designed to identify which risk agents should be prioritized for preventive measures, allowing businesses to proactively address risks before they escalate. The second strategy, HOR 2, goes a step further by prioritizing actions that are not only effective but also reasonable in terms of resource and financial commitments, ensuring that risk mitigation efforts are both impactful and cost-efficient (Nyoman et al. 2009). The Total Effectiveness of Action (TEk) is calculated to evaluate the effectiveness of a specific action in mitigating a particular risk. Determine the relationship between each preventive action and each risk agent (). The values could be {0, 1, 3, 9} which represents, respectively, no, low, moderate, and high relationships between action and agent. The total effectiveness of each action is as follows (Nyoman et al. 2009):

$$TE_k = \sum_j ARP_j E_{jk} \quad (2)$$

The Degree of Difficulty Performing Action (Dk) is a measure of how challenging it is to implement a given risk mitigation action. It assesses factors such as the complexity of the action, time required, resources needed, and potential barriers to implementation. The Effectiveness-to-Difficulty Ratio (ETD) is a key ratio used to prioritize risk mitigation actions by comparing their effectiveness (TEk) to the difficulty (Dk) of performing them (Nyoman et al. 2009). Actions with a high ETD ratio indicate that the action is highly effective relative to its difficulty, making it the most attractive choice for risk mitigation.

$$ETD = (TE_k)/D_k \quad (3)$$

The research framework (Figure 1) integrates SCOR 11.0 with the HOR method to achieve this. The analytical process begins with SCOR 11.0, which is used to systematically map construction supply chain activities into five core processes: plan, source, make, deliver, and return. This mapping serves as the foundation for identifying risk events and associated risk agents at each stage of the supply chain.

Subsequently, HOR Phase 1 is applied to analyze and prioritize risk agents by calculating the ARP, which integrates three key parameters: severity of risk events, occurrence probability of risk agents, and the correlation between them. This phase produces a ranked list of critical risk agents that require prioritized attention. In the next stage, HOR Phase 2 is conducted to develop and evaluate preventive actions for prioritized risk agents. Each preventive action is assessed based on its effectiveness in reducing risk and its level of implementation difficulty, resulting in the ETD ratio, which is used for ranking mitigation strategies. The final outcome of this framework is a set of prioritized and feasible mitigation actions derived from a structured, step-by-step analytical process. The integration of SCOR 11.0 and the HOR method enables structured risk identification, objective risk prioritization, and the strategic selection of mitigation actions. This integrated framework supports data-driven decision-making and enhances the resilience, efficiency, and performance of construction supply chains.

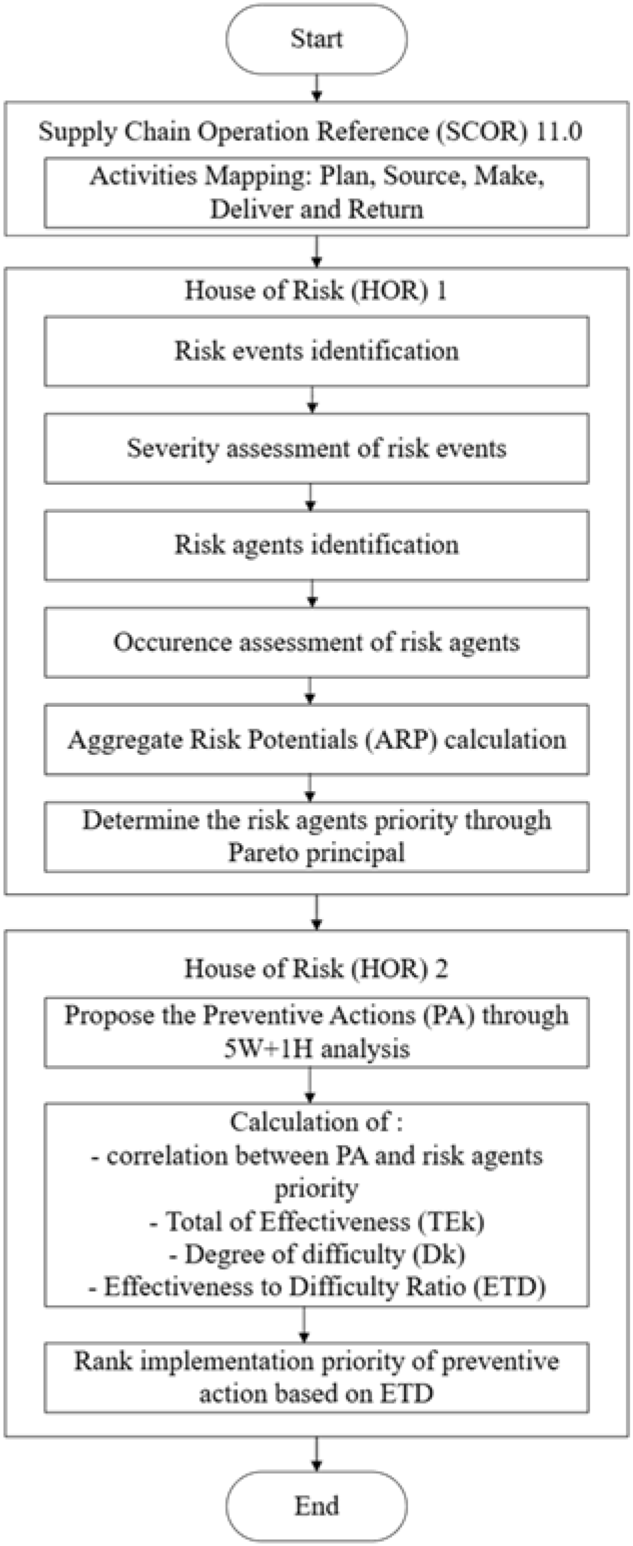

Figure 1. Framework of thought for construction supply chain risk management

RESULTS

In this study, data processing was divided into four stages: risk identification, risk analysis, risk evaluation, and risk mitigation. The HOR Phase 1 method was applied for risk identification, analysis and evaluation. The HOR Phase 2 method was used for risk mitigation.

Risk identification

The mapping of construction supply chain activities was conducted using the SCOR model. These activities are categorized into the processes of planning, sourcing, manufacturing, delivering, and returning, as outlined in Table 2. Risk is defined as the probability of events that may have negative consequences for a company (Berg, 2010). The identification of risk agents and risk events is based on references and cases found in the company. In total, 16 risk events and 17 risk sources were identified in the construction supply chain. Sixteen risk events and 17 risk agents were identified, with the majority of hazards occurring throughout the planning, sourcing, and execution (make) stages. Specifically, planning-related risks (e.g., cost estimation errors and inaccurate material planning) and sourcing-related risks (e.g., supplier credibility, delivery delays, and limited resources) dominate the supply chain, indicating that upstream decision-making and supplier performance are the primary causes of downstream disruptions. Furthermore, execution-stage risks, such as worker carelessness, equipment malfunction, and noncompliance with protocols, show operational flaws that can lead to safety accidents and inefficiency. These trends indicate that risk mitigation efforts should focus on early stage planning accuracy, supplier management, and operational control to effectively minimize the total supply chain risk.

Risk analysis

In this study, SCOR model version 11.0 was employed to facilitate the identification of risk events in the construction supply chain. Table 2 presents the risk events identified within the construction supply chain. This study was based on expert judgment. The experts, consisting of the project manager and the general affairs manager, conducted an assessment of the severity level of the risk events (Table 3), the occurrence level of risk agents (Table 4), and the correlation between the risk agents and the risk events (Table 5) in January-February 2024. We use a 1-9 scale to assess the severity of the risk events and the occurrence of risk agents, where 1 represents "very low" and 9 represents "very high". This scale follows the standard measurement commonly used in the HOR method to ensure consistency in expert judgement. Meanwhile, for the correlation, we used a scale where 9 indicates a strong correlation, 3 indicates a medium correlation, 1 indicates a weak correlation, and 0 indicates no correlation.

The analysis identified seven risk events classified as severity level 1 (very small): E6, E7, E8, E10, E13, E15, and E16. Additionally, two risk events were rated at severity level 2 (small): E4 and E11. Three risk events were categorized as severity level 3 (minor): E9, E12, and E14. One risk event was assigned a severity rating of 4 (very low): E2. Furthermore, one risk event was assessed with a severity level of 7 (high): E1. Lastly, one risk event was rated at severity level 8 (very high): E5.

Table 2. Identification of risk events and risk agents in the construction supply chain

Major Processes	Activity	Risk Agent	Code	Risk Event	Code
Plan	Work planning	Errors in work planning calculations	A1	Insufficient Number of Hired Employees	E1
		Lack of precision in calculating material requirements	A2	Errors in Cost Estimation Compared to Actual Costs	E2
				Errors in Forecasting Material Requirements	E3
		Supplier shortage of Material Stock	A3	Supplier Struggles to Meet Material Demands	E4
	Financial planning	Payment System Inconsistent with the Initial Contract	A4	Late Payment Deadlines	E5
		Fluctuations in Material Prices	A5	Errors in Cost Estimation Compared to Actual Costs	E2
Source	Procurement of goods by suppliers	Errors in the Delivery Process	A6	Material Damage	E6
		Materials Received Not Matching the Purchase Quantity	A7	Supplier's Poor Credibility	E7
		Limited Availability of Technical Equipment Rentals	A8	Lack of Required Technical Equipment	E8
		Limited Supplier Fleet Capacity	A9	Delays in Material Delivery by the Supplier	E9
Make	Work execution	Materials Not Used Immediately	A10	Decline in Material Quality	E10
		Worker Negligence	A11	Workplace Accidents	E11
		Inadequate Equipment Maintenance	A12	Equipment Malfunctions During Work Activities	E12
		Improper Use of Technical Equipment	A13		
		Non-Compliance of Work with Standard Procedures	A14	Excessive Use of Materials	E13
		Outdoor Work Activities Affected by Bad Weather	A15	Temporary Work Suspension	E14
Deliver	Handover of work to the customer	Delays in project Completion	A16	Extension of Work Beyond the Contract Period	E15
Return	Return of work by the customer	Poor quality of work	A17	Rework or Repairs	E16

The results of the HOR Phase I assessment are presented in Tables 3, 4, 5, and 6. The Pareto diagram in Figure 2 illustrates that 80% of the problems are caused by 20% of the failure causes in a process. Therefore, the types of errors that account for a cumulative 80% of the total are selected under the assumption that this 80% can represent all types of errors (Abyad, 2021). The Pareto diagram in Figure 2 illustrates that a small number of risk agents contribute disproportionately to the total ARP. Specifically, the Pareto analysis revealed that a small number of dominant risk agents primarily connected to payment system inconsistencies (A4), inaccurate material demand estimation (A2), and errors in task planning calculations (A1) accounted for almost 80% of the overall ARP value. This suggests that financial and planning-related risks are the most significant causes of interruptions in the building supply chain.

Based on Table 6 and Figure 2, the priority risk agents in this study were determined using the Pareto principle. The ARP, calculated using equation (1), is used to classify the top 80% is used to classify the top 80% as priority risk agents, while the remaining 20% are classified as non-priority. By focusing on mitigating the top 80% of the highest-risk causes, the overall risk can be significantly reduced.

Table 7 presents the results of the identification of preventive actions. Three prioritized risk sources were identified: sources A4, A2, and A1. For each risk source, five proposed preventive actions (mitigation measures) were identified. Table 7 assesses the correlation between mitigation measures and risk agents by evaluating the relationship between prioritized risk sources and mitigation actions. The correlation scale used was 9 (strong correlation), 3 (medium correlation), 1 (weak correlation), and 0 (no correlation). The level of difficulty in implementing preventive actions is also considered. The difficulty level was rated on a scale of 1 (very easy), 2 (easy), 3 (moderately difficult), 4 (difficult), and 5 (very difficult).

Table 3. Severity assessment of identified risk events

Major Processes	Activity	Risk Event	Code	Project Manager	GA Manager	Severity
Plan	Work planning	Insufficient number of hired employees	E1	7	7	7
		Errors in cost estimation compared to actual costs	E2	4	5	4
		Errors in forecasting material requirements	E3	4	3	3
		Supplier struggles to meet material demands	E4	2	2	2
		Financial planning	E5	8	9	8
		Late payment deadlines	E2	4	5	4
		Errors in cost estimation compared to actual costs	E2	4	5	4
Source	Procurement of goods by suppliers	Material damage	E6	1	2	1
		Supplier's poor credibility	E7	1	2	1
		Lack of required technical equipment	E8	1	1	1
		Delays in material delivery by the supplier	E9	4	3	3
Make	Work execution	Decline in material quality	E10	1	1	1
		Workplace accidents	E11	2	2	2
		Equipment malfunctions during work activities	E12	4	2	3
		Excessive use of materials	E13	2	1	1
		Temporary work suspension	E14	3	3	3
Deliver	Handover of work to the customer	Extension of work beyond the contract period	E15	1	1	1
Return	Return of work by the customer	Rework or repairs	E16	1	1	1

Table 4. Occurrence assessment of identified risk agents

Major Processes	Activity	Risk Agent	Code	Project Manager	GA Manager	Occurrence
Plan	Work planning	Errors in work planning calculations	A1	2	3	2
		Lack of precision in calculating material requirements	A2	3	3	3
		Supplier shortage of Material Stock	A3	1	2	1
	Financial planning	Payment System Inconsistent with the Initial Contract	A4	5	4	4
		Fluctuations in Material Prices	A5	3	1	2
Source	Procurement of goods by suppliers	Errors in the Delivery Process	A6	1	1	1
		Materials Received Not Matching the Purchase Quantity	A7	5	6	5
		Limited Availability of Technical Equipment Rentals	A8	1	1	1
		Limited Supplier Fleet Capacity	A9	1	2	1
Make	Work execution Handover of work to the customer	Materials Not Used Immediately	A10	2	3	2
		Worker Negligence	A11	1	1	1
		Inadequate Equipment Maintenance	A12	3	1	2
		Improper Use of Technical Equipment	A13	2	1	1
		Non-Compliance of Work with Standard Procedures	A14	1	1	1
		Outdoor Work Activities Affected by Bad Weather	A15	3	2	2
Deliver	Handover of work to the customer	Delays in project Completion	A16	1	1	1
Return	Return of work by the customer	Poor quality of work	A17	1	1	1

Table 5. HOR Phase 1

Major Process	Risk Event	Risk Agent																	Severity
		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	
Plan	E1	3																	7
	E2		9			3													4
	E3		1																3
	E4			3															2
	E5				9														8
Source	E6						1												1
	E7							1											1
	E8								1										1
	E9									3									3
Make	E10										1								1
	E11											3							2
	E12												3	3					3
	E13														1				1
	E14															3			3
Deliver	E15																1		1
Return	E16																	3	1
Occurrence		2	3	1	4	2	1	5	1	1	2	1	2	1	1	2	1	1	
ARP		42	117	6	288	24	1	5	1	9	2	6	18	9	1	18	1	3	
Priority		3	2	10	1	4	17	11	15	8	13	9	5	7	14	6	16	12	

Table 6. Risk Agent Priority Based on ARP

Risk Agent	Code	Priority	ARP	Cumulative ARP	% ARP	Cumulative % ARP	Category
Payment System Inconsistent with the Initial Contract	A4	1	288	288	52.27%	52.27%	Priority Risk Agent
Lack of precision in calculating material requirements	A2	2	117	405	21.23%	73.50%	
Errors in work planning calculations	A1	3	42	447	7.62%	81.13%	
Fluctuations in Material Prices	A5	4	24	471	4.36%	85.48%	Non-Priority Risk Agent
Inadequate Equipment Maintenance	A12	5	18	489	3.27%	88.75%	
Outdoor Work Activities Affected by Bad Weather	A15	6	18	507	3.27%	92.01%	
Improper Use of Technical Equipment	A13	7	9	516	1.63%	93.65%	
Limited Supplier Fleet Capacity	A9	8	9	525	1.63%	95.28%	
Worker Negligence	A11	9	6	531	1.09%	96.37%	
Supplier shortage of Material Stock	A3	10	6	537	1.09%	97.46%	
Materials Received Not Matching the Purchase Quantity	A7	11	5	542	0.91%	98.37%	
Poor quality of work	A17	12	3	545	0.54%	98.91%	
Materials Not Used Immediately	A10	13	2	547	0.36%	99.27%	
Non-Compliance of Work with Standard Procedures	A14	14	1	548	0.18%	99.46%	
Limited Availability of Technical Equipment Rentals	A8	15	1	549	0.18%	99.64%	
Delays in project Completion	A16	16	1	550	0.18%	99.82%	
Errors in the Delivery Process	A6	17	1	551	0.18%	100.00%	

Table 7. Preventive Action of Priority Risk Agents

Risk Agent	Code	Preventive Action	Code	Correlation	Degree of difficulty
Payment System Inconsistent with the Initial Contract	A4	Estimate contingency reserves for unexpected costs	PA1	3	4
		Develop alternative payment schemes for suppliers with set payment terms	PA2	3	3
Lack of precision in calculating material requirements	A2	Create SOPs detailing the material specifications for the work to be done	PA3	9	2
		Forecast material prices based on price fluctuation trends	PA4	3	3
Errors in work planning calculations	A1	Build an automated system to estimate the required workforce based on the work contract	PA5	9	5

Table 8 presents the results of HOR Phase 2. HOR 2 is developed after identifying and prioritizing risk agents in the HOR 1 phase. It focuses on evaluating and ranking preventive actions (PAs) aimed at mitigating the most critical risks. Five preventive actions were proposed to mitigate the three priority risk agents: A4, A2, and A1. The actions of estimating contingency reserves for unexpected costs (PA1) and developing alternative payment schemes for suppliers with set payment terms (PA2) are intended to mitigate the inconsistent payment system with the initial contract (A4). These risk agents dominate because they emerge from early stage decision-making processes (planning and financial management), which have a knock-on effect on future supply chain operations. For example, a payment system inconsistent with the initial contract (A4) can disrupt supplier relationships and cause material flow delays, whereas mitigating the lack of precision in calculating material requirements (A2) has a direct impact on procurement efficiency and cost control. Similarly, errors in work planning calculations (A1) can cause resource misallocation and operational inefficiency. This explains why these risks have a major impact on the total ARP and are prioritized for reduction in the study. To mitigate the lack of precision in calculating material requirements (A2), the proposed actions are creating SOPs detailing the material (PA3) and forecasting material prices based on price fluctuation trends (PA4). Lastly, building an automated system to estimate the required workforce based on the work contract (PA5) is a preventive action to mitigate errors in work planning calculations (A4). The calculation of the Total Effectiveness of actions (TEk) is used to rank the preventive actions. These actions were ranked from 1 to 5 under the codes PA3, PA2, PA1, PA4, and PA5, respectively. This means that PA3 to PA5 represent preventive actions in order of effectiveness, from most to least effective.

This study combines the SCOR model and HOR method to create a clear and complete picture of the entire construction supply chain. It does not focus on one area; it considers risks related to materials, labor, and finances simultaneously. By identifying 16 risk events and 17 risk agents and using tools such as ARP and Pareto analysis, this study clearly shows which risks require attention first.

In comparison, M.A.T Dvaipayana et al. (2024) identified 26 risk events and 21 risk agents, with 10 risk agents selected as risks to be mitigated. Using Fuzzy-AHP, the study proposed best five mitigation actions: auditing every result of recording data on sales, materials, fleet, and production; ensuring that the production department understands the SOP and concrete production flow; tracking each delivery fleet to monitor the real-time location; periodic checking and repairing of production machines or fleet machines; and applying 5S in material and concrete production. This study provides more specific actions to prevent errors in planning material requirement stocks and pay attention to the financial aspect.

Compared to other study by Ahmad and Susanty (2019) which identified 17 risk agents and three were selected as priorities to be mitigated: unbalanced project progress with material delivery, limited availability of transportation modes and the supplier in fluctuating production. Meanwhile the study by Hoi-Lam Ma and Wai-Hung (2018) identified 20 risk agents and 10 risks agents were selected as priorities to be mitigated, three risk agents with highest ARP: inaccurate information exchange among departments, immediate change in demand and poor quality of inward goods/materials from supplier to manufacturer. However, both studies lack specific mitigating actions, whereas this study completes the HOR-2 phase and proposes preventive actions (PA) to manage risks. Given the similar focus on material planning and supplier issues, this study provides concrete mitigation actions, such as estimating contingency reserves for unexpected costs, developing alternative payment schemes for suppliers with set terms, and building an automated system to estimate the required workforce based on work contracts.

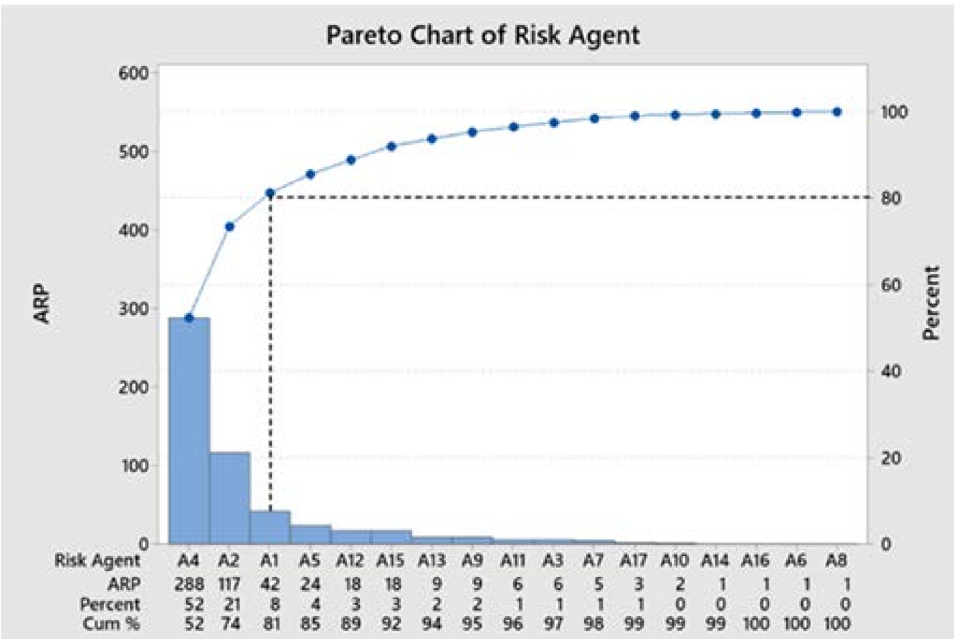

Figure 2. Pareto chart of risk agent based on ARP

Table 8. HOR Phase 2 Analysis: Ranking of Preventive Actions

Code	Risk Agent	Preventive Action (PAk)					ARPj
		PA1	PA2	PA3	PA4	PA5	
A4	Payment System Inconsistent with the Initial Contract	3	3	0	0	0	288
A2	Lack of precision in calculating material requirements	0	0	9	3	0	117
A1	Errors in work planning calculations	0	0	0	0	9	42
Total Effectiveness of action (TEk)		864	864	1053	351	378	
Degree of Difficulty Performing Action (Dk)		4	3	2	3	5	
Effectiveness to Difficulty Ratio (ETD)		216.0	288.0	526.5	117.0	75.6	
Rank of Priority		3	2	1	4	5	

Compared to the research by Wibowo and Ahyudanari (2020), which identified 14 risk events and 15 risk agents, the HOR-1 phase identified four critical risk agents: fast-changing implementation requirements, delayed payments, supplier selection issues, and material fabrication delays. The HOR-2 phase then proposed three mitigation actions: coordinating with finance to monitor supplier bills, coordinating with the production division for an accurate procurement schedule, and evaluating the supplier-selection process. While their study suggests preventive actions for priority risk agents, this paper goes further by providing detailed proactive mitigation strategies, not only focusing on coordination and evaluation but also introducing active measures, such as estimating contingency reserves for unexpected costs, developing alternative payment schemes with set terms, creating SOPs for material specifications, forecasting material prices based on price fluctuation trends, and building an automated system for workforce estimation based on work contracts.

This study offers practical implications for improving risk management practices in construction supply chains, particularly by enabling more effective resource planning, reducing delays, and minimizing cost overruns through structured and data-driven decision-making. The integration of SCOR 11.0 with the HOR method offers a robust and structured approach to supply chain risk management in construction. SCOR 11.0 provides a comprehensive process-based framework that breaks down the supply chain into five key areas: Plan, Source, Make, Deliver, and Return, enabling detailed and systematic mapping of activities where risks may arise. This granular view of the supply chain ensures that no stage is overlooked in risk identification. When combined with the HOR method, which includes HOR 1 for identifying and prioritizing risk agents based on ARP and HOR 2 for selecting the most effective preventive actions (PAs), the result is a highly efficient risk management process. The SCOR acts as an operational blueprint, whereas the HOR provides an analytical mechanism to quantify and proactively address risks. This synergy enhances the accuracy of risk detection, prioritization, and mitigation, allowing for data-driven decisions and targeted interventions that improve the overall resilience and performance of construction supply chains.

Managerial Implication

This study provides several critical insights that companies should consider when planning and managing risks in construction supply chains.

1. Comprehensive Framework: The integrated use of the SCOR model and HOR method offers a robust tool that systematically maps the entire construction supply chain, highlighting vulnerabilities across the material, labor, and financial domains.
2. Holistic Risk Assessment: By identifying 16 risk events and 17 risk agents, this study ensures that companies have a complete view of potential disruptions, enabling them to address a wide range of issues rather than focusing solely on one area.
3. Quantitative Prioritization: The use of tools such as ARP and Pareto analysis helps companies precisely prioritize which risks to tackle first, ensuring that resources are focused on the most critical threats.
4. Targeted Mitigation Strategies: This research outlines specific preventive actions, such as establishing alternative payment schemes, improving material estimation accuracy, and automating labor calculations, that companies can adopt to reduce the likelihood of costly disruptions.
5. Improved Operational Efficiency: Proactively managing risk through this comprehensive framework can lead to smoother project execution, fewer delays, and reduced cost overruns, ultimately enhancing overall operational efficiency.

6. Data-Driven Decision-Making: The quantitative approach provides clear empirical evidence for decision-making, enabling companies to allocate resources effectively and implement risk mitigation strategies based on real data.
7. Scalability and Adaptability: Although designed for the construction sector, the integrated framework can be adapted to other industries, making it a versatile tool for broader risk management applications.
8. Opportunity for Future Enhancement: This study highlights the need to simplify data collection and incorporate external factors, such as global supply chain disruptions or natural disasters, suggesting avenues for further research to refine and enhance the model's practical applicability.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In the construction supply chain, 16 risk events and 17 risk agents were identified in this study. Among these, the top-priority risk agents include payment schemes that do not align with the initial contract, inaccuracies in calculating material requirements, and errors in work planning calculations. These findings show that the most critical risks are financial management and early stage planning, which have a major impact on downstream supply chain performance. The main contribution of this study is the integration of the SCOR model with the HOR method, which provides a structured and quantitative framework for the complete detection, prioritization, and reduction of risks.

Several mitigation actions have been proposed to address these risks. First, developing standard operating procedures (SOPs) that outline clear material specifications for the tasks being performed is essential. Additionally, creating alternative funding schemes for supplier payments with specified due dates can help to manage financial risks more effectively. Contingency reserves should also be established to account for unforeseen costs and provide a buffer for unexpected expenses. To mitigate the volatility of material prices, forecasting based on historical price trends has been proposed. Finally, implementing an automated system to calculate the number of workers required for specific work contracts will streamline the labor management process and reduce errors related to workforce estimation. These strategic mitigation actions are aimed at minimizing the most critical risks in the construction supply chain, ensuring smoother project execution, and enhancing operational efficiency.

Recommendations

Future studies should include more experts to increase the robustness of the assessment, use real-time project data for dynamic risk assessment, and investigate the incorporation of digital technologies such as the Internet of Things or data analytics to improve predictive risk management. Additionally, the generalizability and efficacy of this framework will be validated by applying it to various sectors and project scales.

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