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Supply Chain Risk Modeling: An Examination of Influencing Factors and Risk Management Strategies

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ABSTRACT

Supply chains in today's business environment face numerous complexities and uncertainties that can substantially affect organizational performance and resilience. This study aimed to identify, assess, and prioritize supply chain risks using Failure Mode and Effects Analysis (FMEA) indicators and to determine the weights of these indicators through the Step-wise Weight Assessment Ratio Analysis (SWARA) method. In this study, 22 major risks were identified across five categories: supplier risks, production and operational risks, logistics and transportation risks, environmental and external risks, and technological and information risks. Data were collected from 15 supply chain experts. The results indicated that raw material shortages, delivery delays, dependence on specific suppliers, and global crises were the most influential risks affecting supply chain performance. The findings highlight the importance of resource management, delivery scheduling, supplier diversification, and the adoption of emerging technologies to mitigate risks and enhance supply chain transparency and resilience. Furthermore, the weighted prioritization of risks enables managers to allocate resources optimally and focus on the most critical threats. The results of this study can support organizations in making strategic and operational decisions when confronting uncertainty and crises.

Keywords: supply chain risk, risk management, FMEA, SWARA, resilience, risk prioritization, information technology

Introduction

Supply chains have become increasingly complex, interconnected, and geographically dispersed as organizations seek access to specialized resources, lower production costs, broader markets, and greater operational flexibility. Although these developments have enabled firms to improve efficiency and competitiveness, they have also increased exposure to a wide range of risks that can interrupt the flow of materials, information, financial resources, and finished products. Modern supply chains operate as networks of interdependent suppliers, manufacturers, logistics providers, distributors, technology platforms, and customers, meaning that disruption at one point can rapidly affect multiple organizations and processes. Consequently, supply chain risk management has evolved from a narrow operational concern into a strategic priority directly associated with organizational continuity, profitability, responsiveness, sustainability, and resilience. Organizations are therefore required not only to identify individual risks but also to understand their relative importance, interactions, propagation patterns, and potential consequences across the entire supply network (1, 2).

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Supply chain risk may be broadly understood as the possibility that an uncertain event or condition will disrupt supply chain activities and negatively affect the achievement of operational or strategic objectives. Such risks may originate within the organization, among suppliers and customers, across transportation and logistics systems, or in the broader political, economic, technological, environmental, and social environment. Traditional sources of risk include supplier failure, raw material shortages, quality problems, equipment breakdowns, inventory inaccuracies, human errors, transportation delays, demand fluctuations, and insufficient coordination. More recent developments have expanded this risk landscape to include cyberattacks, information-system failures, geopolitical instability, sanctions, pandemics, climate-related events, and disruptions associated with highly interconnected global networks. Because these risks differ in terms of probability, severity, detectability, duration, and controllability, effective management requires a structured framework capable of evaluating multiple risk dimensions simultaneously (3, 4).

Globalization has intensified both the benefits and vulnerabilities of supply chains. Firms increasingly depend on international suppliers, cross-border transportation routes, outsourced production, and globally distributed inventories. This dependence improves access to diverse resources and markets but also exposes organizations to disruptions occurring far beyond their direct control. Political tensions, border restrictions, currency instability, trade regulations, regional conflicts, and global health emergencies may interrupt production and distribution even when the focal organization itself remains operational. The COVID-19 pandemic provided a particularly clear example of how global disruption can create simultaneous shocks in supply, demand, logistics, labor availability, and financial performance. Research examining globalization and pandemic-related disruptions has shown that supply chain risks can substantially undermine operational performance when organizations lack adequate preparedness, coordination, and adaptive capacity (3). The experience of large-scale disruptions has therefore reinforced the need to move from reactive crisis management toward anticipatory, risk-based supply chain planning.

Supply chain resilience has become a central concept in this context. Resilience refers to the capacity of a supply chain to prepare for disruptions, absorb their effects, maintain essential functions, recover within an acceptable period, and adapt to changing conditions. A resilient supply chain does not necessarily avoid all disruptions; rather, it possesses the capabilities required to reduce vulnerability and restore performance. These capabilities may include supplier diversification, flexible sourcing, safety stocks, redundant capacity, alternative transportation routes, real-time information sharing, collaborative planning, and rapid decision-making. Resilience is closely linked to risk management because organizations cannot build appropriate response capabilities without first identifying and prioritizing their most significant exposures. Risk management strategies designed for supply chain sustainability and resilience must therefore integrate preventive, responsive, and adaptive measures instead of focusing exclusively on cost reduction or short-term efficiency (4).

The importance of resilience is especially evident in industries characterized by complex supplier relationships, high technological dependence, and strict delivery requirements. The automotive industry, for example, relies on extensive networks of component manufacturers and logistics providers, and even a minor disruption may suspend entire production lines. Stakeholder-oriented research in this sector suggests that resilience strategies should account for the interests, capacities, and responsibilities of multiple supply chain actors rather than treating risk as a problem belonging to a single organization. Collaborative stakeholder engagement can improve information exchange, joint problem-solving, risk visibility, and coordinated responses to disruptions (5). Such findings indicate that supply chain risk management should be approached as an interorganizational process that requires shared understanding and collective action.

An additional challenge arises from the propagation of risk across interconnected supply chain networks. A disruption rarely remains confined to its point of origin. Supplier failure may create production delays, inventory shortages, transportation rescheduling, contractual penalties, customer dissatisfaction, and reputational damage. The structure of the network and the role of individual nodes influence the extent and speed of this propagation. Research on supply chain network resilience has emphasized that different node types contribute differently to network vulnerability and recovery, and that resilience analysis should consider both the characteristics of individual nodes and their relational positions (2). Similarly, models inspired by epidemic diffusion processes have demonstrated how disruption can spread among supply chain members and how targeted interventions may help control network-wide deterioration (6). These perspectives show that risk assessment should not treat risks as completely independent events but should recognize their potential interactions and cascading effects.

Risk propagation is particularly important when organizations depend heavily on a limited number of critical suppliers. Single sourcing may reduce purchasing costs and simplify coordination, but it also creates concentrated vulnerability. When a key supplier experiences financial problems, capacity constraints, quality failures, or external disruption, the buying organization may have limited alternatives. Diversification and multi-sourcing can reduce this vulnerability, although these strategies may introduce additional costs and coordination requirements. Similar trade-offs arise in inventory management, where lean systems reduce holding costs but may increase exposure to unexpected shortages. Therefore, supply chain risk management frequently requires balancing efficiency against redundancy, responsiveness, and resilience. A suitable risk-prioritization model can assist managers in determining where additional safeguards are justified and where the consequences of disruption are sufficiently severe to warrant preventive investment.

Production and operational risks constitute another major category of concern. Equipment failure, human error, low productivity, insufficient financial resources, and poor inventory planning can reduce capacity and create bottlenecks. Manufacturing environments are composed of interdependent processes, making it difficult to evaluate the consequences of risk through intuition alone. Simulation-based approaches have been used to model disruption scenarios and prioritize risks according to their effects on system performance. Discrete-event simulation, for example, can reproduce the dynamic behavior of manufacturing supply chains and estimate the consequences of alternative disruptions and mitigation measures (7). Such methods provide detailed insights but may require substantial data, technical expertise, and modeling resources. In many organizational settings, managers require assessment techniques that remain systematic and analytically rigorous while also being feasible when data are limited and expert judgment is the primary source of information.

Logistics and transportation risks also have direct consequences for supply chain reliability. Delivery delays may result from inadequate infrastructure, congestion, customs procedures, weather conditions, labor shortages, route disruption, or poor scheduling. Because timely delivery is essential to production continuity and customer satisfaction, the ability to predict and manage late deliveries has become a major focus of supply chain analytics. Recent research has examined deep-learning approaches to predicting late delivery risk, showing the growing importance of advanced predictive methods in strengthening supply chain resilience (8). Predictive models can enable organizations to intervene before disruptions escalate; however, their effectiveness depends on data quality, information-system integration, and managerial capacity to translate predictions into action. Therefore, technological tools should complement rather than replace structured risk identification and prioritization.

Information processing is increasingly viewed as a fundamental capability in supply chain resilience. Organizations need timely, accurate, complete, and accessible information to recognize threats, coordinate responses, and adjust plans. Digital supply chains support visibility across organizational boundaries and enable faster analysis of inventory levels, supplier performance, transportation status, and emerging disruptions. Empirical evidence indicates that information-processing capabilities and digital supply chain development can strengthen resilience through more effective supply chain risk management (9). This relationship implies that digitalization creates value not merely by automating transactions but by improving the organization's ability to detect, interpret, and respond to risk.

Blockchain technology has also been proposed as a means of improving traceability, transparency, and trust among supply chain partners. Blockchain-based systems can provide shared and tamper-resistant records of transactions and product movements, potentially reducing information asymmetry and facilitating coordination. Research has shown that blockchain capabilities may contribute to improved supply chain performance through mediating organizational and operational mechanisms (10). Nevertheless, the introduction of digital technologies also generates new forms of risk, including cybersecurity threats, integration difficulties, data-governance problems, and dependence on technological infrastructure. Risk management must therefore consider both the protective value and the potential vulnerabilities of digital transformation.

Technological capabilities are similarly important in circular and sustainable supply chains. Circular supply chain models emphasize resource recovery, reuse, recycling, product-life extension, and reduced waste. These models require information sharing, traceability, coordination, and technological integration across multiple actors. A systematic review of technology-enabled circular supply chains has shown that digital and operational technologies can support the development of circular business models by improving visibility, resource efficiency, and collaboration (11). At the same time, circular systems may introduce additional complexity because materials move through reverse as well as forward flows. This complexity reinforces the need for comprehensive risk assessment frameworks that consider technological, operational, environmental, and interorganizational dimensions.

Environmental and epidemic disruptions have also stimulated research into resilient supply chain network design. Food supply chains are particularly vulnerable because disruptions may affect product availability, quality, public health, and social welfare. Research on food supply networks exposed to epidemic disruption has demonstrated the importance of network design decisions that incorporate resilience rather than focusing solely on conventional cost optimization (12). Such research highlights the need for alternative facilities, flexible capacities, and contingency planning. Although advanced optimization models can support strategic network design, organizations still need practical tools for identifying which risks deserve immediate managerial attention.

The multiplicity of supply chain risks has led to the development of various modeling and evaluation frameworks. The Supply Chain Operations Reference model has been used as a foundation for organizing risk management activities according to standardized supply chain processes. A SCOR-based modeling framework can connect risk identification with processes such as planning, sourcing, production, delivery, and return, thereby providing a structured representation of where risks arise and how they affect performance (13). Such frameworks are valuable because they link abstract risk concepts to observable operational activities. However, process-based classification alone does not determine which risks are most critical, and supplementary prioritization techniques are required.

Multi-factor modeling offers another approach by combining several indicators or dimensions of risk rather than relying on a single measure. Supply chain risks vary in their likelihood, consequences, visibility, interdependence, and strategic significance. Multi-factor models can improve managerial decision-making by integrating these dimensions into a more comprehensive assessment (1). Nevertheless, the usefulness of any multi-factor model depends on the appropriateness of the selected criteria and the method used to assign their relative importance. Treating all criteria as equally important may oversimplify expert judgments and produce rankings that do not accurately reflect organizational priorities.

Failure Mode and Effects Analysis is one of the most widely used methods for structured risk assessment. FMEA identifies potential failure modes and evaluates them using severity, occurrence, and detectability. Traditionally, these three indicators are multiplied to calculate a Risk Priority Number. The method is attractive because it is systematic, understandable, and applicable across manufacturing, operations, quality management, and supply chain contexts. However, conventional FMEA has several limitations. Different combinations of severity, occurrence, and detectability can produce identical scores even when their managerial implications differ. Moreover, equal weighting assumes that severity, occurrence, and detectability contribute equally to risk importance. In many supply chain situations, the consequences of disruption may be more important than detectability, or frequent moderate events may demand greater attention than rare severe events. Therefore, modified FMEA methods are needed to reflect expert priorities more accurately.

Multi-criteria decision-making techniques can address this limitation by determining differentiated weights for risk indicators. The Step-wise Weight Assessment Ratio Analysis method is particularly suitable when expert judgment is central to the decision process. SWARA requires experts to rank criteria and evaluate the relative importance of each criterion compared with the preceding criterion. This stepwise process produces normalized weights that represent the experts' collective assessment of criterion importance. Combining SWARA with FMEA can therefore improve risk prioritization by preserving the practical structure of FMEA while overcoming the equal-weight assumption.

The relevance of integrated risk-modeling approaches has also been demonstrated in sector-specific research. In the automotive parts supply chain, fuzzy cognitive mapping and interpretive structural modeling have been applied to evaluate, rank, and examine relationships among risks (14). This line of research confirms that supply chain risks are interrelated and that prioritization can support more targeted mitigation strategies. In project-oriented and industrial settings, risk management has also been linked to supply chain and project success. Evidence from Iran's defense industries indicates that risk management and green supply chain practices can contribute to project outcomes, emphasizing the strategic importance of integrating risk considerations into organizational decision-making (15).

Despite the growing literature on supply chain risk, several practical and methodological gaps remain. Many studies focus on one category of risk, one industrial context, or one advanced modeling technique. Others emphasize resilience strategies without providing a transparent mechanism for ranking a diverse set of operational, logistical, environmental, technological, and supplier-related threats. Highly sophisticated models may also be difficult to implement in organizations that lack extensive historical data or specialized analytical infrastructure. Expert-based methods remain particularly valuable in these contexts because experienced managers and specialists can identify emerging risks that are not yet represented in formal databases.

A comprehensive framework should therefore combine qualitative exploration with quantitative prioritization. Qualitative analysis enables researchers to capture context-specific risks through the experiences and judgments of supply chain experts. It is especially useful for identifying risks that are complex, emerging, or difficult to measure directly. Quantitative assessment subsequently enables comparison, weighting, and ranking. The combination of thematic analysis, FMEA, and SWARA can provide a coherent sequence in which risks are first extracted from expert knowledge, then evaluated according to established FMEA indicators, and finally prioritized using weights that reflect the actual importance assigned to those indicators.

Such an integrated approach offers several managerial advantages. First, it creates a structured inventory of risks across multiple supply chain domains. Second, it reduces the possibility that managers will focus exclusively on highly visible problems while overlooking severe but less frequent threats. Third, weighted prioritization facilitates the allocation of limited financial, technological, and human resources. Fourth, the resulting rankings can inform supplier development, inventory planning, maintenance programs, logistics redesign, cybersecurity investment, regulatory monitoring, and contingency planning. Finally, the framework can contribute to resilience by directing attention toward the risks most likely to undermine continuity and recovery.

Accordingly, the aim of the present study was to identify, evaluate, weight, and prioritize supply chain risks through an integrated framework combining thematic analysis, Failure Mode and Effects Analysis, and the Step-wise Weight Assessment Ratio Analysis method.

Methods and Materials

The present study employed a mixed-methods design comprising qualitative and quantitative phases. In the first phase, a qualitative approach, particularly thematic analysis, was used to identify the principal supply chain risks. The study population consisted of experts in supply chain management, risk management, and related academic fields. Participants were selected through purposive sampling. Ultimately, 15 experts with academic or professional experience in supply chain and risk management were selected as the study sample. Data were collected through semi-structured interviews. Following full transcription, the interview data were analyzed through open, axial, and selective coding, and the principal themes associated with supply chain risks were extracted. In the second phase, the identified risks were assessed using the FMEA approach. This method is based on three principal indicators: severity (S), occurrence probability (O), and detectability (D). In conventional FMEA models, these indicators are assumed to have equal weights. However, to improve analytical accuracy, the SWARA method was used in this study to determine the weight of each indicator. In this process, the 15 participating experts prioritized the indicators according to their perceived importance. The relative importance of each indicator compared with the preceding indicator was then determined, after which the adjustment coefficients and final weights of the indicators were calculated.

In the third phase, a modified risk priority score was calculated for each identified risk factor. This score was determined based on the experts' evaluations of the risks and the indicator weights obtained through the SWARA method. The risks were subsequently ranked, and the most critical threat domains within the supply chain were identified. To establish the credibility of the findings, member checking and inter-rater agreement assessment were employed. Accordingly, the present study developed an integrated framework for identifying, assessing, and ranking supply chain risks that can be practically applied by managers and decision-makers.

Findings and Results

A qualitative thematic analysis was conducted to identify the risks affecting the supply chain. For this purpose, 15 experts in supply chain management, risk management, and related industries were selected as research participants. Data were collected through semi-structured interviews. During the interviews, questions were posed regarding challenges, threats, and risk-generating factors across different supply chain processes, and the experts presented their perspectives. The data analysis process was conducted in three stages: open, axial, and selective coding. During open coding, all statements and sentences related to risks were extracted and treated as initial codes. During axial coding, similar and overlapping codes were organized into intermediate categories. During selective coding, the intermediate categories were organized under overarching themes representing the major dimensions of supply chain risk.

Based on thematic analysis and a review of the theoretical literature, five major categories of risks were identified: supplier risks, production and operational risks, logistics and transportation risks, environmental and external risks, and technological and information risks. Each category comprised several subthemes. A detailed description of these categories is presented below.

Supplier risks: Suppliers constitute one of the most important sources of supply chain risk. These risks range from raw material shortages or unavailability to poor quality and failure to fulfill contractual obligations. Raw material shortages may result from market crises, problems experienced by upstream producers, or political and trade restrictions, ultimately disrupting the entire supply chain. Excessive dependence on one or several specific suppliers also increases supply chain vulnerability because any disruption affecting those suppliers directly influences the flow of materials. Furthermore, the poor quality of raw materials and suppliers' failure to comply with relevant standards impose additional costs and rework on the organization and negatively affect customer trust. In addition, failure to fulfill commitments and delays in dispatching orders can disrupt production processes and lead to customer dissatisfaction.

Production and operational risks: Due to their complex and dynamic nature, production and operational activities are exposed to several risks. Machinery defects and breakdowns can halt production lines, reduce production capacity, and increase maintenance and repair costs. Human error, particularly in environments in which processes are performed manually, represents another serious threat that can reduce productivity and cause potentially irreparable losses. Low resource utilization efficiency is also a major challenge and is generally associated with ineffective management, a lack of advanced technologies, or obsolete equipment. Moreover, insufficient financial resources restrict an organization's ability to invest in process improvement and ultimately weaken its competitiveness. Ineffective inventory management and inadequate planning can also result in material and product shortages or surpluses, both of which can be detrimental.

Logistics and transportation risks: Logistics and transportation, as the backbone of the supply chain, are consistently exposed to significant risks. Delivery delays caused by infrastructure deficiencies, weather conditions, or managerial shortcomings can negatively affect the organization's overall planning and customer service levels. Transportation infrastructure problems, including inadequate roads, customs restrictions, and equipment shortages, can disrupt the smooth flow of goods. In addition, high distribution costs resulting from rising fuel prices, transportation tariffs, or inefficient distribution networks can directly affect organizational profitability. Disruptions to transit routes, particularly during political crises or natural disasters, can also cause prolonged interruptions in supply and distribution.

Environmental and external risks: Environmental and external risks are often beyond the direct control of organizations, yet they can exert substantial effects on supply chains. Market fluctuations and sudden changes in the prices of raw materials or products can challenge organizational planning and budgeting. Sudden shifts in demand, particularly in consumer goods and perishable-product industries, complicate inventory management and may lead to shortages or surpluses. Global crises, such as pandemics and wars, are prominent examples of external risks capable of halting entire supply chains. Sanctions and political restrictions are additional significant factors in countries such as Iran, where they restrict access to markets and resources. Furthermore, continuous changes in laws and regulations, particularly in taxation, environmental protection, and trade, increase uncertainty in the planning and execution of organizational activities.

Technological and information risks: In the contemporary era, in which technology and information play central roles in supply chain management, technological and information risks have become particularly important. Weaknesses in information systems may delay data processing, produce decision-making errors, and cause poor coordination among organizational units. Cyberattacks also constitute serious threats to the confidentiality, integrity, and availability of data and can cause substantial financial and reputational losses. A lack of data transparency and the presence of incomplete or contradictory information represent additional challenges that hinder accurate planning and evidence-based decision-making. Finally, difficulties in tracking goods due to the absence of technological infrastructure, such as radio-frequency identification (RFID) and the Internet of Things (IoT), can reduce supply chain transparency and increase the risks of fraud or loss of goods.

Table 1. Identified Supply Chain Risks

Major Risk Category	Subrisks
Supplier risks	Raw material shortages
	Dependence on a specific supplier
	Failure to fulfill commitments
	Poor raw material quality
Production and operational risks	Machinery defects
	Human errors
	Low productivity
	Insufficient financial resources
	Ineffective inventory management
Logistics and transportation risks	Delivery delays
	Transportation infrastructure problems
	High distribution costs
	Disruptions to transit routes
Environmental and external risks	Market fluctuations
	Sudden changes in demand
	Global crises
	Sanctions and political restrictions
	Changes in laws and regulations
Technological and information risks	Weak information systems
	Cyberattacks
	Lack of data transparency
	Difficulty tracking goods

In this study, the indicators of Failure Mode and Effects Analysis (FMEA), comprising severity, occurrence probability, and detectability, were used to assess and rank the identified supply chain risks. However, one of the principal challenges associated with FMEA is that these three indicators are commonly assigned equal weights, although their relative importance may differ according to expert judgments and the specific characteristics of the supply chain. Therefore, the SWARA method, an expert judgment-based multi-criteria decision-making technique, was used to determine the weight of each indicator.

The SWARA method is based on the participation of a group of experts and their subjective prioritization of evaluation indicators. In the present study, 15 experts and managers associated with supply chain activities were selected as the study sample. These participants included procurement managers, production managers, logistics specialists, information technology specialists, and risk management experts. They were selected based on criteria such as professional experience, academic expertise, and familiarity with the company's supply chain.

Initially, the experts prioritized the indicators according to their relative importance. Analysis of their judgments demonstrated that severity (S) was considered the most important indicator because the magnitude of the damage caused by a risk event has the greatest effect on supply chain stability and efficiency. Occurrence probability (O) was ranked second because it represents the likelihood that a particular risk will materialize. Detectability (D) was ranked last because, although the ability to identify a risk before it occurs is essential, the experts considered it less influential in strategic decision-making.

After establishing the priority order, the experts determined the relative importance of each indicator compared with the preceding indicator. The relative importance value was set at 0.25 for the second indicator, occurrence probability, and 0.40 for the third indicator, detectability. These values represent the differences in importance between each indicator and the preceding higher-ranked indicator and were used to calculate the adjustment coefficients.

Based on the formula (K_j = S_j + 1), the adjustment coefficients were calculated as 1.00 for severity, 1.25 for occurrence probability, and 1.40 for detectability. The adjusted weighting coefficients ((Q_j)) were then calculated. For the first and most important indicator, (Q_1) was set equal to 1.00, whereas the values of the subsequent indicators were calculated by dividing the preceding (Q) value by the corresponding adjustment coefficient.

Finally, the relative weight of each indicator was obtained by dividing its (Q_j) value by the sum of all (Q_j) values. These weights represented the contribution of each indicator to the overall risk assessment. The final weights were as follows: severity (S) = 0.45, occurrence probability (O) = 0.36, and detectability (D) = 0.19. These weights indicate that the experts placed the greatest emphasis on the magnitude of damage caused by the risks. Consequently, risks with severe consequences were assigned higher management priority. Occurrence probability, with a weight of 0.36, had a moderate level of importance, whereas detectability, with a weight of 0.19, had the smallest influence on the final assessment.

Table 2. Weights of the FMEA Indicators

Indicator	Priority	Relative Importance	Adjustment Coefficient	Relative Weight	Final Weight
Severity	1	—	1.00	1.000	0.45
Occurrence probability	2	0.25	1.25	0.800	0.36
Detectability	3	0.40	1.40	0.571	0.19

Following the identification of the major and secondary supply chain risks and the weighting of the FMEA indicators using the SWARA method, the next stage involved determining risk priorities to identify which risks posed the greatest threats to supply chain performance and sustainability. In this study, each risk was rated by 15 experts based on severity, occurrence probability, and detectability. The priority of each risk was subsequently calculated using the weights obtained through the SWARA method. The application of weights ensured that the actual contribution of each indicator to risk prioritization was considered, thereby producing a more accurate and realistic analysis.

Table 3 presents the weighted priorities of the 22 identified supply chain risks. As shown in the table, raw material shortages had the highest weighted priority score of 8.62 and were therefore identified as the most critical supply chain risk. This risk received a very high severity score and a considerable occurrence probability score, indicating that its occurrence could severely disrupt the performance of the entire supply chain.

Delivery delays and dependence on a specific supplier had weighted priority scores of 7.79 and 7.87, respectively, and were placed in the next positions. These findings demonstrate the importance of delivery-time management and supplier diversification in reducing supply chain vulnerability. Risks related to suppliers' failure to fulfill commitments and poor raw material quality were ranked fourth and fifth, emphasizing the importance of continuously monitoring and evaluating supplier performance and implementing raw material quality-control procedures.

Global crises and machinery defects also received high priority scores and therefore require preventive measures and continuous risk mitigation programs. Other risks, including cyberattacks, disruptions to transit routes, and sanctions and political restrictions, were among the 10 highest-ranked risks. This result demonstrates the influence of technological, logistical, and environmental factors on supply chain sustainability. These risks highlight the importance of designing information security mechanisms, managing transit routes, and monitoring political and economic conditions.

From a managerial perspective, risks such as human errors, transportation infrastructure problems, insufficient financial resources, and market fluctuations occupied the middle ranks. Although their priority was lower than that of the critical risks, they still require monitoring and risk mitigation programs to reduce their cumulative effects on supply chain performance.

Risks such as difficulty tracking goods, weak information systems, changes in laws and regulations, ineffective inventory management, and low productivity were ranked lower. Nevertheless, given their potential effects on supply chain efficiency and transparency, management should also consider these risks and implement appropriate preventive measures.

Overall, the findings presented in Table 3 indicate that raw material shortages, delivery delays, dependence on a specific supplier, and global crises constitute the most important supply chain threats and should therefore receive the primary attention of managers. Weighted prioritization enables managers to allocate limited resources optimally for risk reduction and make strategic decisions based on realistic and data-driven analyses. This analysis also facilitates the targeted implementation of supply chain risk mitigation programs in accordance with the actual importance of the risks and contributes to strengthening supply chain resilience in the face of crises.

Table 3. Ranking of Supply Chain Risks

Rank	Risk	Severity	Occurrence Probability	Detectability	Weighted Priority
1	Raw material shortages	9.2	8.7	7.1	8.62
2	Delivery delays	7.5	9.0	6.2	7.79
3	Dependence on a specific supplier	8.5	7.8	6.5	7.87
4	Failure to fulfill commitments	8.0	7.5	6.0	7.44
5	Poor raw material quality	7.5	6.8	6.2	7.00
6	Global crises	8.5	6.0	6.0	7.13
7	Machinery defects	8.2	6.4	5.1	6.96

8	Cyberattacks	8.0	5.3	6.0	6.65
9	Disruptions to transit routes	7.0	6.8	5.5	6.64
10	Sanctions and political restrictions	8.0	5.5	5.5	6.63
11	Human errors	7.0	6.5	5.5	6.54
12	Transportation infrastructure problems	6.8	6.5	5.5	6.45
13	Insufficient financial resources	7.3	6.0	5.2	6.43
14	Market fluctuations	6.5	7.0	5.2	6.43
15	Sudden changes in demand	6.4	7.2	5.0	6.42
16	Lack of data transparency	7.5	5.5	5.5	6.40
17	Difficulty tracking goods	7.2	5.8	5.0	6.28
18	Weak information systems	7.0	6.0	5.0	6.26
19	Changes in laws and regulations	7.2	5.8	5.2	6.32
20	Ineffective inventory management	7.0	5.8	5.0	6.19
21	Low productivity	6.8	6.2	5.0	6.24
22	High distribution costs	6.5	6.0	5.0	6.04

Discussion and Conclusion

The present study sought to identify, assess, and prioritize the principal risks affecting supply chain performance through an integrated framework combining qualitative thematic analysis, Failure Mode and Effects Analysis (FMEA), and the Step-wise Weight Assessment Ratio Analysis (SWARA) method. The qualitative findings identified 22 risks organized into five major categories: supplier risks, production and operational risks, logistics and transportation risks, environmental and external risks, and technological and information risks. The quantitative analysis further demonstrated that severity was the most influential FMEA indicator, with a weight of 0.45, followed by occurrence probability with a weight of 0.36 and detectability with a weight of 0.19. Among the identified risks, raw material shortages received the highest weighted priority score. Dependence on a specific supplier, delivery delays, failure to fulfill commitments, poor raw material quality, global crises, machinery defects, cyberattacks, disruptions to transit routes, and sanctions and political restrictions were also ranked among the most critical threats. These findings suggest that supply chain vulnerability is not attributable to a single operational weakness but emerges from the interaction of sourcing, production, logistics, environmental, and technological factors.

The identification of raw material shortages as the most critical risk indicates that continuity of supply remains one of the most fundamental determinants of supply chain stability. A shortage of essential materials can immediately reduce production capacity, delay customer orders, increase procurement costs, and create cascading disruptions throughout downstream operations. This finding is consistent with the broader supply chain risk literature, which emphasizes that disruptions originating at supplier or resource nodes can propagate rapidly through interconnected networks and affect multiple stages of production and distribution (2, 6). Xue et al. demonstrated that supply chain resilience depends not only on the existence of disruption but also on the type and structural importance of the affected node. Accordingly, raw material suppliers often represent critical upstream nodes whose failure can generate disproportionate consequences across the network (2). Similarly, the risk-propagation approach developed by Liang et al. suggests that disturbances can spread through supply chain relationships in a manner comparable to contagion, particularly when firms lack sufficient buffers, alternative sourcing arrangements, or network control mechanisms (6).

The high ranking of dependence on a specific supplier further reinforces the importance of upstream concentration risk. Reliance on a limited supplier base may create operational efficiency under stable conditions, but it substantially increases vulnerability when a key supplier experiences financial distress, production failure, quality problems, political restrictions, or transportation disruption. The result aligns with research emphasizing the importance of network redundancy, stakeholder coordination, and flexible sourcing as foundations of supply chain resilience (4, 5). Han and Um argued that risk management strategies should be closely integrated with sustainability and resilience capabilities because organizations must be able to absorb disruptions and maintain critical functions rather than merely optimize routine performance (4). Likewise, the stakeholder perspective adopted by Jum'a et al. indicates that effective resilience strategies require coordination among suppliers, manufacturers, logistics providers, and other actors whose decisions jointly determine the capacity of the supply chain to respond to threats (5). The present finding therefore implies that supplier diversification, collaborative supplier development, and continuous supplier evaluation are essential measures for reducing concentration-related vulnerability.

Delivery delays were also identified as one of the highest-priority risks. This result reflects the central role of time reliability in modern supply chains, particularly in systems characterized by lean inventory, just-in-time production, and tightly coordinated distribution schedules. Delayed delivery can interrupt production, increase inventory imbalance, reduce customer service quality, and generate contractual or reputational consequences. The importance of this risk is supported by Douaioui et al., who emphasized the value of predictive approaches for identifying late-delivery risks and improving supply chain resilience (8). Their use of deep-learning methods demonstrates that late delivery is not merely a transportation issue but a complex outcome influenced by interacting operational, logistical, and informational variables. The present study complements that perspective by showing that delivery delay remains a major managerial concern even when assessed through expert-based risk prioritization. Thus, organizations should combine predictive analytics with operational interventions such as improved scheduling, carrier evaluation, route diversification, and real-time shipment monitoring.

Failure by suppliers to fulfill commitments and poor raw material quality were ranked immediately after the most critical risks. These results indicate that supplier risk is multidimensional and includes not only material availability but also reliability, compliance, and quality consistency. Failure to fulfill commitments can cause production instability and undermine long-term collaboration, whereas poor-quality inputs may increase inspection costs, rework, waste, product failure, and customer dissatisfaction. A SCOR-based perspective supports the need to locate these risks within sourcing and production processes and to connect risk assessment with standardized supply chain activities (13). The SCOR framework is particularly relevant because it links supplier performance, procurement, manufacturing, delivery, and return processes within a unified structure. The present findings suggest that risk identification should therefore be integrated with supplier performance metrics and operational process monitoring rather than treated as an isolated managerial exercise.

Global crises were also assigned a high weighted priority, confirming the continuing importance of external disruptions in contemporary supply chain management. Pandemics, geopolitical conflicts, financial shocks, and international trade restrictions can simultaneously affect supply, demand, labor availability, transportation, and access to markets. The high priority assigned to global crises is consistent with evidence showing that globalization increases supply chain exposure to disruptions occurring beyond organizational and national boundaries (3). Duong et al. showed that globalization and the COVID-19 pandemic significantly shaped the relationship between risk and supply chain performance, underscoring the need for firms to strengthen preparedness for large-scale and systemic disruptions (3). Research on epidemic-prone food supply chains similarly indicates that resilience must be incorporated into network design through flexible capacity, alternative facilities, and contingency planning (12).

Therefore, the current finding supports a shift from locally focused operational risk management toward scenario-based planning that addresses globally transmitted shocks.

Sanctions and political restrictions were also ranked among the 10 most important risks. This result is particularly meaningful in settings where access to international suppliers, technologies, financial systems, or transportation networks may be constrained by political conditions. Such restrictions can increase procurement costs, lengthen lead times, reduce supplier options, and create uncertainty in contractual and investment decisions. Although external political risks may be difficult for individual firms to control, their consequences can be mitigated through supplier localization, market diversification, strategic inventory, contractual flexibility, and the development of alternative financial and logistical channels. The findings are also compatible with the broader argument that supply chain risk management must account for contextual and country-specific factors rather than relying exclusively on generic risk lists (1). Multi-factor modeling is especially useful in such environments because it enables organizations to integrate political, economic, operational, and technological dimensions into a unified evaluation framework (1).

Machinery defects were the highest-ranked production and operational risk, demonstrating that internal operational continuity remains essential even when supplier and environmental risks receive substantial attention. Equipment breakdowns can stop production lines, reduce capacity utilization, increase maintenance expenses, and delay order fulfillment. The prominence of machinery failure is consistent with simulation-based research showing that manufacturing disruptions can significantly affect overall supply chain performance and that risk prioritization should consider dynamic interactions between production processes and downstream activities (7). Chari et al. illustrated the value of discrete-event simulation for examining how manufacturing risks influence system performance under different disruption scenarios (7). The present study supports this conclusion but offers a more accessible expert-based approach that may be applied when detailed operational data required for simulation are unavailable.

Human errors, low productivity, insufficient financial resources, and weak inventory management were placed in the middle or lower sections of the ranking. Their comparatively lower scores should not be interpreted as evidence that they are unimportant. Rather, their effects may be more gradual, localized, or manageable than the consequences of major material shortages or external crises. Human error can still contribute to quality problems, accidents, inaccurate data, and operational inefficiencies. Financial constraints can limit investment in maintenance, technology, supplier development, and resilience. Weak inventory management may intensify both shortages and excess stock. These risks may also interact with higher-ranked risks. For instance, poor inventory planning can worsen the effects of a supply interruption, while inadequate financing may prevent the organization from developing alternative suppliers. The modeling work of Ershadi et al. similarly indicates that supply chain risks are structurally interrelated and should be evaluated not only by their isolated importance but also by their influence on other risks (14).

Cyberattacks received a high priority score, highlighting the growing strategic importance of technological and information risks. As supply chains become more digitally integrated, organizations increasingly depend on enterprise systems, cloud platforms, communication networks, automated equipment, and shared data. Cyberattacks can interrupt operations, compromise confidential information, manipulate records, and undermine stakeholder trust. The significance of this finding aligns with research showing that digital supply chain capabilities and information-processing capacity contribute to resilience through improved risk management (9). Digitalization can strengthen visibility and responsiveness, but it also creates technological dependencies that must be protected. Therefore, digital supply chain development should be accompanied by cybersecurity governance, access controls, backup systems, incident-response procedures, and continuous employee training.

The finding that weak information systems, limited data transparency, and difficulty tracking goods remained meaningful risks also supports the importance of information quality in supply chain management. Incomplete, delayed, or inconsistent information can impair planning, prevent early risk detection, and reduce coordination among supply chain actors. Blockchain and related technologies have been proposed as mechanisms for increasing transparency, traceability, and trust in supply chain relationships (10). Rashid et al. showed that blockchain can influence supply chain performance through mediating operational and organizational mechanisms (10). Similarly, technology-enabled circular supply chains depend on accurate information exchange and product traceability across forward and reverse material flows (11). The current results therefore suggest that investment in digital traceability systems, integrated databases, RFID, IoT technologies, and blockchain-based records may reduce information asymmetry and improve the detectability and management of supply chain risks.

The weighting results provide an additional contribution to the interpretation of the findings. Severity received the largest weight, followed by occurrence probability and detectability. This indicates that experts placed greater emphasis on the consequences of risk events than on the organization's ability to detect them. Such a weighting structure is reasonable in supply chain environments where highly severe disruptions can create extensive financial, operational, and reputational damage even when their probability is moderate. It also demonstrates the limitation of conventional FMEA models that assign equal importance to severity, occurrence, and detectability. By incorporating SWARA, the present study produced weights reflecting expert judgment and organizational context. This approach is compatible with multi-factor risk modeling, which argues that risk assessment should integrate several dimensions while recognizing their unequal influence on decision-making (1).

The findings also reveal that the supply chain risks with the highest priority originated from different categories. Raw material shortages and dependence on specific suppliers represented supplier risks; delivery delays represented logistics risk; machinery defects represented operational risk; global crises and sanctions represented external risk; and cyberattacks represented technological risk. This distribution confirms that supply chain resilience cannot be achieved through a single intervention. A firm may strengthen supplier relationships but remain exposed to cyber threats, transportation disruption, or geopolitical instability. Effective resilience therefore requires a portfolio of preventive, adaptive, and recovery-oriented capabilities (4). It also requires the coordination of risk management with sustainability and strategic performance objectives. Research in Iranian industrial settings has similarly demonstrated that risk management and green supply chain practices can contribute to project success and broader organizational outcomes (15). Accordingly, supply chain risk management should be embedded in strategic planning rather than treated solely as an operational or compliance function.

Overall, the results support the use of an integrated qualitative and quantitative framework for supply chain risk assessment. Thematic analysis enabled the extraction of contextually relevant risks from expert knowledge, FMEA provided a structured evaluation based on severity, occurrence, and detectability, and SWARA differentiated the importance of the assessment criteria. This combination addresses the practical need for a transparent and understandable prioritization method while avoiding the equal-weight limitation of conventional FMEA. The findings are consistent with previous studies emphasizing risk propagation, resilience strategies, digital capabilities, process-based modeling, and multi-factor assessment (2, 6, 9, 13). The resulting rankings can help decision-makers distinguish critical threats from lower-priority issues and allocate resources according to the relative magnitude of supply chain vulnerability.

The present study had several limitations. First, the risk identification and weighting processes were based on the judgments of 15 experts; although these participants possessed relevant academic and professional experience, the relatively small sample may limit the generalizability of the results. Second, expert evaluations are inherently subjective and may be influenced by individual experience, organizational position, or familiarity with particular categories of risk. Third, the study assessed risks at one point in time, whereas supply chain risks and their relative importance can change rapidly in response to technological, political, economic, or environmental developments. Fourth, the analysis focused on the prioritization of individual risks and did not quantitatively model causal interactions or cascading effects among them. Finally, the weighted priority scores were not validated using longitudinal organizational performance data or observed disruption outcomes.

Future studies should replicate the proposed framework with larger and more diverse expert samples drawn from different industries, geographical regions, and organizational levels. Comparative research could examine whether the weights assigned to severity, occurrence, and detectability vary across manufacturing, healthcare, food, automotive, energy, and service supply chains. Researchers should also integrate causal modeling, network analysis, simulation, or system dynamics to investigate interactions and propagation pathways among risks. Longitudinal studies could evaluate how risk priorities change over time and whether the implementation of mitigation strategies improves operational performance and resilience. Future research could additionally compare SWARA-FMEA with alternative multi-criteria decision-making approaches and validate risk rankings against historical disruption data, financial losses, delivery performance, and recovery duration.

Managers should use the risk rankings to direct immediate attention toward raw material availability, supplier dependence, delivery reliability, global disruption preparedness, and cybersecurity. Organizations should diversify critical suppliers, establish backup sourcing agreements, maintain appropriate safety stocks, monitor supplier quality and commitment, and develop alternative transportation routes. Preventive maintenance programs should be strengthened to reduce machinery-related disruption, while information systems should support real-time visibility, shipment tracking, and early-warning indicators. Managers should periodically reassess risk scores because changes in markets, regulations, technologies, and political conditions can alter risk priorities. The proposed framework should be incorporated into regular strategic and operational review processes so that resource allocation, contingency planning, and resilience initiatives remain aligned with the most significant and current supply chain threats.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adheried in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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