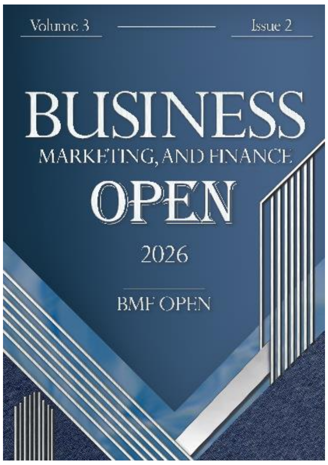
Developing a Qualitative Model for Crisis Prediction and Management in Inter-Industry Supply Chains

Davod Ojaghi [1], Shadi Shahverdiani [2,*], Artin Beytari [3] and Sara Yousefzadeh [4]

[1] Department of Accounting, ShQ.C., Islamic Azad University, Shahr-e-Qods, Iran;
[2] Department of Accounting, ShQ.C., Islamic Azad University, Shahr-e-Qods, Iran;
[3] Department of Accounting, ShQ.C., Islamic Azad University, Shahr-e-Qods, Iran;
[4] Department of Accounting, ShQ.C., Islamic Azad University, Shahr-e-Qods, Iran;

* Correspondence: Shadishahverdiani@iau.ac.ir



Citation: Ojaghi, D., Shahverdiani, S., Beytari, A., & Yousefzadeh, S. (2026). Developing a Qualitative Model for Crisis Prediction and Management in Inter-Industry Supply Chains. *Business, Marketing, and Finance Open*, 3(2), 1-17.

Received: 15 October 2025
Revised: 11 March 2026
Accepted: 18 March 2026
Published: 30 March 2026

Abstract: In complex and interconnected industrial environments, crises can rapidly exert extensive effects on the flow of materials, information, and financial resources, and their management requires a systematic, proactive, and network-based approach. The absence of an integrated qualitative model for predicting and managing crises in inter-industry supply chains based on a dynamic network approach has become a fundamental challenge for the country's supply chain system. Therefore, the present study aimed to develop a qualitative model for crisis prediction and management in inter-industry supply chains. The research method was qualitative and based on content analysis through the systematic coding of measures and their integration into conceptual and principal components. Using a qualitative approach and content analysis, this study identified 35 key measures associated with supply chain crises and organized them into 12 conceptual components. These components were subsequently integrated into five principal components: (1) crisis and supply chain identification and analysis, (2) risk monitoring and information management, (3) crisis prediction, learning, and preparedness, (4) resilience, coordination, and crisis response, and (5) leadership, control, and post-crisis improvement. The findings indicate that effective crisis management requires inter-industry coordination, information integration, organizational learning, and network resilience. The proposed model can provide a strategic framework for improving the performance of inter-industry supply chains when confronting crises. In addition to contributing theoretically to the crisis management literature, the findings offer practical applications for managers and policymakers in designing preparedness programs and rapid-response mechanisms.

Keywords: crisis management, inter-industry supply chain, qualitative prediction, resilience, inter-industry coordination

1. Introduction

Contemporary supply chains operate as complex, interconnected, and increasingly interdependent networks in which firms, suppliers, logistics providers, financial institutions, technology platforms, public agencies, and customers are linked through continuous flows of materials, information, capital, and services. Although such connectivity can improve efficiency, specialization, responsiveness, and market reach, it also creates structural exposure to disruption. A crisis occurring in one organization, industry, geographic region, or infrastructure system may propagate rapidly through upstream and downstream relationships and generate cascading operational, financial, social, and reputational consequences. Recent research therefore conceptualizes supply chain crises not merely as isolated interruptions but as network-level events whose consequences spread through interdependencies, bottlenecks, shared resources, and critical nodes. The notion of systemically important supply chains further emphasizes that the failure of a limited number of highly connected actors or infrastructures can produce extensive ripple effects across industries and national economies [1-3]. This networked vulnerability has made crisis prediction and management a central concern of strategic management, operations management, logistics, risk governance, and industrial policy.

The growing importance of this issue reflects the increasing frequency and diversity of disruptive events. Supply chains now confront pandemics, geopolitical conflicts, sanctions, extreme weather events, cyberattacks, transportation failures, raw-material shortages, energy disruptions, financial instability, technological breakdowns, supplier insolvency, and sudden fluctuations in demand. These events may differ in origin and duration, but they commonly generate shortages, delivery delays, cost escalation, production stoppages, capacity imbalances, and uncertainty in decision-making. The COVID-19 pandemic demonstrated that disruption can simultaneously affect supply, production, logistics, workforce availability, and consumption patterns, thereby exposing weaknesses that conventional risk-management practices had often underestimated [4-6]. Research on pandemic-related disruption has also shown that crisis effects may persist beyond the initial shock because recovery is constrained by backlogs, supplier failures, transportation congestion, changing customer behavior, and uneven restoration of capacity [7-9]. Accordingly, crisis management in supply chains must encompass not only immediate response but also anticipation, continuity, recovery, adaptation, and long-term transformation.

A major source of vulnerability is the long-standing managerial emphasis on efficiency, cost minimization, lean inventories, supplier concentration, and tightly synchronized operations. These practices can generate competitive advantages during stable periods, yet they may reduce redundancy and limit the ability of supply networks to absorb shocks. Evidence indicates that excessively lean inventory systems can amplify losses when disruptions are prolonged, geographically dispersed, or simultaneous across multiple tiers [10]. This creates a fundamental tension between efficiency and resilience, because investments in safety stock, alternative suppliers, flexible capacity, and backup logistics may appear costly before a crisis but become essential once disruption occurs [11]. Humanitarian and emergency supply chains face a similar challenge, as they must combine lean principles with agility, speed, and responsiveness under conditions of urgency and resource scarcity [12]. Therefore, an effective crisis-management model should not treat efficiency and resilience as mutually exclusive objectives; rather, it should provide mechanisms through which organizations can dynamically balance cost control, responsiveness, flexibility, and continuity.

Supply chain resilience has consequently emerged as a core theoretical and practical concept in crisis management. Resilience commonly refers to the capacity of a supply chain to anticipate disruption, absorb its effects, maintain critical functions, recover operations, and adapt to altered conditions. However, resilience is not a single organizational attribute. It is generated through a combination of visibility, flexibility, redundancy, collaboration, learning, technological capability, resource reconfiguration, and coordinated decision-making. Reviews of the field indicate that resilience must be assessed through both capabilities and performance outcomes, including robustness, recovery speed, service continuity, responsiveness, and adaptive capacity [13, 14]. Empirical evidence further suggests that resilience improves organizational performance when it is embedded in strategic routines, critical dynamic capabilities, and balanced systems of measurement and control [15, 16]. Thus, resilience should be understood as a multidimensional and evolving capability rather than a static stock of resources.

The concept of supply chain viability extends this reasoning by emphasizing the survivability of intertwined supply networks under severe and prolonged disruption. While resilience often focuses on recovery toward a prior operational state, viability highlights the ability of supply networks to maintain essential functions through adaptation, structural reconfiguration, and changes in business models, products, sourcing patterns, and network relationships [17]. This distinction is particularly important in inter-industry supply chains, where disruptions in one sector may affect the availability of energy, transportation, communications, finance, health services, food, or industrial inputs in another sector. The interdependence of such systems means that the crisis-management capacity of a single organization is insufficient when critical decisions, resources, and information are distributed across multiple industries. Critical systems perspectives therefore call for a shift from firm-centered analysis toward broader network, ecosystem, and societal levels of analysis [18]. Such a shift requires an integrated model capable of representing cross-sector dependencies, systemic risks, cascading failures, and shared recovery responsibilities.

Risk identification and continuous monitoring constitute the first essential functions of such a model. Supply chain risks arise from environmental, operational, financial, technological, logistical, strategic, and relational sources. Their effects depend not only on the probability of occurrence but also on network position, exposure, substitutability, and the vulnerability of affected nodes. Studies focused on logistics and emergency supply chains have emphasized the need to identify, prioritize, and mitigate risks before they escalate into widespread crises [19, 20]. Research on relief-item distribution similarly demonstrates that inadequate transportation planning, uncertain demand, limited infrastructure, and poor coordination can seriously impair crisis response [21]. Broader reviews of supply chain risk management also highlight the importance of selecting suitable combinations of avoidance, mitigation, transfer, acceptance, and contingency strategies [22]. Nevertheless, traditional risk registers and periodic assessments are often insufficient for dynamic inter-industry networks because they do not fully capture interaction effects, rapidly changing conditions, or cascading failure pathways.

For this reason, crisis prediction increasingly depends on data integration, real-time monitoring, simulation, and predictive analytics. Big data analytics can improve manufacturing agility, operational visibility, and decision quality by enabling organizations to detect patterns, identify emerging anomalies, and respond more rapidly to changes in supply and demand [23]. Predictive analytics can strengthen resilient supply chain networks by transforming large volumes of operational data into forecasts, risk indicators, and actionable scenarios [24]. Supplier disruption studies further show that data analytics can support the identification of warning signals before supplier failure becomes operationally critical [25]. Real-time data are particularly valuable during crises because they reduce information latency and improve responsiveness across procurement, production, logistics, and customer-service functions [26]. Data-driven approaches have also been used to classify and explain supply chain problems during crises, reinforcing the importance of systematic information processing in decision support [27]. Therefore, information integration and governance should be considered central components of crisis prediction rather than merely technical support activities.

Artificial intelligence and Industry 4.0 technologies further expand the capacity to predict, interpret, and manage disruption. Artificial intelligence can support anomaly detection, demand forecasting, supplier assessment, route optimization, scenario analysis, and adaptive decision-making, particularly when crises involve large-scale uncertainty and rapidly changing data [28, 29]. AI-based simulation and intelligent prediction can also model complex interactions within supply chain systems and estimate the possible consequences of alternative managerial responses [30]. More recent research suggests that AI-driven risk management can enhance resilience in entrepreneurial and project-based supply chains by improving anticipation, resource allocation, and adaptive response [31]. However, AI adoption also introduces challenges related to data quality, transparency, organizational readiness, skills, ethics, and governance, which must be incorporated into any comprehensive model [32]. Industry 4.0 capabilities similarly contribute to resilience through connectivity, automation, visibility, and decentralized coordination, but their value depends on the organization's dynamic resource base and capacity to integrate technology with managerial processes [33, 34].

Digital twins, blockchain, and simulation technologies are particularly relevant to network-level crisis management. Digital supply chain twins create virtual representations of physical networks that can be used to simulate disruption scenarios, analyze ripple effects, and test recovery strategies before implementation [3]. Simulation-based analysis has demonstrated the value of digital models in predicting the impacts of epidemic outbreaks and identifying the timing and magnitude of supply chain disruptions [35]. Digital twins have also been applied to food retail and emergency supply chains to evaluate the effects of disruptions and support resilience planning [7, 36]. Blockchain can improve traceability, trust, and coordination by creating shared and tamper-resistant records across organizations, while agent-based analysis suggests that blockchain-supported coordination may reduce ripple effects under certain network conditions [37]. Moreover, blockchain-enabled redesign can support more circular and adaptive supply chains by improving transparency and interorganizational collaboration [38]. Yet these technologies are effective only when accompanied by appropriate governance, interoperability, shared standards, and cross-industry participation.

Technology alone cannot ensure effective crisis management because resilience is also shaped by organizational flexibility, supplier relationships, leadership, and institutional conditions. Data analytics capabilities yield stronger resilience outcomes when they are complemented by organizational flexibility and the ability to reconfigure resources [39]. Strategic supplier relationships can improve continuity and recovery, although the benefits of digital transformation depend on trust, coordination, and mutual commitment between supply chain partners [40]. Supply chain innovation may also create competitive advantage by improving responsiveness, process integration, and value creation across organizational boundaries [41]. At the institutional level, government effectiveness can strengthen the relationship between dynamic digital capabilities and supply chain resilience by providing regulatory stability, infrastructure, coordination, and public support [42]. Consequently, crisis-management models should account for both internal organizational capabilities and external governance conditions.

Coordination is especially important in inter-industry and humanitarian contexts, where multiple organizations must act under severe time pressure, incomplete information, and conflicting priorities. Resilience in food supply chains exposed to geopolitical crises depends on reorganization capabilities, cross-level adaptation, and the capacity to renew relationships and operational configurations [43]. Humanitarian supply chains similarly require collaboration among government agencies, relief organizations, donors, logistics providers, local communities, and private firms, along with sustainability-oriented enabling conditions [44]. Integrated disaster-relief network design models demonstrate that pre-positioning, transportation planning, facility location, inventory allocation, and uncertainty management must be jointly considered [45]. Crisis logistics is therefore not a secondary operational function but a strategic mechanism for sustaining response capacity, especially in contexts involving national security, public health, or armed-forces support [46]. These findings underscore the need for an interorganizational framework that specifies how information, authority, resources, and responsibilities should be coordinated before, during, and after crises.

Strategic leadership and governance provide the institutional foundation for such coordination. Crisis management requires decision structures that can operate under uncertainty, establish priorities, allocate resources, resolve conflicts, and maintain accountability. Strategic management research emphasizes that organizations need integrated planning, environmental analysis, rapid decision-making, and adaptive control to manage crises effectively [47]. Sectoral governance studies similarly show that crisis-management systems require clearly defined dimensions, components, responsibilities, and coordination mechanisms [48]. Digital transformation has also increased the importance of strategic control systems capable of combining real-time information with adaptive performance monitoring [49]. In supply chain contexts, financial arrangements and Supply Chain 4.0 capabilities can contribute to risk reduction and organizational performance when embedded in broader governance and financing structures [50]. A crisis-management framework must therefore integrate leadership, information governance, strategic control, and performance evaluation rather than treating them as separate managerial domains.

Preparedness and organizational learning are equally essential because crises often reveal weaknesses that were not visible during normal operations. Organizations that systematically document previous disruptions, conduct scenario exercises, evaluate responses, and transfer lessons across units are better positioned to improve future preparedness. Crisis management should therefore be regarded as a cyclical process involving anticipation, response, recovery, evaluation, and continuous improvement. Multi-case evidence indicates that organizations differ substantially in how they interpret disruption, mobilize resources, communicate with partners, and institutionalize lessons after crises [51]. Empirical research on risk-management practices also suggests that structured supply chain risk management can reduce disruption impacts when practices are effectively implemented and integrated across organizational functions [52]. At the same time, robust and resilient network design models demonstrate that preparedness must be translated into concrete decisions regarding capacity, sourcing, transportation, inventory, and responsiveness [53]. Thus, learning must produce actionable changes in network design and operating procedures.

Post-crisis recovery is not simply a return to normality. Severe disruption may alter customer expectations, competitive positions, stakeholder trust, and brand relationships. Qualitative evidence suggests that supply chain disruptions can affect consumer experiences and brand loyalty, especially when organizations communicate poorly or fail to maintain service continuity [54]. Recovery strategies should therefore address not only operational restoration but also reputational repair, stakeholder communication, service reliability, and confidence-building. Strategic inventory management and technological integration can further strengthen continuity and recovery in extreme climate contexts by creating buffers and improving visibility [55]. Resilient supply chain design likewise requires a portfolio of mitigation strategies, including diversification, redundancy, flexible contracts, alternative routes, and collaborative contingency plans [56]. These mechanisms enable organizations to move beyond short-term recovery toward sustained adaptation and improvement.

Despite the rapid expansion of the literature, several conceptual and practical gaps remain. Many studies focus on specific technologies, individual industries, isolated disruptions, or single dimensions of resilience. Others examine risk identification, digitalization, coordination, inventory, or recovery separately, without integrating these elements into a coherent qualitative framework. Research has also frequently adopted a firm-level or single-supply-chain perspective, whereas real crises often spread across inter-industry networks. The impact of disruptions on organizational performance has long been recognized, but the pathways through which network structure, information, leadership, resilience, and recovery interact remain insufficiently integrated [57]. Similarly, evidence on resilience and robustness confirms their value in mitigating crisis impacts, yet these concepts require clearer operational alignment with prediction, preparedness, response, and improvement processes [9]. The need for a comprehensive model is particularly evident where supply networks are characterized by strong interdependencies, limited information sharing, fragmented governance, and uneven technological capability.

Accordingly, a qualitative model for crisis prediction and management in inter-industry supply chains should integrate several complementary domains: crisis identification and supply chain mapping; environmental, operational, financial, and technological risk monitoring; information integration and data governance; qualitative prediction and scenario development; organizational learning and crisis knowledge management; supplier flexibility and logistics resilience; inter-industry coordination and trust; participatory decision-making and rapid response; crisis communication and leadership; adaptive control and continuous monitoring; management of interdependencies; and post-crisis recovery and improvement. Such integration is consistent with the view that supply chain resilience depends on the alignment of risk mitigation, robust optimization, digital solutions, collaboration, and adaptive capabilities [14]. It also reflects evidence that crisis-management effectiveness emerges from the interaction of managerial, technological, structural, and institutional mechanisms rather than from any single intervention. By organizing these mechanisms into an integrated conceptual system, a qualitative model can provide managers and policymakers with a clearer basis for evaluating preparedness, identifying capability gaps, coordinating cross-sector action, and improving network-level resilience.

Therefore, the aim of the present study was to develop a qualitative model for crisis prediction and management in inter-industry supply chains.

2. Methodology

In general, research methods in the behavioral sciences can be classified according to two criteria: the purpose of the research and the method of data collection. In terms of purpose, the present study is applied research, and in terms of method, it is descriptive and correlational. The study is descriptive because it seeks to provide an objective, realistic, and systematic description of events, occurrences, and issues associated with the research domain. Descriptive research aims to describe the conditions or phenomena under investigation. The present study is classified as applied research because it was designed to support crisis management in inter-industry supply chains. Because it does not involve access to or the use of a laboratory setting, it is also categorized as descriptive research. In terms of its nature, the study is further classified as evaluative research.

The information and data required for this study were collected through a library-based method. The information required to develop the theoretical foundations of the research, which constitutes an important stage of any research project, was obtained by consulting various academic and research centers and reviewing reputable domestic and international scientific publications, available collections of articles, reports, findings from research plans and projects, and previous research records. Relevant materials were also retrieved and used through internet searches and consultation of related websites. Content analysis was employed to analyze the information.

3. Findings and Results

This qualitative study was conducted by reviewing previous studies and research concerning crisis management in inter-industry supply chains. Conventional qualitative content analysis was used to analyze the data. The method adopted in the present study was descriptive–analytical and based on content analysis. Content analysis refers to any systematic and objective technique used to extract the characteristics of a message.

Step One: Formulating the Research Question

The figure below presents the research questions together with the parameters examined in the study.

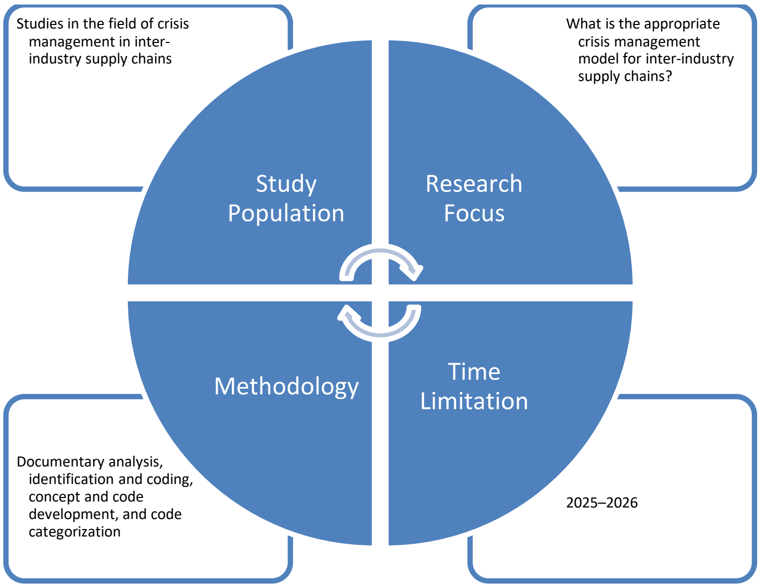


Figure 1. Research Parameters and Questions Based on the First Step of the Meta-Synthesis Method

Step Two: Systematic Review of the Literature

At this stage, all texts relevant to the objectives of the study were reviewed. Studies meeting the eligibility criteria were selected for inclusion in the meta-synthesis analysis. In meta-synthesis studies, secondary data generated through qualitative methods within the relevant research domain are used to collect research data.

Step Three: Selecting Appropriate Categories

At this stage, the researcher evaluated the quality of the retrieved sources based on the selected keywords related to crisis management in inter-industry supply chains.

Step Four: Extracting Information from the Texts

At this stage of the qualitative meta-study, or meta-synthesis, the researcher was required to select one of the nine methods associated with this approach, taking into account the nature of the subject and the collected sources. In the present study, content analysis was employed as the method for extracting information from the final selected sources.

Step Five: Analysis and Synthesis of the Qualitative Findings

In the fifth step, after information had been extracted in the preceding stage through content analysis, the qualitative findings reported in previous studies were analyzed, synthesized, and interpreted in order to provide an integrated and systematic interpretation based on a novel approach (Sandelowski & Barroso, 2007). Accordingly, all identified codes were classified into categories containing conceptually similar items. The following table presents the codes and categories using a comparative approach.

Table 1. Codes and Categories of the Research Components: First Stage

Measures	Code
Identification of crisis types	C01
Analysis of inter-industry stakeholders	C02
Supply chain mapping	C03
Assessment of node vulnerability	C04
Monitoring environmental risks	C05
Monitoring operational risks	C06
Monitoring financial risks	C07

Monitoring technological risks	C08
Information integration across industries	C09
Sharing crisis-related data	C10
Data and decision governance	C11
Qualitative predictive capability	C12
Crisis scenario development	C13
Organizational learning	C14
Documentation of previous crisis experiences	C15
Supplier flexibility	C16
Diversification of supply sources	C17
Logistics resilience	C18
Interorganizational coordination	C19
Inter-industry trust mechanisms	C20
Participatory decision-making	C21
Rapid response to disruptions	C22
Prioritization of resources during crises	C23
Supply network reconfiguration	C24
Crisis knowledge management	C25
Crisis communication	C26
Organizational preparedness culture	C27
Crisis leadership	C28
Continuous monitoring of warning indicators	C29
Adaptive control mechanisms	C30
Management of interdependencies	C31
Inter-industry synergy	C32
Post-crisis recovery	C33
Evaluation of crisis management performance	C34
Continuous model improvement	C35

Subsequently, through the integration of the indicators, the following new codes were extracted:

Table 2. Codes and Categories Based on a Comparative Approach: Second Stage

Constituent Measures	Component Title	Component Code
S01, S02, S03	Crisis identification and nature	M01
S04, S05, S06	Analysis of supply chain structure	M02
S07, S08, S09	Risk monitoring and assessment	M03
S10, S11, S12	Information integration and governance	M04
S13, S14, S15	Qualitative prediction and scenario development	M05
S16, S17, S18	Crisis learning and knowledge management	M06
S19, S20, S21	Supply flexibility and resilience	M07
S22, S23, S24	Inter-industry coordination and collaboration	M08
S25, S26, S27	Crisis decision-making and response	M09
S28, S29, S30	Crisis communication and leadership	M10
S31, S32, S33	Control, monitoring, and adaptation	M11
S34, S35	Recovery and continuous improvement	M12

Subsequently, through the integration of the indicators, the following new codes were extracted:

Table 3. Codes and Categories Based on a Comparative Approach: Third Stage

Integrated Components	Principal Component Title	Principal Component Code
M01, M02	Crisis and supply chain identification and analysis	P01
M03, M04	Risk monitoring and information management	P02
M05, M06	Crisis prediction, learning, and preparedness	P03
M07, M08, M09	Resilience, coordination, and crisis response	P04
M10, M11, M12	Leadership, control, and post-crisis improvement	P05

The network of the principal and subthemes is presented below.

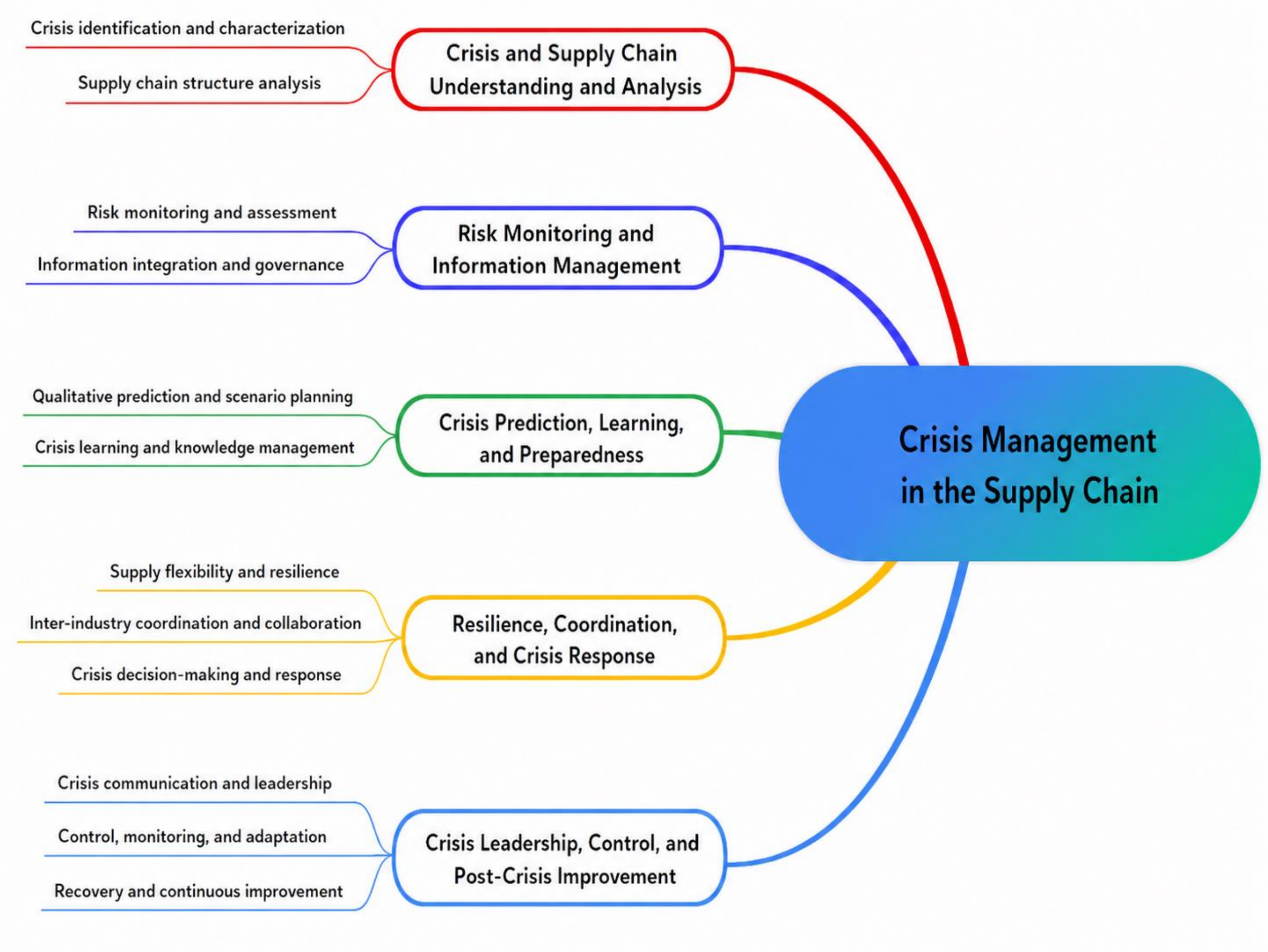


Figure 2. Network of the Principal and Subthemes of the Study

4. Discussion and Conclusion

The present study aimed to develop a qualitative model for crisis prediction and management in inter-industry supply chains. Through qualitative content analysis, 35 key measures were identified and organized into 12 conceptual components. These components were subsequently integrated into five principal dimensions: (1) crisis and supply chain understanding and analysis, (2) risk monitoring and information management, (3) crisis prediction, learning, and preparedness, (4) resilience, coordination, and crisis response, and (5) crisis leadership, control, and post-crisis improvement. The findings indicate that effective crisis management in inter-industry supply chains cannot be reduced to a single organizational capability or operational procedure. Rather, it depends on a coherent system through which industries identify threats, understand network interdependencies, monitor emerging risks, share information, anticipate alternative scenarios, coordinate responses, preserve critical operations, and institutionalize lessons after disruption. The proposed model therefore presents crisis management as a continuous and network-based process extending from pre-crisis diagnosis to post-crisis recovery and improvement.

The first principal component, crisis and supply chain understanding and analysis, consisted of crisis identification and characterization and supply chain structure analysis. This finding shows that crisis management begins with a precise understanding of both the disruptive event and the network through which its effects may spread. In inter-industry supply chains, a crisis may originate outside the focal industry and subsequently move through shared suppliers, infrastructure, transportation channels, financial relationships, or technological dependencies. Therefore, managers must identify the nature, source, scale, duration, and possible consequences of the crisis while simultaneously mapping suppliers, customers, intermediaries, critical nodes, and cross-industry dependencies. This result is consistent with the argument that supply chain disruptions produce extensive ripple effects because interconnected networks transmit operational shocks beyond the original point of failure [1, 3]. It is also aligned with systematic evidence showing that cascading failures are intensified when interdependencies and vulnerable nodes are not recognized in advance [2]. From this perspective, supply chain mapping is not merely a descriptive activity; it is an analytical mechanism for identifying concentrations of dependency, single points of failure, substitution constraints, and potential routes of crisis propagation.

The importance of structural analysis is also supported by the concept of intertwined supply network viability. Inter-industry supply chains are embedded in wider economic systems in which energy, transportation, communication, finance, healthcare, food, and manufacturing sectors depend on one another. Under severe disruption, the survival of one network may depend on the continuity of another. The viability perspective therefore extends conventional resilience by emphasizing adaptation, reconfiguration, and preservation of essential functions across interconnected systems [17]. Similarly, critical systems research argues that supply chain analysis must move beyond firm-level optimization and address systemic interactions, boundary conditions, and broader societal consequences [18]. The present finding reinforces this position by locating crisis recognition and supply chain structure analysis at the foundation of the proposed model. Without such understanding, risk monitoring may be fragmented, response priorities may be poorly defined, and resources may be allocated to visible symptoms rather than critical causes.

The second principal component, risk monitoring and information management, incorporated risk monitoring and assessment together with information integration and governance. The results suggest that effective crisis management requires a continuous flow of accurate, timely, and interpretable information across organizations and industries. In complex supply networks, environmental, operational, financial, technological, logistical, and relational risks interact dynamically. Consequently, periodic risk assessments are insufficient when conditions change rapidly and disruptions spread across multiple tiers. This result is consistent with previous studies emphasizing the need to identify and prioritize supply chain risk factors systematically, especially in logistics and emergency contexts [19, 20]. It also agrees with evidence from relief distribution systems showing that inadequate risk assessment, uncertain demand, transportation constraints, and weak coordination can undermine crisis response [21]. Therefore, the risk-monitoring function in the proposed model should be interpreted as an ongoing process rather than a one-time diagnostic stage.

The emphasis on information integration and governance is equally important. Inter-industry crisis management depends on the ability of organizations to share data across institutional boundaries while preserving data quality, access control, accountability, and decision rights. Big data analytics has been shown to improve agility and performance by enabling faster recognition of changing operational conditions [23]. Predictive analytics can also strengthen resilient supply chain networks through early warning, forecasting, and pattern recognition [24]. Likewise, supplier-disruption research demonstrates that analytical use of supply chain data can reveal warning signals before failures become critical [25]. Real-time data further enhance responsiveness by reducing delays between the emergence of a problem and managerial action [26]. These studies support the present result that information integration is not a secondary technical issue but a central governance capability. In the absence of shared and reliable information, organizations may respond inconsistently, duplicate efforts, conceal vulnerabilities, or make decisions based on incomplete representations of the crisis.

The third principal component, crisis prediction, learning, and preparedness, included qualitative prediction and scenario planning as well as crisis learning and knowledge management. This finding indicates that effective crisis management must be proactive rather than predominantly reactive. Prediction in highly uncertain environments cannot always rely on precise numerical forecasts because crises may be unprecedented, nonlinear, or shaped by ambiguous political, social, and technological conditions. Qualitative prediction and scenario planning therefore provide a practical means of exploring alternative futures, identifying plausible disruption pathways, and examining the consequences of different managerial choices. Simulation-based research has demonstrated the value of anticipating epidemic-related supply chain impacts and estimating the timing and severity of disruption [35]. Artificial intelligence-based prediction similarly supports the modeling of complex supply chain interactions and alternative scenarios [30]. Moreover, AI-driven risk-management systems can enhance preparedness by improving anomaly detection, forecasting, and resource allocation [31]. The present study extends these insights by positioning prediction alongside learning and preparedness, thereby emphasizing that forecasting tools must be embedded within organizational routines.

The inclusion of crisis learning and knowledge management further demonstrates that preparedness depends on the ability to convert previous experiences into institutional knowledge. Organizations that document disruptions, assess response failures, preserve operational lessons, and transfer knowledge across units are better positioned to anticipate future crises. Multi-case research shows that organizations differ considerably in how they interpret crisis experiences and institutionalize learning after disruption [51]. Structured risk-management practices can also mitigate disruption impacts when lessons are translated into procedures, contingency plans, and cross-functional coordination mechanisms [52]. This result is also consistent with evidence that dynamic digital capabilities and organizational flexibility jointly strengthen resilience [39, 42]. Accordingly, preparedness in the proposed model is not limited to maintaining emergency plans. It includes scenario exercises, documentation of crisis experiences, development of response competencies, and continuous revision of assumptions about network vulnerability.

The fourth principal component, resilience, coordination, and crisis response, integrated supply flexibility and resilience, inter-industry coordination and collaboration, and crisis decision-making and response. This was the broadest component in the model and reflects the operational core of crisis management. The findings indicate that supply chains must possess sufficient flexibility to substitute suppliers, reallocate inventory, alter transportation routes, adjust production capacity, and reconfigure network relationships. Such flexibility enables the network to absorb disruption and maintain essential functions. This result is consistent with resilience literature identifying flexibility, redundancy, visibility, collaboration, and recovery capability as central dimensions of supply chain resilience [13, 14]. It also agrees with empirical findings showing that resilience supports organizational continuity and performance when embedded in dynamic capabilities and strategic measurement systems [15, 16].

The findings also highlight the tension between operational efficiency and crisis resilience. Lean inventories, supplier concentration, and tightly synchronized operations may improve efficiency during stable periods but amplify losses during prolonged disruptions [10]. Consequently, crisis management requires a context-sensitive balance between efficiency and redundancy rather than an exclusive commitment to either principle [11]. The integration of lean and agile capabilities in humanitarian supply chains similarly demonstrates that efficient resource use must be combined with responsiveness and flexibility [12]. The present model supports this balanced view by incorporating both resilience and coordinated response, implying that preparedness investments should be evaluated not merely as costs but as protective capacities that preserve continuity under uncertain conditions.

Inter-industry coordination and collaboration emerged as a distinct element of the same principal component. This finding is especially significant because crisis response usually requires the simultaneous participation of suppliers, manufacturers, logistics providers, government agencies, financial institutions, emergency organizations, and local communities. Research on food supply chains exposed to geopolitical crises shows that resilience depends on reorganization capabilities and coordinated adaptation across network levels [43]. Humanitarian supply chain studies also emphasize collaboration, sustainability enablers, and shared resource mobilization during disasters and pandemics [44]. Integrated relief supply chain models similarly demonstrate that facility location, inventory allocation, transportation, and demand uncertainty must be managed jointly rather than independently [45]. These findings support the present conclusion that crisis response in inter-industry networks must be participatory, collaborative, and governed through clearly defined relationships.

The inclusion of rapid decision-making and response further indicates that coordination must result in timely action. During crises, delayed decisions can intensify shortages, increase costs, and permit disruption to spread across the network. Data-driven decision support, digital twins, and blockchain technologies can improve response quality by increasing visibility and enabling scenario testing [36, 37]. Digital supply chain twins also support the analysis of ripple effects and the evaluation of recovery strategies [3]. Nevertheless, technological systems remain dependent on organizational trust, leadership, and willingness to share information. Strategic supplier relationships and digital transformation are more effective when partners possess mutual commitment and collaborative routines [40]. Therefore, the present findings suggest that crisis response should combine technological visibility with relational coordination and clearly distributed decision authority.

The fifth principal component, crisis leadership, control, and post-crisis improvement, consisted of crisis communication and leadership, control, monitoring and adaptation, and recovery and continuous improvement. This finding demonstrates that crisis management requires sustained strategic direction before, during, and after disruption. Leaders must establish priorities, communicate decisions, manage stakeholder expectations, allocate scarce resources, and preserve coordination under uncertainty. Strategic management research has long emphasized that crisis response depends on environmental analysis, adaptive planning, rapid decision-making, and integrated control [47]. Governance research likewise indicates that effective crisis systems require clearly specified responsibilities, coordination structures, and accountability mechanisms [48]. The present model confirms these arguments and shows that leadership must be connected to monitoring and control rather than treated as an isolated behavioral capability.

Adaptive control is particularly important because predetermined plans may become ineffective as crisis conditions evolve. Digital transformation enables strategic control systems to incorporate real-time information and adjust priorities dynamically [49]. Supply Chain 4.0 capabilities and appropriate financing mechanisms can further reduce risk and improve organizational performance when they are integrated into broader managerial systems [50]. The findings therefore imply that control during crises should not be rigid. Instead, organizations need continuous monitoring, flexible performance indicators, rapid feedback loops, and authority to revise decisions. This adaptive orientation is also consistent with the role of Industry 4.0 in strengthening supply chain capability and resilience through connectivity, automation, and resource reconfiguration [33, 34].

Finally, the inclusion of recovery and continuous improvement indicates that crisis management does not end when immediate operations are restored. Recovery involves rebuilding capacity, repairing stakeholder relationships, evaluating performance, and redesigning vulnerable processes. Previous research has shown that post-pandemic recovery can be constrained by supplier failures, backlogs, demand changes, and uneven restoration of capacity [6, 8]. Disruptions may also affect customer experience and brand loyalty, demonstrating that recovery includes reputational as well as operational dimensions [54]. Strategic inventory management, technological integration, supplier diversification, and flexible network design can strengthen long-term recovery and adaptation [55, 56]. Overall, the proposed model indicates that effective crisis management is cyclical: each crisis should generate knowledge, revised controls, strengthened capabilities, and improved preparedness for future disruptions.

This study was based on qualitative content analysis of existing documentary sources, and its findings are therefore influenced by the scope, quality, and conceptual orientation of the reviewed studies. Some industry-specific practices, informal coordination mechanisms, and context-dependent crisis responses may not have been fully represented in the available literature. The qualitative integration of measures also involved interpretive judgment in coding, categorizing, and combining concepts. In addition, the resulting model was not tested empirically across particular industries, organizations, or crisis situations. Consequently, the relative importance, causal relationships, and operational feasibility of the identified components remain to be established through field-based research.

Future studies should validate the proposed model using interviews, Delphi panels, surveys, case studies, and structural modeling across different industrial sectors. Comparative research could examine whether the importance and configuration of the five principal components differ across manufacturing, energy, transportation, healthcare, food, and technology supply chains. Longitudinal studies are also needed to investigate how crisis-management capabilities evolve before, during, and after actual disruptions. Researchers should develop measurable indicators for each component and examine the causal relationships among risk monitoring, information integration, preparedness, resilience, coordination, leadership, and recovery performance. Further studies could also explore the moderating roles of environmental uncertainty, digital maturity, organizational size, governance quality, and inter-industry dependence.

Managers and policymakers should use the proposed model as a diagnostic framework for evaluating crisis-management readiness across inter-industry supply networks. Organizations should map critical dependencies, establish shared risk-monitoring systems, define data-governance protocols, conduct scenario exercises, and maintain mechanisms for documenting and transferring crisis knowledge. Supply chains should also develop alternative suppliers, flexible logistics arrangements, joint contingency plans, and clear decision-authority structures. Cross-industry crisis committees can improve communication and coordination when responsibilities extend beyond the boundaries of individual organizations. Finally, managers should conduct formal post-crisis evaluations and use the resulting lessons to revise performance indicators, response protocols, supplier strategies, and network designs continuously.

Authors' Contributions

Authors equally contributed to this article.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

Acknowledgments

Authors thank all participants who participate in this study.

Conflict of Interest

The authors report no conflict of interest.

Funding/Financial Support

According to the authors, this article has no financial support.

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