Proceedings of CONF-BPS 2026 Symposium: GenAI, Labour Markets, and the Economics of Human and Financial Capital
DOI: 10.54254/2754-1169/2026.LD31515

Multidimensional Risk Identification and Resilience Building in Global Supply Chains

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Abstract. Entering the third decade of the 21st century, global supply chains reveal considerable systemic vulnerabilities due to the cumulative effects of pandemic disruptions, geopolitical conflicts, and recurrent extreme weather phenomena. Conventional supply chain models focused on cost efficiency and lean operations encounter ongoing difficulties. This study establishes a comprehensive framework for evaluating global supply chain hazards from a multidimensional risk viewpoint, incorporating political, economic, and natural concerns. It methodically examines the initiating mechanisms, transmission routes, and interconnected impacts of each risk category. The study provides a streamlined risk assessment methodology that equips organizations with actionable analytical tools, including an indicator system and a multidimensional risk matrix, to ascertain risk exposure levels and comprehend risk structures. This study formulates a supply-chain resilience strategy system tailored for complex and uncertain situations, which is based on four essential dimensions: structural robustness, process adaptability, information-driven capability, and collaborative governance. The research demonstrates that by recognizing risks from various dimensions and integrating conceptual quantitative assessment tools, enterprises can more efficiently pinpoint critical vulnerabilities, improve supply chain resilience, and bolster their shock resistance and enduring competitive advantage in high-uncertainty contexts.

Keywords: Risk Identification, Response Strategies, Supply Chain Resilience, Supply Chain Optimization

1. Introduction

Operating within highly interconnected structures, global supply chains face cumulative systemic risks, compelling a shift from efficiency-oriented lean paradigms toward resilience. Although Supply Chain Risk Management (SCRM) research has explored diverse external risks, existing studies often adopt a fragmented and single-dimensional perspective, lacking an integrated framework that links risk sources with resilience strategies. Addressing this gap, this study develops a comprehensive framework for risk identification and assessment, and proposes a resilience strategy system aligned with political, economic, and environmental risks. The core contributions include: (1) evaluating political, economic, and environmental risks in global supply chains; (2)

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formulating a systematic risk identification and assessment methodology; and (3) proposing a risk–strategy alignment approach to support managerial decision-making for resilience enhancement.

2. Literature review

2.1. Research on supply chain risk management

As globalization intensifies, Supply Chain Risk Management (SCRM) has become crucial for coping with external disruptions. Existing research generally conceptualizes SCRM as a process encompassing risk identification, evaluation, response, and monitoring [1-3]. However, current studies still tend to address risk dimensions in isolation, lacking attention to the interdependencies among political, economic, and environmental disruptions. This gap underscores the need for a more systematic, multi-dimensional risk identification framework capable of capturing the complex interactions underlying global supply chain vulnerabilities.

2.2. Research on multidimensional risk

Multidimensional risk studies indicate that global supply chains simultaneously face political, economic, and environmental shocks with cross-border transmission and systemic propagation characteristics. Political risks originate from geopolitical conflicts, sanctions, and policy interventions, and may induce cross-regional amplification effects that threaten supply chain continuity [4]. Economic risks stem from macroeconomic volatility and market fluctuations, typically transmitting through demand, cost, and financial channels. Natural risks arise from extreme weather and climate-related events, and their increasing frequency and intensity further elevate systemic vulnerabilities in combination with other disturbances [5]. Investigation of Supply Chain Resilience Strategies

Supply chain resilience refers to a system's capacity to withstand disruptions and recover to its original or an improved state [1]. Recent research further underscores the role of digital capabilities-such as visibility, predictive analytics, and data-driven early warning systems-in enhancing resilience under complex and uncertain environments [6,7]. Accordingly, resilience solutions are shifting from reactive responses toward proactive risk mitigation.

3. Framework for multidimensional risk identification

3.1. Theoretical underpinnings of the multidimensional risk framework

The theoretical basis for multidimensional risk identification is mostly derived from systems theory and complex network theory. Drawing on systems theory and complex network theory, highly interconnected supply chains are vulnerable to external shocks that may be amplified through network effects. As a result, hazards from many sources can swiftly spread through supply chain networks, demonstrating features of cross-regional transmission and systemic collapse. This paper develops an external risk framework encompassing three dimensions—political, economic, and natural—aligned with the institutional, market, and environmental underpinnings of supply networks. The next sections will examine the triggering mechanisms and transmission paths of these three risk categories using case studies.

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3.2. The red sea crisis and identification of political risks

In late 2023, armed conflict in the Red Sea region disrupted maritime shipping and forced liner companies to reroute vessels, resulting in longer transit times and elevated logistics costs. The incident can be classified as a cross-regional political risk, where a localized geopolitical shock propagated along international shipping corridors and modified global transport configurations [8].

Figure 1 illustrates the underlying transmission mechanism: political disruptions occurring at a critical maritime node propagated through global shipping routes, influenced port operations along downstream corridors, and ultimately reshaped regional transport flows.

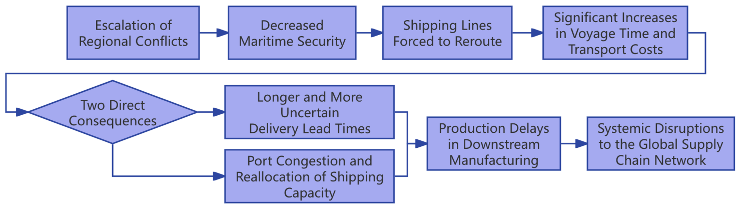

Figure 1. Risk transmission mechanism in the red sea conflict

3.3. Global semiconductor shortage and economic risk assessment

Between 2020 and 2022, the global semiconductor shortage led to a persistent supply bottleneck that constrained downstream manufacturing activities. The incident can be classified as an economic risk, in which supply constraints within an upstream, highly concentrated industry propagated to downstream sectors such as automotive production.

Figure 2 illustrates the underlying transmission mechanism: supply-side bottlenecks at a concentrated upstream node generated structural imbalances, which subsequently diffused across industries with significant dependence on semiconductors.

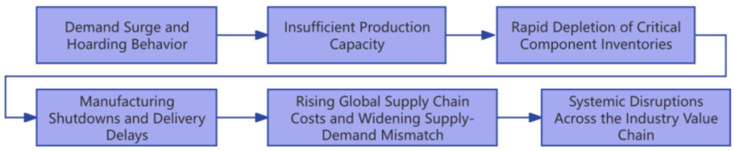

Figure 2. Risk transmission mechanism in the global semiconductor shortage

3.4. Crisis of water levels in the Panama Canal and identification of natural risks

In 2023, reduced water levels in the Panama Canal, driven by climate change and prolonged drought, led to draft restrictions and navigation quotas that disrupted global shipping flows [9]. The incident can be classified as a natural risk, where environmental stress on a critical infrastructure node constrained maritime capacity and generated prolonged uncertainty over navigability.This case demonstrates how environmental stress at a critical infrastructure node can propagate through global logistics networks.

DOI: 10.54254/2754-1169/2026.LD31515

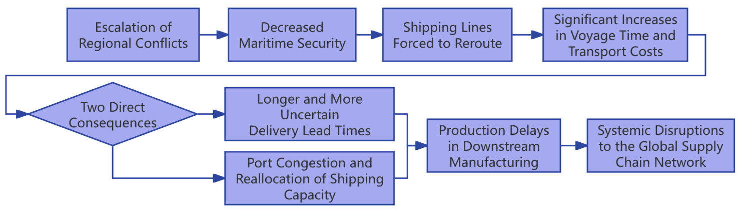

Figure 3. Risk transmission mechanisms in the water level crisis of the Panama Canal

3.5. Interrelated effects of multidimensional risks

Political, economic, and natural risks interact and amplify through shared supply chain structures. Their interdependencies primarily propagate along three pathways: critical transit nodes; core component supply; and infrastructure capacity. These pathways convert localized disruptions into network-level consequences, implying that risk management must shift from isolated, single-point control toward multidimensional identification and assessment.

4. Streamlined quantitative framework for risk evaluation

4.1. Principles for developing the indicator system

To ensure practical applicability, indicators were selected according to criteria of validity, data availability, risk coverage, and cross-country comparability. These criteria support a coherent and operational indicator system for multi-dimensional risk assessment.

4.2. Multidimensional risk indicator framework

This study constructs a multi-dimensional indicator system covering political, economic, and natural risks. The indicators capture policy-related disruptions, market and financial volatility, and climate- or disaster-induced hazards relevant to supply chain operations. Table 1 summarizes the structured classification of risk dimensions, categories, and representative indicators used for subsequent assessment.

Table 1. Structured risk classification table

Risk Dimension	Risk Category	Subcategory of Risk Type	Significance of the Indicator
Political Risk	Political Uncertainty	Economic Policy Uncertainty Index	Reflects the level of disruption to stability caused by changes in government policy
	Trade Barrier Risk	Tariff growth rate, Frequency of export controls	Reflecting the impact of trade policies on supply chain costs and accessibility
	Number of geopolitical conflicts	Number of conflicts/attacks	Measures cross-border logistics security and the likelihood of transport disruptions
Economic Risk	Market Volatility Risk	Oil price volatility, Global PMI	Reflecting the impact of demand-side and macroeconomic fluctuations on supply chain operations
	Cost Volatility Risk	Raw material Price Index	Measures procurement cost instability and reflects supply tightness
	Financial risks	Exchange rate fluctuations, Interest rate changes	Reflects funding chain pressure and cross-border transaction costs
	Structural Vulnerability	Supply concentration (HHI), Dependency ratio	Identifying critical vulnerabilities in the supply chain

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Table 1. (continued)

Natural Risks	Climate anomaly risks	Frequency of extreme weather events	Measuring the disruption caused by extreme weather to transportation and production
	Natural Disaster Risks	Flood Index, Hurricane Index, Earthquake Index	Measures the exposure of infrastructure to natural disasters
	Long-term Environmental Changes	Annual average temperature change rate	Reflecting the medium-to-long-term impacts of climate change on the supply of agricultural and energy products

4.3. Methodology for constructing a risk matrix

In the risk assessment phase, the objective is to estimate hazards in a comparable manner. This study adopts the Probability–Impact scoring system developed by Hariharan and Balamurugan, where each risk category receives a Probability Score (PS) and an Impact Score (IS) on a 1-5 scale, representing the likelihood of occurrence and severity of disruption, respectively [10]. A score of 1 indicates low likelihood or negligible impact, 3 indicates moderate levels, and 5 indicates a high probability of significant disruption. Risk Exposure (RE) is calculated as:

$$\text{Risk Exposure(RE)} = \text{Probability Score} \times \text{Impact Score} \quad (1)$$

The RE value can be positioned within a Probability-Impact matrix to differentiate exposure levels and prioritize risks.

This study extends this framework by adding the Type of Risk as a third dimension, forming a conceptual 3D P-I Matrix (Figure 4). The Z-axis represents political, economic, and natural risk categories solely for visual differentiation rather than intensity evaluation. Assigning PS and IS values to events under each category enables their joint mapping in three-dimensional space, supporting intuitive identification of high-exposure nodes.

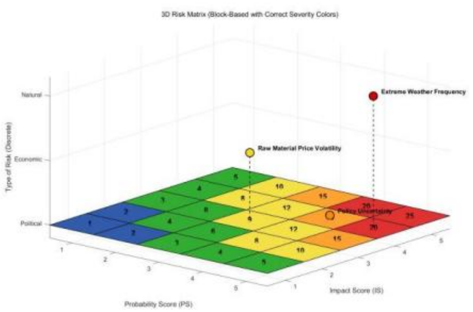

Figure 4. Three-dimensional probability-impact matrix

4.4. Application of the framework and its value

The multidimensional risk indicator system and risk matrix methodology offer organizations a systematic diagnostic tool for recognizing risk exposures and essential nodes. When political, economic, and natural hazards are standardized into quantifiable indicators, comparability is attained. This approach allows organizations to methodically identify risks and detect vulnerabilities. The 3D Probability–Impact Matrix identifies high-exposure dangers, offering a quantitative foundation for formulating resilience solutions. As data capabilities progress, the risk matrix can evolve from a semi-quantitative framework to a data-driven model, creating a perpetually updated dynamic risk monitoring instrument.

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5. Framework for a resilient supply chain strategy

5.1. Characteristics of resilient supply chains

Global supply chain resilience can be conceptualized as a portfolio of system-level capabilities that dampen shock propagation and reduce the likelihood of cascading failures across interdependent networks. When exposed to political, economic, and natural stressors, resilient supply chains rely on structural robustness, adaptability, network visibility, and collaborative coordination to modulate disruption flows along transport corridors, production nodes, and organizational interfaces.

5.2. Structural robustness: redundancy and diversification

Structural robustness functions as the first layer of resistance, extending buffer capacity and alternative routing across critical nodes to prevent immediate chokepoint failures. Redundancy and diversification increase network modularity and decrease concentrated exposure, reducing the probability of synchronized collapse when upstream components or strategic transit hubs are compromised. Under political or natural shocks, such structural buffers decouple localized failures from global flow patterns, limiting cascade depth and maintaining minimal throughput.

5.3. Adaptability: flexibility and agility

Adaptability represents the system's capacity to reconfigure topology and reallocate resources as network states evolve. Flexibility in sourcing and production switching reduces dependency on specific upstream inputs, while agile fulfillment mitigates transient demand–supply mismatches. Through reconfiguration, the system maintains service continuity without requiring proportional redundancy, thus operating as a dynamic response mechanism particularly suited for economic perturbations and medium-horizon resource constraints.

5.4. Transparency & anticipation: digitalization + visualization

Visibility and prediction are increasingly mediated by digital instrumentation, enabling real-time observability of inventories, transport flows, and process conditions. Enhanced observability reduces information latency and supports anticipatory decision-making through forecasting and scenario simulation. By lowering uncertainty about future network states, visibility attenuates amplification mechanisms that would otherwise convert minor perturbations into macro-level volatility.

5.5. Collaborative governance: inter-entity collaboration augments system resilience

Collaboration functions at the inter-entity and inter-jurisdictional layers, facilitating coordinated adjustments that exceed the capacity of individual firms. When shocks exhibit cross-border spillover—such as political sanctions or climate-induced infrastructural degradation—collaborative governance increases the likelihood of resource pooling, information sharing, and synchronized intervention, thus preventing fragmentation and bottleneck-induced cascades.

5.6. Harmonizing strategies with risk dimensions

To operationalize these capabilities, this study introduces a risk–strategy alignment mechanism that embeds political, economic, and natural risk events in a three-dimensional Probability–Impact space

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and maps their exposure levels to resilience strategies. Low-probability, low-impact disturbances are monitored; high-probability but low-impact disturbances favor flexibility and visibility; low-probability but high-impact disturbances require structural robustness; and high-probability, high-impact disturbances necessitate coordinated intervention. This mapping provides a rule-based mechanism for selecting intervention portfolios that minimize systemic vulnerability rather than treating disruptions as isolated events.

6. Conclusion

This This study investigates the systemic vulnerabilities of global supply chains under political, economic, and ecological hazards and develops an analytical “risk–resilience strategy” framework. Drawing on systems theory and complex network perspectives, case evidence illustrates how heterogeneous shocks trigger cascading and cross-regional disruption patterns. A streamlined risk assessment approach is introduced alongside a correspondence between risk sources and resilience capabilities—structural robustness, adaptability, visibility and prediction, and collaboration.

Global supply chain disruptions are evolving from isolated incidents to multi-source, multi-stage, and cross-network systemic events. Interdependencies among political, economic, and natural risks amplify cascading effects and undermine the effectiveness of single-hazard management paradigms. In contrast, multidimensional identification and risk–strategy alignment enable more coherent prioritization and resource allocation. Political risks call for structural resilience and coordinated governance; economic risks emphasize reconfiguration and data-informed flexibility; natural risks require redundant routing, real-time observability, and interregional coordination. The framework offers actionable guidance for firms in supplier selection, regional configuration, and inventory/logistics management, and informs public–industrial collaboration in infrastructure, emergency mechanisms, and data exchange.

While this study contributes to theoretical integration and framework development, limitations remain. The indicator system and risk matrix rely on semi-quantitative judgment and lack full integration of large-scale digital data. Moreover, the proposed matching mechanism is conceptually validated but has not yet been tested under simulated or empirical shock environments. Future research may advance in two directions: (1) incorporating real-time geopolitical, meteorological, and trade data into the risk matrix to establish data-driven monitoring and early-warning systems; and (2) employing complex network simulations or digital twin models to quantitatively examine node failures, redundancy configurations, and resilience strategy effectiveness.

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